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Organic geochemical appraisal of hydrocarbon potential in the Prešov Depression (East Slovakian Neogene Basin)

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Abstract: Tertiary source rocks quality and kerogen maturity are characterized using Rock-Eval pyrolysis and microphotometry. Hydrocarbon generation zones were evaluated by kinetic modeling calibrated on organic matter maturity parameters. Top of oil generation zone is reached at about 2250 m in the northern part and in a depth range of 800 to 1250 m in the central and southern parts of depression.

Key words: Tertiary, kinetic modeling, maturation zonality, hydrocarbon potential, East Slovakia

Introduction

Tertiary sedimentary basin fill in the Prešov Depression reaches down to a depth of 2700 m in the deepest northern part, in the central part close to the Slanské vrchy Mts. to 2500 m. Mesozoic and Paleozoic complexes of the Veporic Unit build the pre-Tertiary basement in the area between Prešov and Košice and, to the south, the basement is represented by Paleozoic of the Gemeric Unit. Volcanism was active during Eggenburgian to Sarmatian period (Slánske vrchy Mts.) and has influenced actual geothermal conditions in this depression. The temperature at depth of 3000 m is about 100 °C in the northern part and 130 °C in the central part close to volcanics.

The aim of the paper is to present organic geochemistry of source rocks as well as the model of organic matter maturation and hydrocarbon generation using Rock-Eval pyrolysis, microphotometry and kinetic modeling of hydrocarbon generation.

Methods and material studied

Sufficient content of total organic carbon (TOC) in sediments is one of the basic criteria for evaluation of potential hydrocarbon perspect of an area. Most of authors refer worldwide the minimum content of 0.5 weight percent of total organic (disseminated) carbon for potential hydrocarbon source rocks.

In the Prešov Depression more than 280 core samples and 18 surface samples were examined. Most of these samples comes from Tertiary sediments, the rest comes from the Mesozoic and partly Paleozoic basement.

Geological setting

Core samples up to 3200 m from deep wells in the central part of the Prešov Depression as well as from hydrogeological wells in the northwestern and northeastern margins of the depression were examinated (Fig. 1). Few investigated samples are from Čierna hora Mts.

Rock-Eval pyrolysis

Rock-Eval pyrolysis represents a standard method used for rapid evaluation of hydrocarbon (HC) potential, kerogen type and maturity. Principles of the method are described e.g. in Espitalié et al. (1985). This method was applied to investigation of all samples with TOC content over 0.2 %. Approximately 50-100 mg of powdered rock was analysed in Agema Brno on Rock-Eval V apparatus. Following parameters represent direct measured values:

S1: free (volatile) hydrocarbons (HC) in mg HC/g rock
S2: fixed (pyrolytic) HC in mg HC/g rock
Tmax: maximum pyrolysis temperature in °C
From these parameters were calculated:
HI - hydrogen index: (S2/TOC)x100 in mg HC/g TOC
PI - production index: S1/(S1+S2)
GP - genetic potential: (S1+S2) in mg HC/g rock
Results are summarized in Tab.1

Microphotometry

Vitrinite reflectance (Ro) measurements enable evaluating the extent of thermal alteration of sedimentary organic matter. Vitrinite is a macerate of humic coals family and is derived from higher terrestrial plants. During the coalification, vitrinite reflectance increases from 0.25 % at the peat stage to more than 4 % at meta-anthracite stage. In selected samples vitrinite reflectance was measured by the first author in Czech Geological Survey, Branch Brno under standard conditions (Stach et al., 1975): monochromatic non-polarized light (546 nm), oil immersion, photometric field 2x2 μm, Leitz MPV 2. Results are summarized in Tab.1.

Source rock study

Pre-Tertiary basement

Mesozoic sediments represent practically all investigated samples from the pre-Tertiary basement. In respect

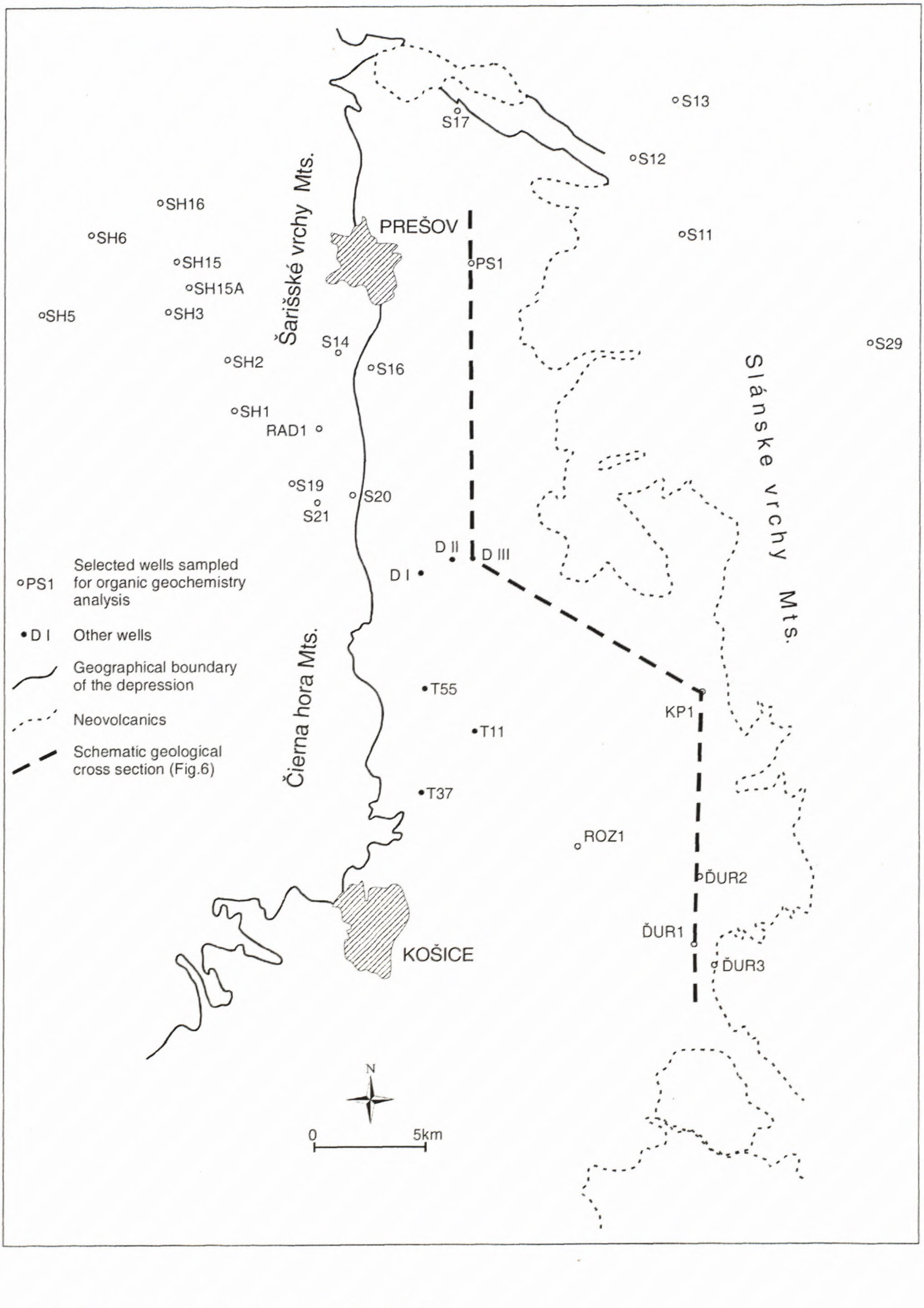

Fig. 1. Prešov Depression - location map of selected wells.

Tab. 1: Summary of organic-geochemical results based on rock-Eval pyrolysis

Litostratigraphy		TOC	S1	S2	HI	PI	Tmax	Ro	Kerogen
		%	mg/g	mg/g	mg/g		oC	%	type
Lower Sarmatian	Stretava Fm.	0.0X	-	-	-	-	-	n.m.	-
Upper Badenian	Klčov Fm.	0.0X - 0.31	0.0X	0.0X - 0.14	31 - 116	0.08 - 0.19	423-430	0.40 - 0.50	III
Middle Badenian	Vranov Fm.	0.0X - 0.65	0.0X	0.24 - 0.42	36 - 261	0.02 - 0.08	430 - 433	0.43 - 0.65	III
Lower Badenian	Nižný Hhrabovec Fm.	0.0X - 0.97	0.0X - 0.10	0.0X - 1.26	10 - 144	0.0X	435 - 438	0.48	III
Karpatian	Kladzany Fm.	0.0X - 0.23	0.0X	0.0X - 0.28	17 - 121	0.0X	432 - 445	0.89 - 0.92	III
	Teriakovce Fm.	0.0X - 1.39	0.0X - 0.12	0.18 - 4.80	76 - 345	0.0X	426 - 447	0.71 - 1.19	III - (II)
Egenburgian	Čelovce Fm.	0.0X - 0.49	0.0X - 0.07	0.36 - 0.76	124 - 353	0.0X	432 - 437	0.45 - 0.56	III - (II)
	Prešov Fm.	0.0X - 0.70	0.0X - 0.11	0.34 - 1.02	73 - 256	0.0X	430 - 433	0.51 - 0.65	III
Egerian	Solivar Fm.	0.0X - 0.94	0.0X	0.42 - 1.20	55 - 305	0.0X	433 - 436	0.58 - 0.70	III
	Biely Potok Fm.	0.38 - 2.67	0.0X - 0.20	0.20 - 4.66	40 - 181	0.0X	427 - 430	n.m.	III
Paleogene	Zuberec Fm.	0.0X - 4.34	0.0X - 0.15	0.0X - 2.52	14 - 434	0.0X - 0.14	430 - 440	0.59 - 0.69	III - (II)
	Huty Fm.	0.0X - 1.18	0.0X	0.0X - 2.76	66 - 257	0.0X - 0.24	436 - 440	0.57 - 0.68	III
	Borovce Fm.	0.0X - 0.20	0.0X	0.0X	18 - 40	0.0X	~ 440	n.m.	III
Mesozoic		0.00 - 0.40	-	-	-	-	-	2.35 - 3.46	?
Paleozoic		0.50 - 3.20	-	-	-	-	-	4.52 - 4.48	?

Explanations: TOC - total organic carbon (weight %), Rock-Eval pyrolysis parameters - S1, S2 (mg HC/g rock), HI (mg HC/g TOC), PI and Tmax (°C), Ro - vitrinite reflectance (%); n.m. – non measured, Kerogen types - III - terrestrial; III-(II) – terrestrial, possible mixed with marine.

to their minimal TOC content (Tab.1) these samples do not represent potential source rocks at present. Only three core samples from the Paleozoic basement (Čaňa 1 well) reached limit values for potential source rocks (0.50 - 0.65 %). These rocks are metamorphosed to very low grade and in this case, TOC values represent structurally more ordered meta- anthracitic to semi-graphitic carbon (Ro = 4.5 %). TOC content in the core sample from Čaňa 1 well (1132 m) is moreover probably influenced also by solidified bitumen, because of increased S1 pyrolytic value (2.85 mg/g) corresponding to free hydrocarbons content. The same is indicated by increased production index value (PI = 0.52) and low maximum pyrolysis temperature value (Tmax = 415 °C) because of deformed S2 pyrolytic peak corresponding to residual hydrocarbon potential (Espitalié et al., 1985).

Tertiary

Paleogene sediments belong to the basement of the Prešov Depression or outcrop in its surrounding (lithostratigraphy after Gross et al., 1984). The depression fill is of Miocene age (lithostratigraphy after Vass and Čverčko, 1985). More detailed information about geological evolution during Miocene is e.g. in Kováč (2000).

Comparison of TOC values shows that practically 50 % of all investigated Paleogene samples overreach the limit 0.5 % value for potential source rock. These increased values were found mainly in the Zuberec and partly in Huty Fms.

Quantitative distribution of TOC content within Neogene basin fill was interpreted separately for Middle and Lower Miocene sediments (Tab. 1). Considerable numbers of Neogene samples mostly from Ďurkov area do not contain any organic carbon. This is most probably caused by an increased presence of volcaniclastic material in these sediments. Origin and type of kerogen are one of very important characteristics that directly influenced the hydrocarbon generative potential. Quality of organic matter was evaluated mainly on the basis of HI, Tmax and S2 parameters (Figs. 2 and 3). Terrestrial kerogen type (III) is dominant for the Tertiary sediments, but in Lower Miocene and Paleogene sediments can be locally found also mixed terrestrial marine kerogen type (HI over 300mg/g; Fig. 2). The maximum residual source potential of Middle Miocene sediments is about 1 kg hydrocarbons per tone of rock, in Lower Miocene and Paleogene sediments it is to 5 kg HC/t of rock.

Model of catagenic zonality

Kerogen maturity and actual burial depth are the most important factors for evaluation of active hydrocarbons generation. Depth related to the organic matter maturation is interpreted mainly by vitrinite reflectance (Ro) and partly also by maximum pyrolytic temperature (Tmax) measurements.

Pre-Tertiary basement

Vitrinite reflectance values (Tab. 1, Fig. 4) measured in cores and surface samples give the evidence about exhausted kerogen from the viewpoint of potential hydrocarbon generation. These rocks were exposed to a weak

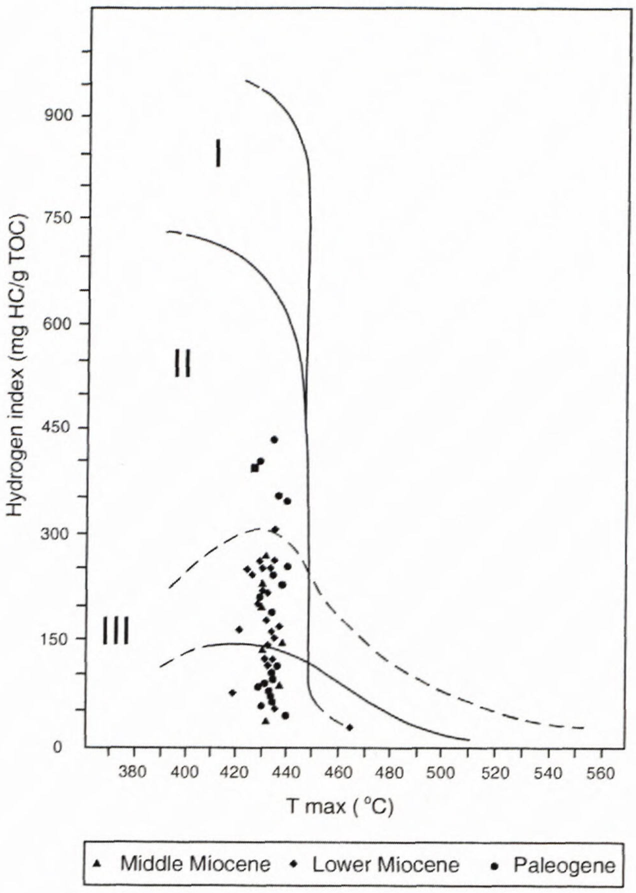

Fig. 2. HI - Tmax diagram indicating kerogen type in Tertiary sediments

maturity of Paleogene sediments depending upon burial depth and corresponding geothermal gradient was observed. The early oil generation zone is reached in this region at depth approximately of 2400 m while in the western elevated margins of the Prešov Depression this zone lies at the surface or in shallow depth below the surface. This, at present passive generation zone was reached in different depth and geothermal conditions than is found at present.

Trend of the organic matter maturity increase in Neogene sediments corresponds to present geothermal conditions in the Prešov depression that is from this point of view considerable heterogenous. Relatively "coolest" part after steady state temperature measurements (Král et al., 1985) is the area near Prešov. On the other hand the eastern part of the depression close to Slanské vrchy Mts. (Ďurkov 1, 2, 3 and Kecerovské Pekľany 1 wells) is an area with increased geothermal gradient (l.c.). Actual kerogen maturity reflects very well the thermal exposition of organic matter in different parts of the depression (Fig. 4).

Principal zones of hydrocarbon generation were determined using mathematical models (Fig. 5). Calculated maturity parameters in all modelled wells were compared to measured (mainly vitrinite reflectance).

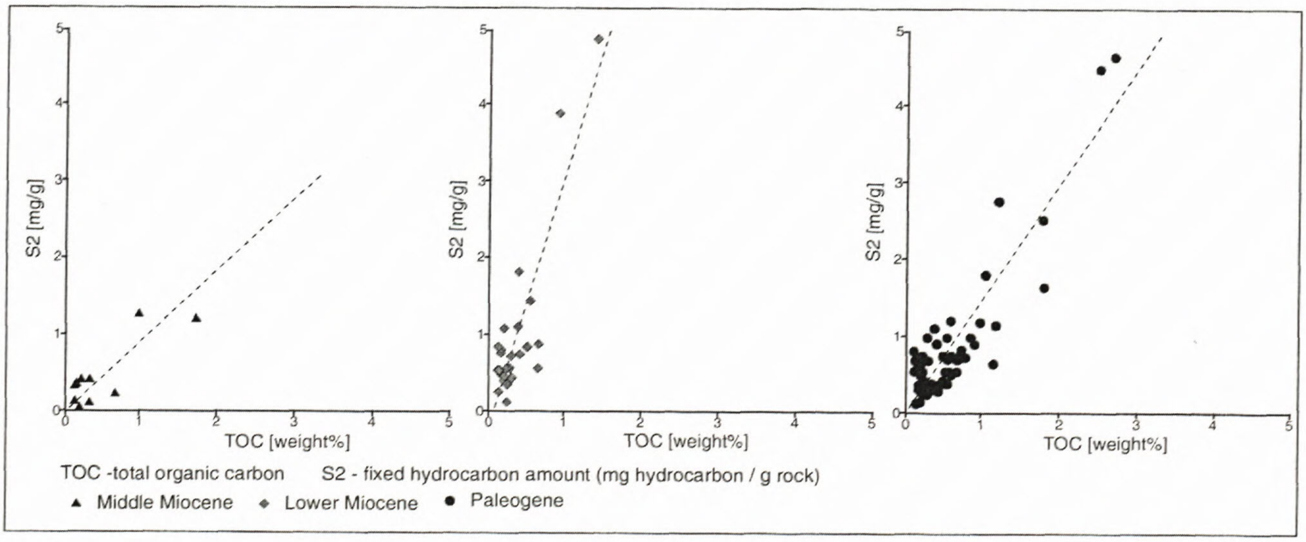

Fig. 3. Tertiary source rocks characteristics based on Rock-Eval pyrolysis

regional metamorphosis. Corresponding depth and geothermal conditions in relation to actual kerogen maturity give no real chance for an active hydrocarbon generation. In other words the pre-Tertiary basement is at present in a passive maturation zone.

Tertiary

Maturity stage of Paleogene sediments depends upon a geotectonic position in the studied depression. In the Prešov area a continual increase of the organic matter

Based on mathematical modelling, map of hydrocarbon generation zones in selected Neogene sedimentary levels for kerogen type III were constructed. Resulting hydrocarbon generation zones in north-south cross section are presented in Fig. 6.

Conclusions

Paleogene (Huty and partly Zuberec Fms.) and Lower Miocene (Teriakovce Fm.) sediments include fairly good

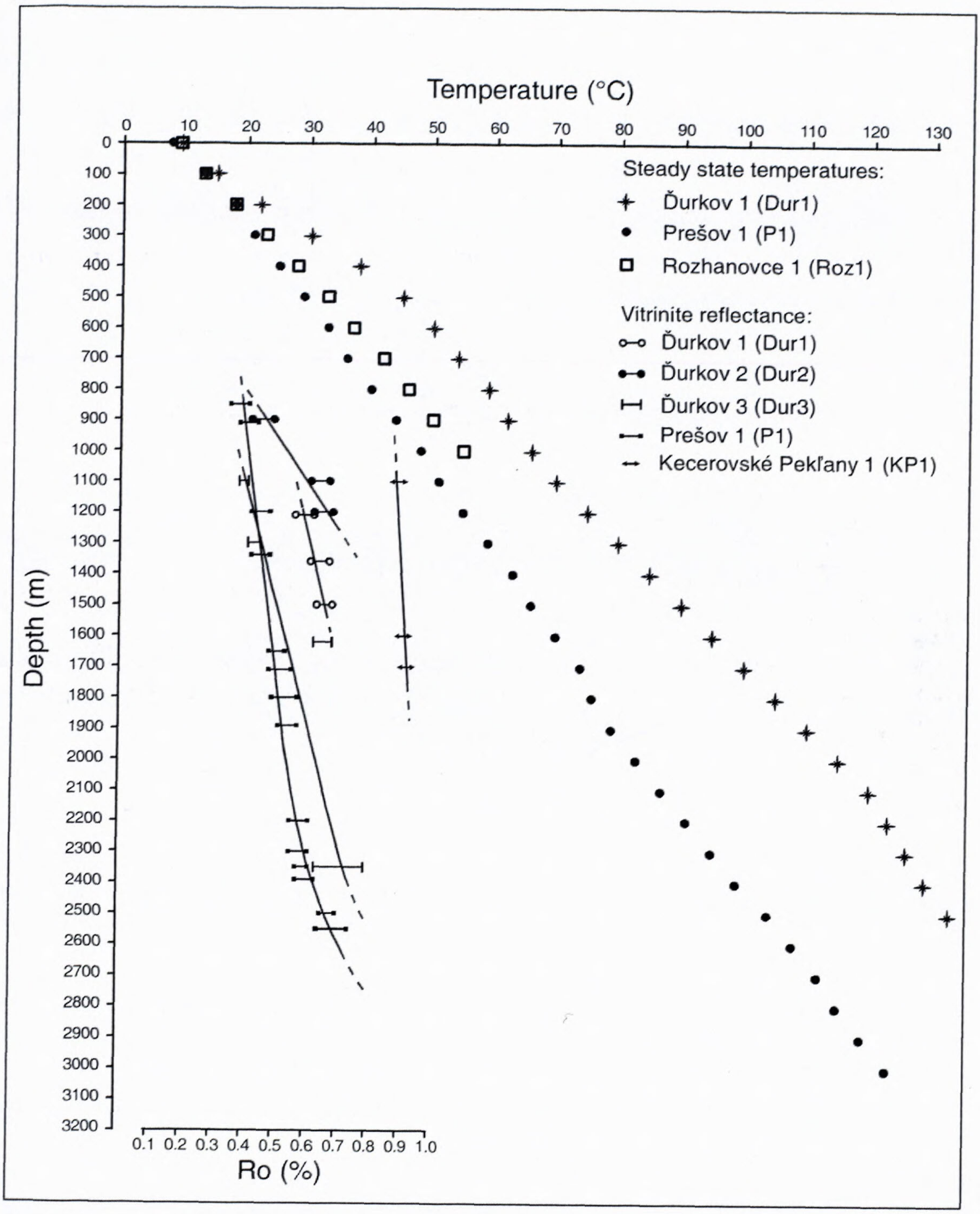

Fig. 4. Steady state temperatures and vitrinite reflectance in selected wells

source rock intervals locally with mixed terrestrial and algal kerogen.

Organic matter maturity in Neogene increases continuously with depth in the northern part and is strongly influenced by increased geothermal gradient close to neovolcanics (Slanské vrchy Mts.).

Top of early oil generation zone is in the northern part reached at depth of approximately 2000 m in Oligocene-Miocene sediments. Southward, near Kecerevské Pekľany lies this zone at depth of 1000 m (Middle to Lower Badenien), then ascends to 600 m below the surface (Upper Badenien) towards the KP 1 well and sinks slowly to depth of approximately 900 m near the Ďurkov 1 well.

Top of the main oil generation zone practically lies approximately 250 m deeper below the early oil zone. This zone involved Oligocene-Miocene and Paleogene sediments in the northern part of the Prešov Depression (e.g. the Prešov 1 well), while Upper and Middle Badenian and Karpatian sediments in the southern part, in Kecerovské Pekľany and Ďurkov area.

In respect to present burial depth, geothermal gradient and uplifting parts of the depression are hydrocarbon

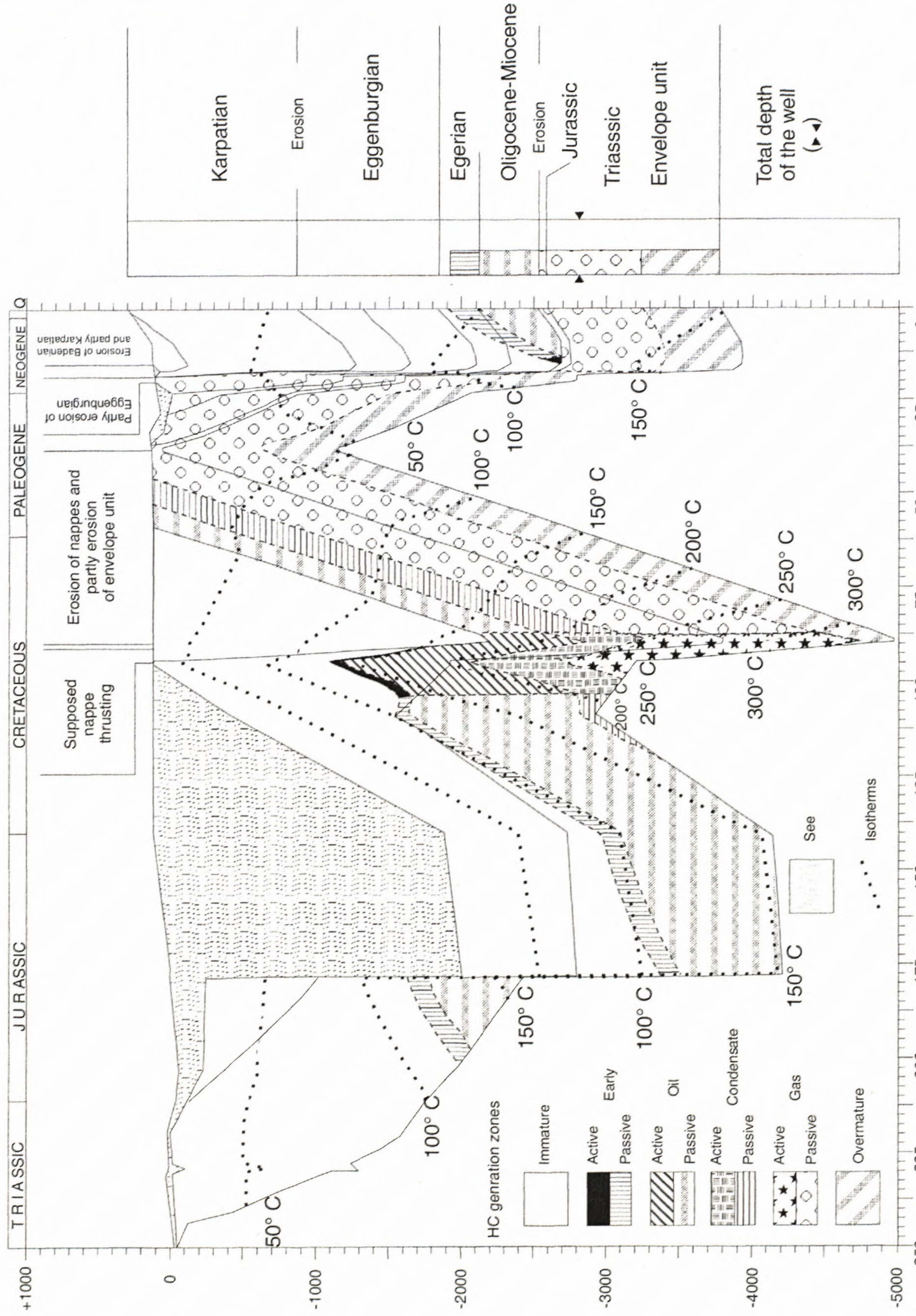

Fig. 5. Burial history and hydrocarbon generation zones in the Prešov 1 well.

generation zones passive in most area. Active generation could be expected only in the deepest buried Paleogene sediments near the Prešov 1 well area.

Acknowledgement

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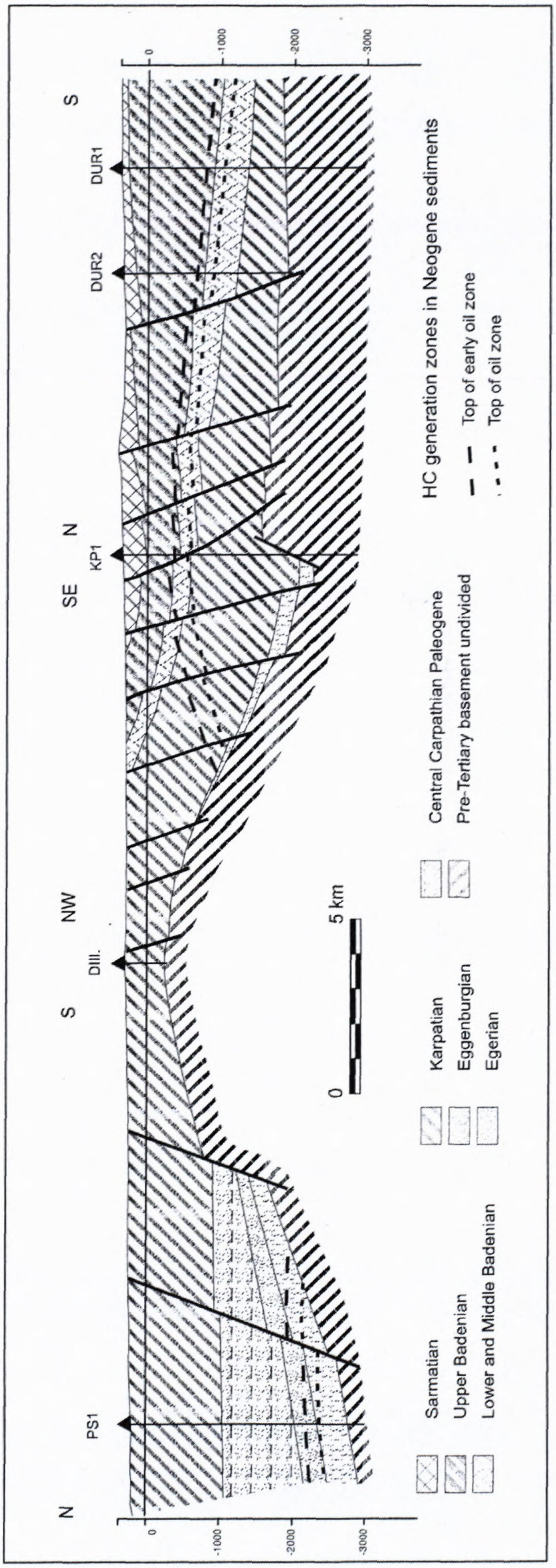

Fig. 6. Zones of hydrocarbon generation in schematic N - S geological cross-section

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Quantitative assessment of generated hydrocarbons in the Prešov Depression (East Slovakian Neogene Basin)

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Abstract: Assessment of hypothetical and speculative hydrocarbon resources in less explored regions is generally based on an analogy to regions with the higher level of exploration. Methodics of calculation of hydrocarbon speculative resources based on the organic geochemistry research of the source rocks of the Prešov Depression is presented as an example.

Key words: organic-geochemical parameters, hydrocarbon generation zones, expulsion, migration, entrapment, hydrocarbon potential evaluation.

Introduction

The hydrocarbon potential evaluation of the Prešov Depression is based mainly on interpretations of organic-geochemical analyses and kinetic modeling of hydrocarbon generation during the geological history (Milička and Pereszlényi, this volume). The aim of this paper is to follow the fate of hydrocarbons during their generation and expulsion from the source rock, migration, and accumulation in traps. For the quantitative assessment of this phenomena we used the method of Waples (1985) based mostly on organic-geochemical parameters.

The results of this method, originally used in American oil industry (e.g. Moshier and Waples, 1985) are expressed in imperial units and only the final calculation is transformed to SI units.

Method

As indicated, one of convenient ways to approach the calculation of hydrocarbon volumes is to divide the process of hydrocarbon accumulation into following phases: generation, expulsion, migration, entrapment and preservation. Waples (1985) proposed the use of the most common organic-geochemical parameters, i.e. the total organic carbon (TOC) content, Rock-Eval pyrolysis yield and maturity as input parameters for the most useful basic hydrocarbon (HC) generation equation as follows:

Volume of HC = (k).(TOC).(HI).(f)

- HC hydrocarbon volume in million barrels oil/cubic mile of source rock
- k conversion constant
- TOC total organic carbon in weight %
- HI hydrogen index in mg HC/g TOC
- f fractional conversion (between 0 - completely immature and 1- fully mature organic matter)

The Paleozoic, Mesozoic, Paleogene, Egerian, Eggenburgian, Karpatian and Badenian sediments entered the hydrocarbon generation windows in the Prešov Depression. However, Paleozoic and Upper Badenian sediments do not meet the criteria for source rocks and therefore they are excluded from further calculations. The Paleogene, Egerian, Eggenburgian, Karpatian, Lower and Middle Badenian sediments reached after modeling the early oil and oil generation zone.

In the case of the Prešov Depression following parameters were considered:

a) Conversion constant k = 0.7 (if the source rock is a shale with density of approx. 2300 kg/m^3 and hydrocarbons correspond to oil density of 900 kg/m^3)

b) Average TOC content in source rocks:

Paleogene	1.0 %
Egerian	0.5 %
Eggenburgian	0.5 %
Karpatian	0.9 %
Lower and Middle Badenian	0.5 %

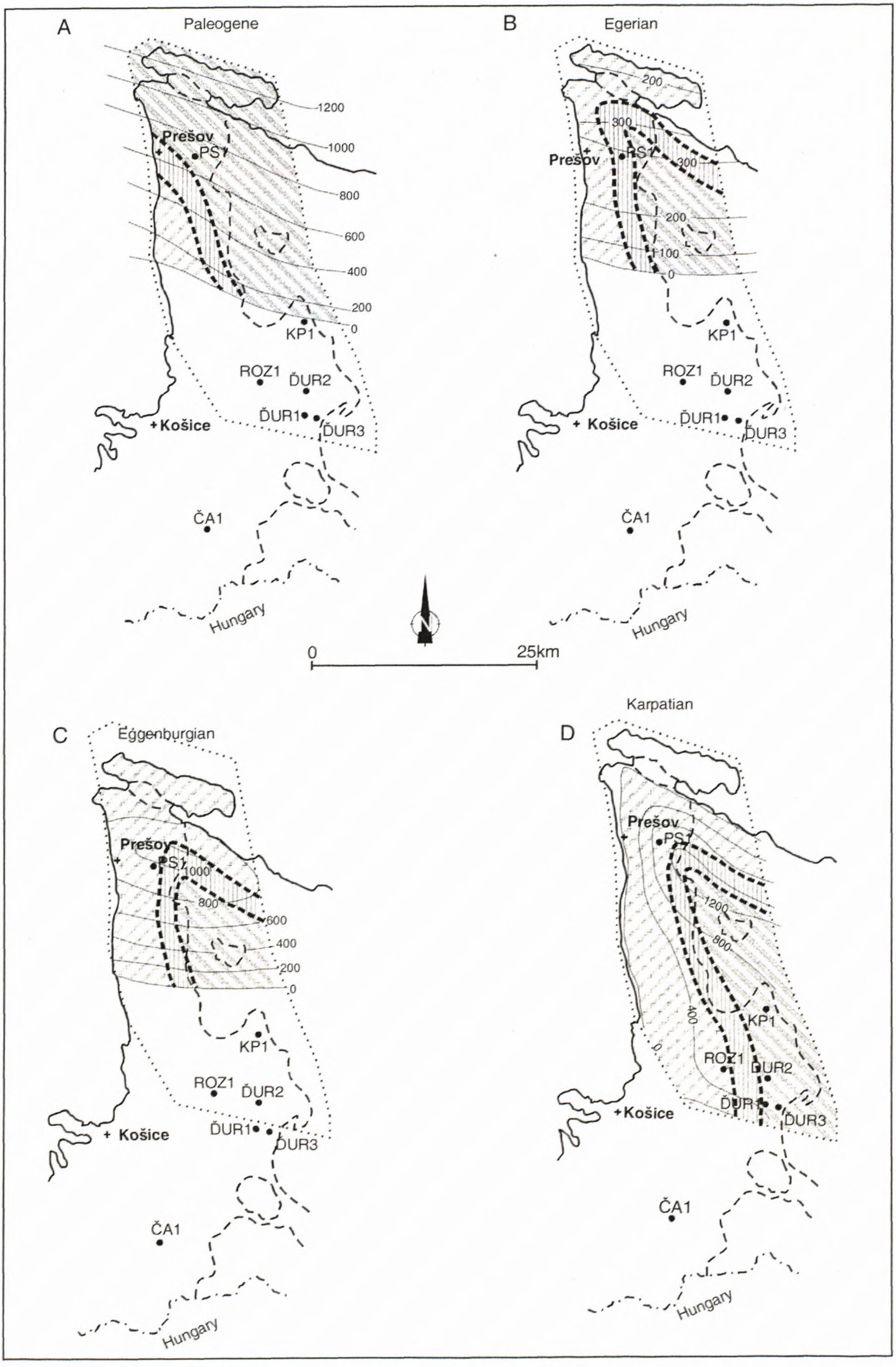
c) Average hydrogene index (HI) of immature organic matter:

Paleogene	350
Egerian	300
Eggenburgian	300
Karpatian	300
Lower and Middle Badenian	200

d) Fractional conversion (f) for each maturity zone calculated from Fig. 2, i.e. from vitrinite reflectance:
Early oil zone: *oil* = 0.00; *gas* = 0.00 Ro = 0.62
Oil zone: *oil* = 0.75; *gas* = 0.10 Ro = 1.00

e) Volume of potential source rocks in individual maturity zones from Figs. 1a-e, summarized in Tab. 1.

f) The kerogen type considered is the type III-II (terrigenous to mixed), i.e. this kerogen can generate about 25 % oil and 75 % gas (Tissot and Welte, 1984). The oil and gas yield in weight % from average TOC content for particular stratigraphic units is shown in Tab. 2.


A
Paleogene
1200
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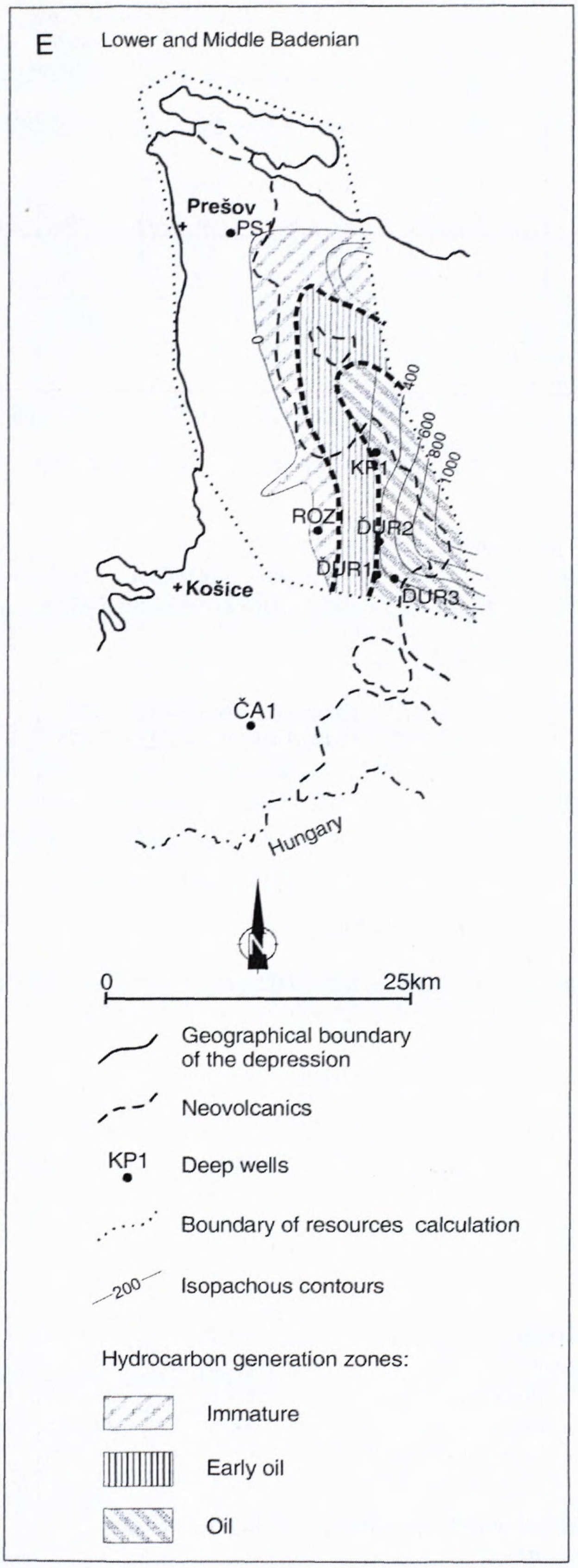

Fig. 1a - calculation of the source rock volume in Paleogene (without Egerian), b - calculation of the source rock volume in Egerian, c - calculation of the source rock volume in Eggenburgian, d - calculation of the source rock volume in Karpatian, e - calculation of the source rock volume in Lower and Middle Badenian.

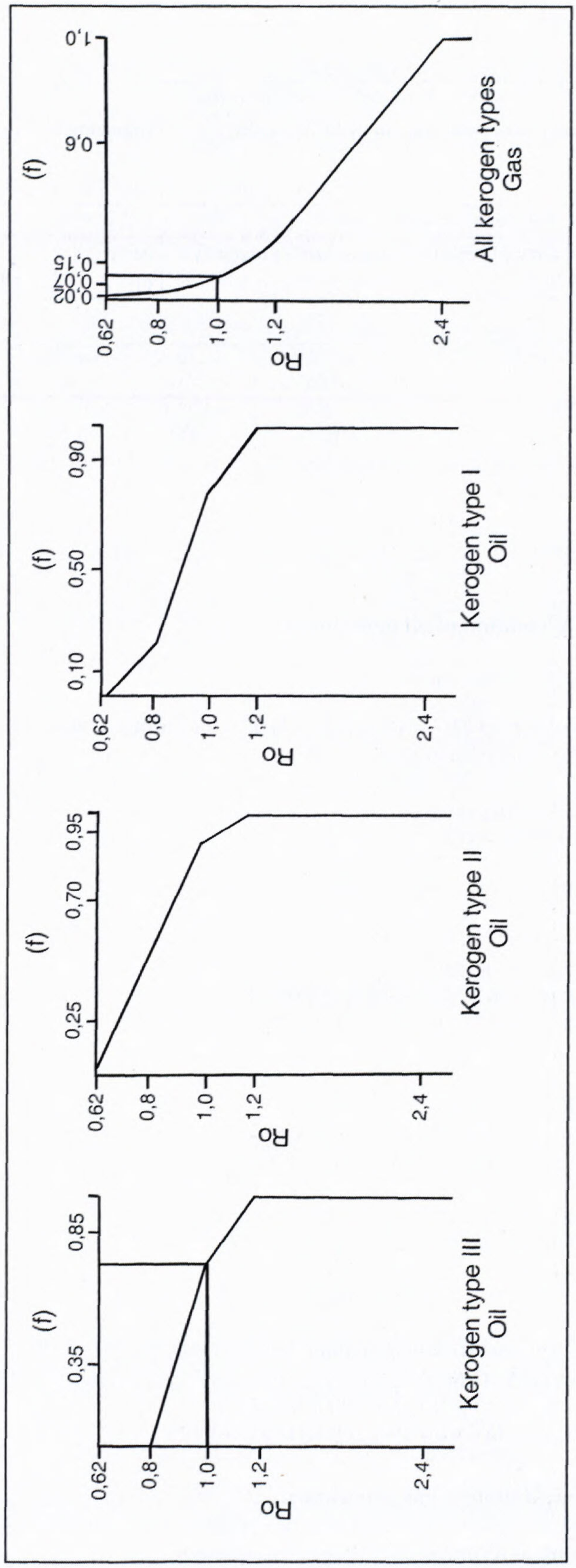

Fig. 2. Relationship between Ro values and fractional conversion (f) of three main groups of kerogene to oil and gas (after Waples, 1985).

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Table 1.

		Paleogene	Egerian	Eggenburgian	Karpatian	Lower and Middle Badenian
Total vol. of sediments (km^3)		332.5	70	175	390	100
volume of sediments in maturity zones	immature	50	30	110	235	27.5
	early	20	15	15	20	10
	oil	262.5	25	50	135	62.5
% of potential source rocks		25	20	20	10	10
volume of sediments in productive maturity zones	early	5	3	3	2	1
	oil	65.625	5	10	13.5	6.25

Table 2.

	wt. % of TOC	wt. % of oil	wt. % of gas
Paleogene	1.0	0.250	0.750
Egerian	0.5	0.125	0.375
Eggenburgian	0.5	0.125	0.375
Karpatian	0.9	0.225	0.675
Upper and Middle Badenian	0.5	0.125	0.375

Calculation of oil generation

General formula:

Volume of HC = (k).(TOC).(HI).(f) in million barrels of oil/cubic mile of source rock

Paleogene
Maturity stage:
early: 0.7 x 0.25 x 350 x 0 = 0
oil: 0.7 x 0.25 x 350 x 0.75 = 45.9375

Egerian
Maturity stage:
early: 0.7 x 0.125 x 300 x 0 = 0
oil: 0.7 x 0.125 x 300 x 0.75 = 19.6875

Eggenburgian
Maturity stage:
early: 0.7 x 0.125 x 300 x 0 = 0
oil: 0.7 x 0.125 x 300 x 0.75 = 19.6875

Karpatian
Maturity stage:
early: 0.7 x 0.225 x 300 x 0 = 0
oil: 0.7 x 0.225 x 300x 0.75 = 35.4375

Lower and Middle Badenian
Maturity stage:
early: 0.7 x 0.125 x 200 x 0 = 0
oil: 0.7 x 0.125 x 200 x 0.75 = 13.125

Calculation of gas generation

General formula:

Volume of HC = (k).(TOC).(HI).(f).(a)

(a) - conversion constant (conversion of gas volume to oil equivalent); if we want to obtain the volume of gas in billions of cubic feet per cubic mile of source rock, constant (a) = 6.

Paleogene
Maturity stage:
early: 0.7 x 0.75 x 350 x 0.02 x 6 = 22.05 = 3.675 oil equivalent
oil: 0.7 x 0.75 x 350 x 0.10 x 6 = 110.25 = 18.375

Egerian
Maturity stage:
early: 0.7 x 0.375 x 300 x 0.02 x 6 = 9.45 = 1.575
oil: 0.7 x 0.375 x 300 x 0.10 x 6 = 47.25 = 7.875

Eggenburgian
Maturity stage:
early: 0.7 x 0.375 x 300 x 0.02 x 6 = 9.45 = 1.575
oil: 0.7 x 0.375 x 300 x 0.10 x 5 = 47.25 = 7.875

Karpatian
Maturity stage:
early: 0.7 x 0.675 x 300 x 0.02 x 2 x 6 = 17.01 = 2.835
oil: 0.7 x 0.675 x 300 x 0.10 x 6 = 85.05 = 14.175

Lower and Middle Badenian
Maturity stage:
early: 0.7 x 0.375 x 200 x 0.02 x 6 = 6.3 = 1.05
oil: 0.7 x 0.375 x 200 x 0.10 x 6 = 31.5 = 5.25

Calculation of total hydrocarbon generation

The amount of total hydrocarbons (oil and gas, the gas volume is expressed in oil equivalent) in million barrels per cubic mile of source rock is shown in Tab. 3.

Table 3.

	Maturity stage	
	Early oil	oil
Paleogene	3.675	64.3125
Egerian	1.575	27.625
Eggenburgian	1.575	27.5625
Karpatian	2.835	49.6125
Upper and Middle Badenian	1.050	18.3750

Expulsion of hydrocarbons during the primary migration

A threshold value of about 50 million barrels of hydrocarbons (oil or oil equivalent) had to be generated from the source rock, before any expulsion could occur. This threshold value was in the Prešov Depression not reached during the early oil zone in any stratigraphic formation i.e., the expulsion practically did not occur except the biogenic gas. In main oil generation zone expulsion occurred only in the case of Paleogene and Karpatian source rocks. The expulsion efficiency from potential source rock near threshold value is assumed to be 50 % for oil and 80 % for gas.

General formula:

Volume of hydrocarbons expelled = (A).(B)

(A) - volume of hydrocarbons generated in million barrels per cubic mile

(B) - expulsion efficiency

Paleogene - oil generation zone

Oil: 45.9375 x 0.50 = 22.96875
Gas: 18.375 x 0.80 = 14.7

Karpatian - oil generation zone

Oil: 35.4375 x 0.50 = 17.71875
Gas: 14.175 x 0.80 = 11.34

Secondary migration and accumulation efficiency

Proposed general secondary migration and accumulation efficiency ranges from 10 to 20 %. Regarding the fact that sediments in the Prešov Depression are within most area in relict maturation stage, to considerable extent tectonically disturbed and often "deteriorated" by volcaniclastics, we used the low efficiency value, i.e. 10 %.

General formula:

Volume of HC accumulated = volume of HC expelled x 0.1 in million barrels per cubic mile of source rock

Paleogene - oil generation zone

Oil: 22.96875 x 0.1 = 2.296875
Gas: 14.7 x 0.1 = 1.47

Karpatian - oil generation zone

Oil: 17.71875 x 0.1 = 1.771875
Gas: 11.34 x 0.1= 1.134

Converted into SI units it corresponds:

Paleogene - oil generation zone

Oil: 0,0876092 mil.m^3/km^3
Gas: 0,0560699 mil.m^3/km^3

Karpatian - oil generation zone

Oil: 0,0675843 mil.m^3/km^3
Gas: 0,0432539 mil.m^3/km^3

Total source volume

General formula:
Total source volume = volume of accumulated HC (in million m^3/km^3) x volume of potential source rocks (km^3).

Paleogene - oil generation zone

Oil: 0.0876092 x 65.625 = 5.7493538
Gas (oil equivalent): 0.0560699 x 65.625 = 3.6795872

Karpatian - oil generation zone

Oil: 0.0675843 x 13.5 = 0.9123881
Gas (oil equivalent): 0.0432539 x 13.5 = 0.5839277

Volume of oil is expressed in millions of cubic meters and volume of gas in billions of cubic meters.

Geological resources in total are as follows:

Σ Oil: 6.6617419 million m^3, i.e. 5.9955677 million ton
Σ Gas: 4.2635149 billion m^3

Conclusion

Presented calculated values represent the approximation of all hydrocarbons potentially generated, migrated and trapped for the whole area of the Prešov Depression. Parameters used for this calculation may of course locally vary - positively or negatively, depending upon the level of geological exploration. Assessment of quantity and quality of speculative (P2) resources is based mostly on analogues to similar, more detailed explored areas. We consider presented genetic-quantitative method, supported by the real analytic data, being not only an assessment but already the calculation. Geological processes involved in hydrocarbon generation, migration and accumulation are considered in this calculation.

From this viewpoint the applied method of speculative resources calculation seems to be universally applicable in hydrocarbon exploration of any area.

Maximum 50 % of hypothetical and speculative resources could generally be converted into the economically interesting reserves using exploration works. In the case of the Prešov Depression it would mean approx. 2.13 billion m^3 of gas and 2.45 million tons of oil.

Using average recoverability coefficient 0.7 for gas and 0.2 for oil it would represent recoverable reserves approx. 1.5 billion m^3 of gas and 490 thousand tons of oil.

We can state, based on above values that the Prešov Depression is an area with the low prospect for exploration of oil and gas fields.

Acknowledgement

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Chemical waste disposal site as a source of groundwater contamination in the multi-AQUIFER system of Upper Silesia, Poland

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Abstract. At present the region of Tarnowskie Góry is the best-known area in Poland because of the negative impact of industrial waste disposal sites on groundwater quality in the Quaternary and Triassic multi-aquifer system. An increase of concentrations of B, Ba, Sr, SO_4, Cl in groundwater of both the aquifers have been noted. The high concentrations of boron (up to 116 mg/dm^3) observed in the Triassic (the Muschelkalk) carbonate aquifer are particularly alarming, because this aquifer is the most important source of potable water for the region of Tarnowskie Góry.

A groundwater-flow model and a solute-transport model were developed for this multi-aquifer system (four aquifers – two Quaternary and two Triassic, separated by three aquitards). Both the Quaternary aquifers are of the transit type, being a source of recharge of lower Triassic aquifers. The horizontal flow in the Triassic aquifers predominates. Results of groundwater monitoring and numerical modelling revealed a significant differentiation of boron migration intensity within the Quaternary and Triassic aquifers, depending on water flow direction. A limited lateral migration of boron within the Quaternary aquifer and practically unlimited migration within the Triassic ones have been observed. Numerical model simulations showed that important big potable-water intakes, being situated at a distance of about 5-9 km NW downgradient from the waste disposal sites, are safe.

Keywords: industrial wastes, boron, contamination, multiple aquifers

Introduction

The region of Tarnowskie Góry constitutes a perfect example of negative environmental impact caused by casually locating waste site that took into account no environmental considerations. In the considered area, the industrial waste disposal sites of the former chemical plant are biggest in Poland. This situation, together with the naturally high groundwater vulnerability to pollution, has resulted in a progressing degradation of water quality in the Quaternary and Triassic aquifers. Locating the wastes in the watershed area has additionally complicated the situation, leading to multidirectional contamination spreading (Fig. 1).

The high concentration of boron is perceived as particularly dangerous since it reached 240 mg/dm^3 in the Quaternary aquifer, and 116 mg/dm^3 in the Triassic one. This critical situation resulted in closing of many water intakes situated nearby. Therefore a complex remediation of this area together with relocation of wastes have been performed.

In order to assess the current and perspective spreading of boron in the groundwater of the analysed multilayered flow system a numerical modelling has been applied. Groundwater flow and single component (for boron) solute transport numerical models of the four-layer system was worked out (Kowalczyk et al., 2003).

Waste disposal site

The region of the Chemical Works "Tarnowskie Góry", which are at the final stage of liquidation process, was an area where for many years the diverse industrial activities took place. The list of these activities encompasses: silver and led ore mining (from the 12th century), an iron milling (the second half of the 19th century), manufacture of silk paper (1892-1919), and production of paints and chemicals (1921-1995). But the Chemical Works "Tarnowskie Góry" that have manufactured over 30 various inorganic chemicals for over 75 years, among them mainly barium, boron, zinc, copper, and strontium, proved to be particularly environmentally hazardous. The used obsolete technologies generated large amounts of production wastes. The wastes together with the sludge from a sewage treatment plant were stored directly on the ground without any security means that could prevent the exfiltration of leachates. In this way there came into being the waste dumps containing dangerous compounds of barium, boron, strontium, zinc, and copper. The dumps covered an area of over 27 ha and their mass was estimated at circa 1.4 million tonnes (Fig. 1).

An analysis of selected samples of the wastes showed that they have diverse chemical compositions with domination of sulphates (up to 49600 mg/kg d.m.), calcium (up to 31170 mg/kg d.m.) and magnesium (up

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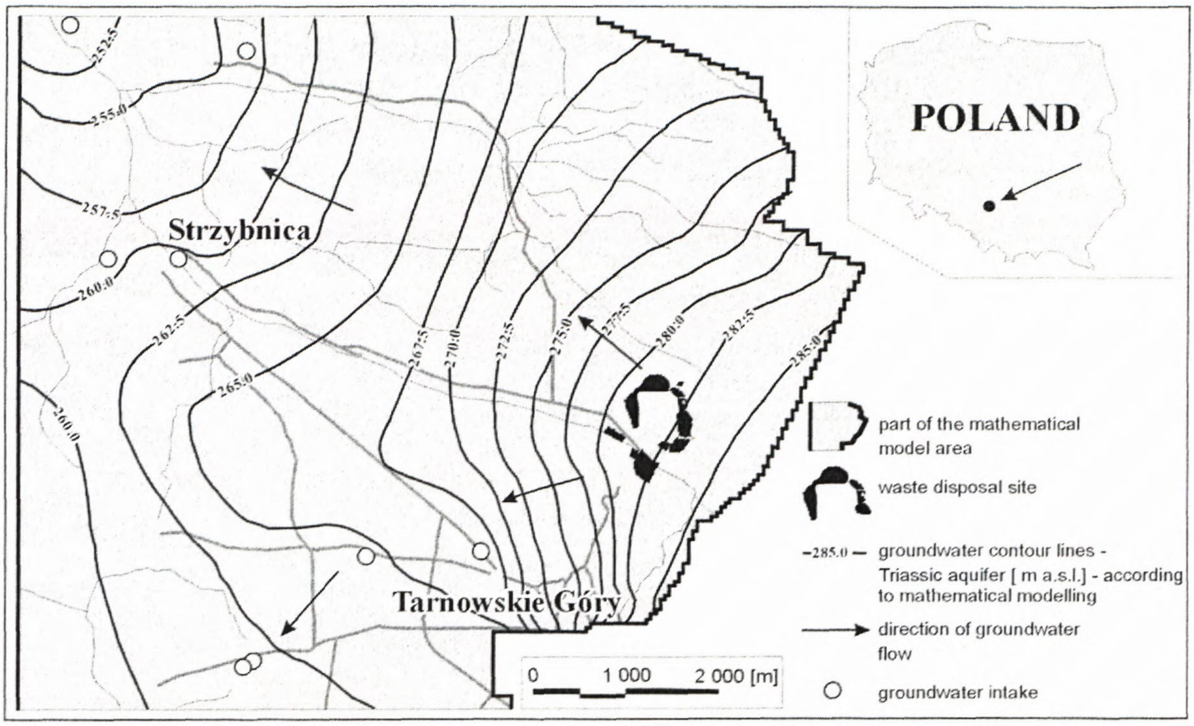

Fig.1 Location of the studied area and groundwater features

to 10840 mg/kg d.m.). Boron content ranged from 65.3 to 2216 mg/kg d.m., barium content from 81.9 to 443.6 mg/kg d.m., strontium content from 1646.7 to 8576.0 mg/kg d.m., copper from 93.9 to 9556 mg/kg d.m., zinc from 305.9 to 9500 mg/kg d.m. and arsenic from 95.3 to 901.8 mg/kg d.m. (Rubin, 1999).

The wastes were characterized by diverse but generally high active porosity (7-50 %) that decreased with their age. The lower porosity features the earlier stored wastes. Until recent the wastes did not constitute any essential barrier to the vertically infiltrating water (the hydraulic conductivity of investigated wastes ranged from $6.25 .10^{-8}$ to $6.4 .10^{-7}$ m/s) (Rubin, 1999). Moreover the karst-fissure character of rocks and their secondary permeability increase, caused by the many centuries of mining activity, facilitated the pollutants generated by the wastes to spread within the carbonate karst-fissured aquifer. Conducted dynamic leaching tests on selected waste samples showed a very high leachability of boron (up to 634 mg/l) and a lower one of strontium (up to 30 mg/l) and arsenic (up to 5.2 mg/l). Some samples also showed a high leachability of sulphates (up to 4989 mg/l) and chlorides (up to 1517 mg/l; Rubin, 1999).

The Chemical Works ceased its production activity in 1995 and was subjected to a liquidation process. In the mid-2000s implementation of a project of complex neutralization of the wastes together with polluted-land reclamation have begun. The scope of work planned within the project included construction of the Central Waste Disposal Facility (CWDF) on an area of 14.11 ha and a storage capacity of about 1.5 million m^3 and relocation of the whole of wastes and polluted ground from below the waste dumps to the facility. CWDF is a modern facility that satisfies all ecological requirements. It is an above-ground-ranging object (after closing of 17 m in height above ground surface). It has 5 cells with sealed bottom and draining systems.

Groundwater occurrence and monitoring

The Tarnowskie Góry region is located in the southern part of Poland (Fig. 1) and belongs to the Silesian-Cracow Monocline consisting of the Triassic formation discordantly overlying folded and faulted Paleozoic base. The Triassic formation is covered by Quaternary deposits of various lithology and thickness. There are Quaternary and Triassic aquifers in the hydrogeological profile. Thickness of these aquifers varies from a few to more than 50 m and from 40 to 150 m respectively. The Quaternary aquifer most often consists of two water-bearing horizons with discontinuos spread. Hydraulic conductivity of the Quaternary aquifer varies from 0.1 m/24 h up to 15 m/24 h. The water of this aquifer is polluted and is not used. The most important and abundant is the Triassic karst-fissured carbonate aquifer (dolomites and limestones with marl interbeddings). Hydraulic conductivity of the Triassic aquifer varies from 1 m/24 h to 16 m/24 h and its effective porosity is estimated between 0.04-0.06. In places both the aquifers form four separated water-bearing horizons: two within the Quaternary and two within the Triassic (Muschelkalk and Roethian; Fig. 2). The Quaternary aquifer is discharged by the Drama and Stoła rivers in local flow systems. In shallower part of the Triassic aquifer (Muschelkalk) both local and regional flow systems have been formed while in the deeper one (Roethian) only regional flow system has developed. The groundwater flows out of the watershed area in the waste disposal sites vicinity to the NWW and SWW (Fig. 1). Velocity of groundwaterflows in the Quaternary aquifer ranges from 0.001 to 1 m/24 h, whereas in the Triassic aquifer from 0.1 to 3 m/24 h.

The groundwater quality monitoring network in this area has been subjected to multiple modifications since 1990 when it was brought into existence. Unfortunately the mentioned sites have been systematically monitored only since 1999 (Rubin and Witkowski, 2002). Current groundwater quality monitoring network consists of 45 observation wells which monitor the Quaternary (20 wells) and the Triassic (25 wells) aquifers (Fig. 3). The wells are 4 to 28 metres deep, in case of the Quaternary

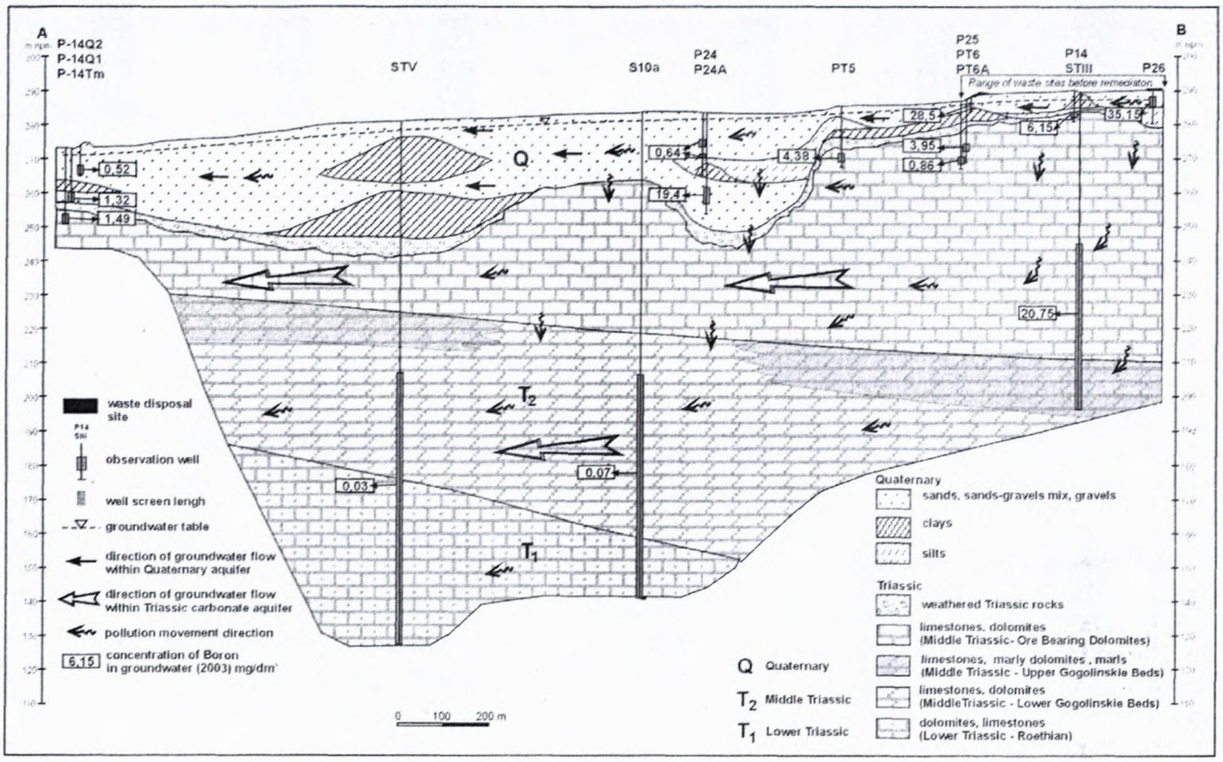

Fig. 2. Hydrogeochemical cross-section.

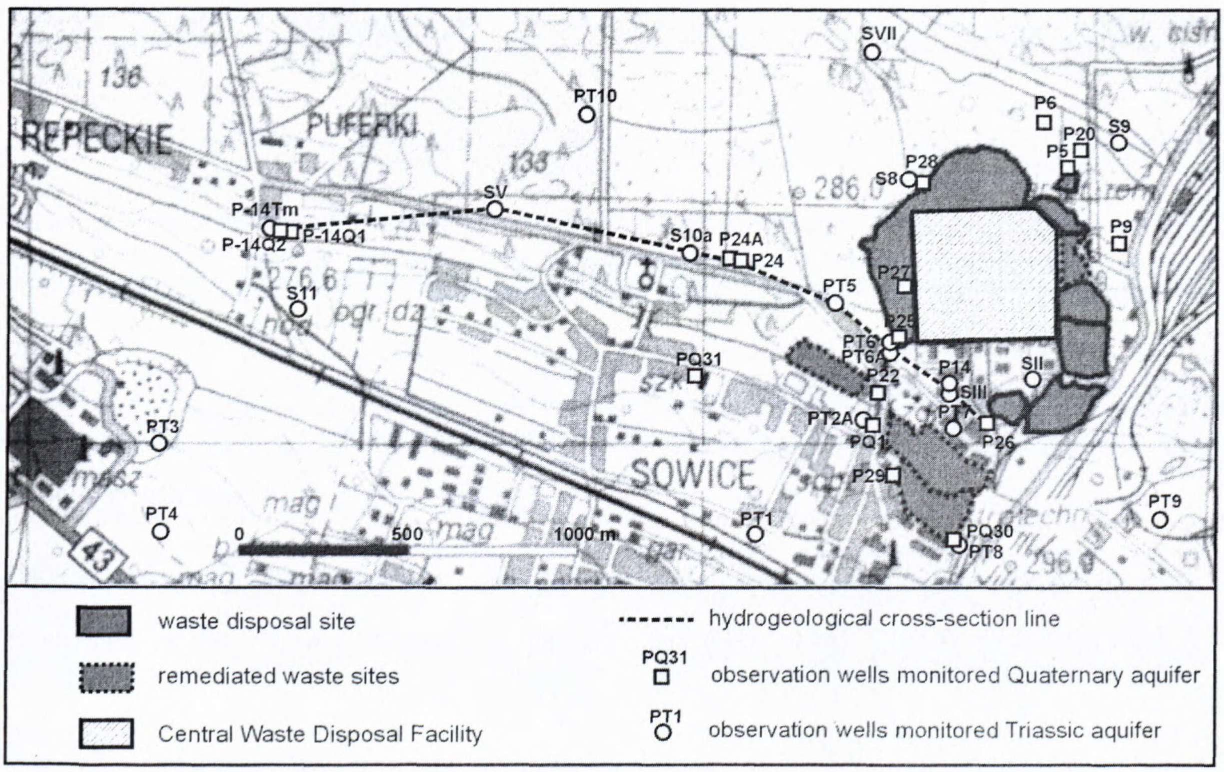

Fig. 3. Groundwater quality monitoring network.

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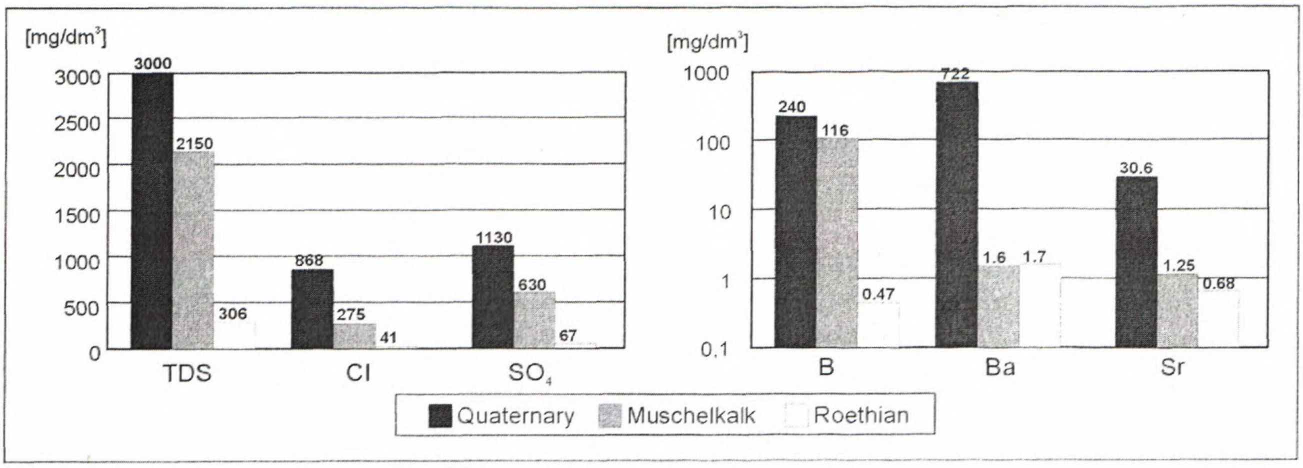

Fig. 4. Maximum concentration of selected groundwater pollution indicators.

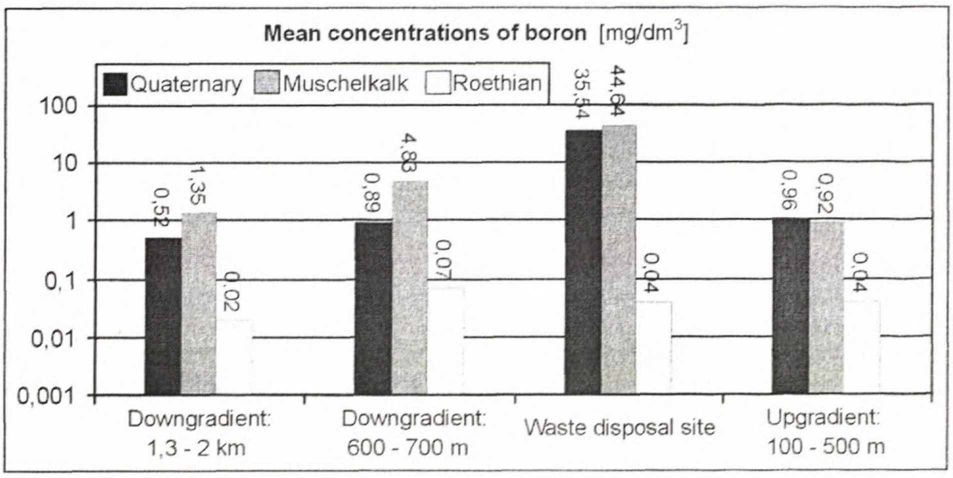

Fig. 5. Changes of boron concentration along selected groundwater flow pathways

aquifer, and 15 to 155 metres deep, in the case of Triassic one. There are only 5 groups of nested observation wells. Each of the groups consists of 2 to 3 wells (altogether 12 wells).

Field measurements encompassed the determination of temperature, pH, specific conductance and oxidation-reduction potential Eh. The range of chemical indicators determined by the laboratory tests has been changed. Currently 24 indicators are determined: TDS, COD, $N-NH_4$, $N-NO_3$, Cl, SO_4, HCO_3, Ca, Mg, Na, K, Al, As, Ba, B, Cd, Cr, Cu, Fe, Sr, Zn, detergents (only for the Quaternary aquifer), trichloroethene and tetrachloroethene (only for the Triassic aquifer).

Modelling

A groundwater-flow model and a solute-transport model were developed for the multi-aquifer system. The groundwater-flow system was simulated in three dimensions using the MODFLOW-96 computer code (McDonald and Harbaugh, 1988; Pollock, 1994; Zheng and Wang, 1999). MODFLOW was used in combination with MODPATH in order to determine the migration route and time of a contaminant from a waste disposal site to the existing well fields. MT3D was used in the solute-transport model. The model cell size is 50 x 50 m so the models were discretized into 231 rows and 113 columns. The models were vertically discretized into four layers (two Quaternary and two Triassic ones) separated by three aquitards. The models were calibrated for present period by means of the trial-and-error methodology using water-level data and boron-concentration data.

It was assumed that the current spatial distribution of boron concentration in the system under consideration is a result of its infiltration from the wastes taking place for the last 70 years. The simulated boron concentrations for that period stay in acceptable agreement with the measured data.

Groundwater quality

Groundwater quality in **the Quaternary aquifer** is very differentiated but generally it is very bad. Highly contaminated water is observed in the area of waste site: TDS – up to about 3000 mg/dm^3, Cl – up to 868 mg/dm^3, SO_4 – up to 1130 mg/dm^3, B – up to 240 mg/dm^3, Ba – up to 722 mg/dm^3, Sr – up to 30.6 mg/dm^3 (Fig. 4). Temperature of the groundwater varies seasonally between 5 °C (in winter) and 15.5 °C (in summer).

In the waste disposal area in the Quaternary aquifer groundwater in comparison to the water of upgradient zone a 60-time increase of the average boron concentra-

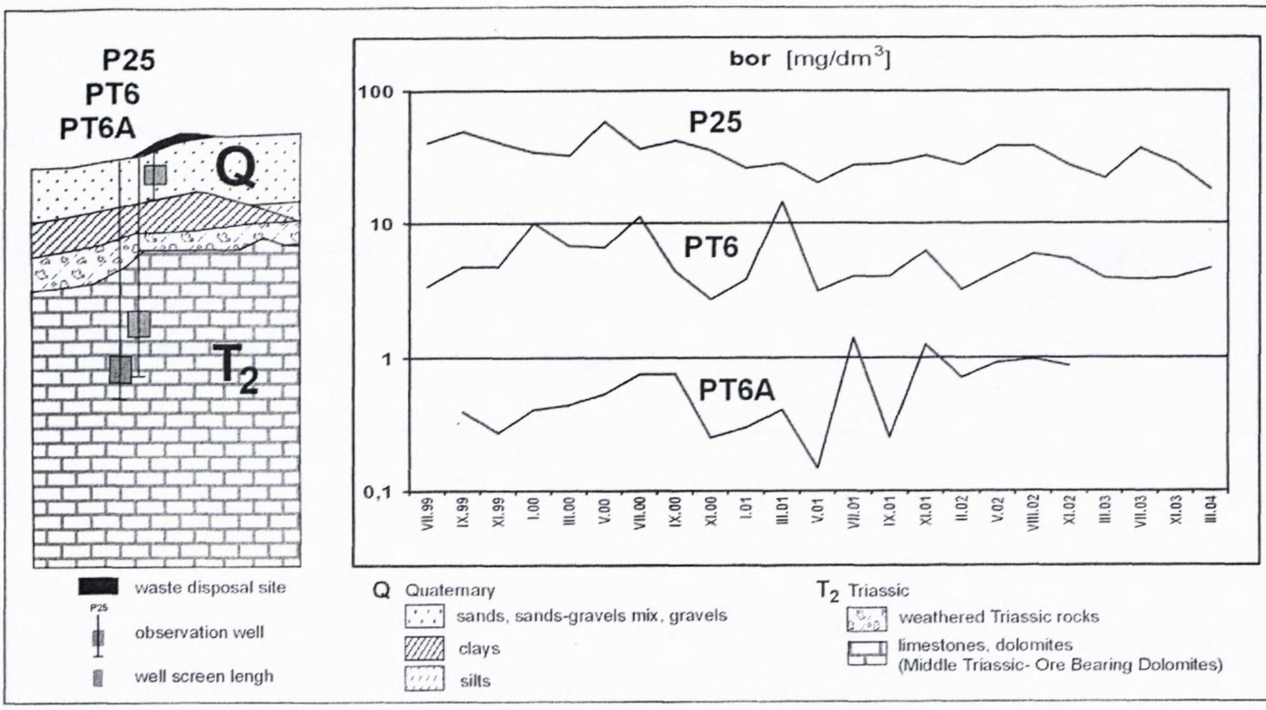

Fig. 6. Changes of boron concentration in groundwater in selected nested piezometers.

tion and a 26-time increase of the average strontium concentration have been observed (Fig. 5). The Quaternary aquifer groundwater in that area also shows increased concentrations of zinc, aluminium, cadmium, manganese, nickel, led, iron, ammonia and nitrates.

Generally similar groundwater quality of Quaternary aquifer in upgradient areas as well as downgradient ones (at a distance of about 2 km from the waste sites) is observed. It indicates a limited lateral migration of contaminants within the Quaternary aquifer.

Within **the Muschelkalk aquifer** the chemical variability of groundwater is connected with location of observation points referred to the disposed waste body and its location in the aquifer profile. Groundwater of this aquifer is generally less contaminated as compared with the Quaternary one (Fig. 4). Significantly contaminated water (locally even more than the one in the Quaternary aquifer) was noticed only in the top part of the Muschelkalk in the area of waste disposal sites and adjacent downgradient areas (up to about 1 km from the sites; TDS – up to 2150 mg/dm^3, Cl – up to 275 mg/dm^3, SO_4 – up to 630 mg/dm^3, B – up to 116 mg/dm^3, Ba – up to 1.6 mg/dm^3, Sr – up to 1.25 mg/dm^3; Rubin and Witkowski, 2003). In the waste disposal site area there have also been observed increased concentrations of ammonia, nitrates, manganese, iron, zinc, cadmium and nickel.

Water of better quality was observed at the base parts of the Muschelkalk aquifer in the area of the considered sites and at a distance of up to about 2 km downgradient from them (TDS – up to 694 mg/dm^3, Cl – up to 78.8 mg/dm^3, SO_4 – up to 127 mg/dm^3, B – up to 1.49 mg/dm^3, Ba – up to 0.1 mg/dm^3, Sr – up to 0.327 mg/dm^3). Temperature of groundwater within the Muschelkalk aquifer is more stable and varies from 10 °C to 12 °C.

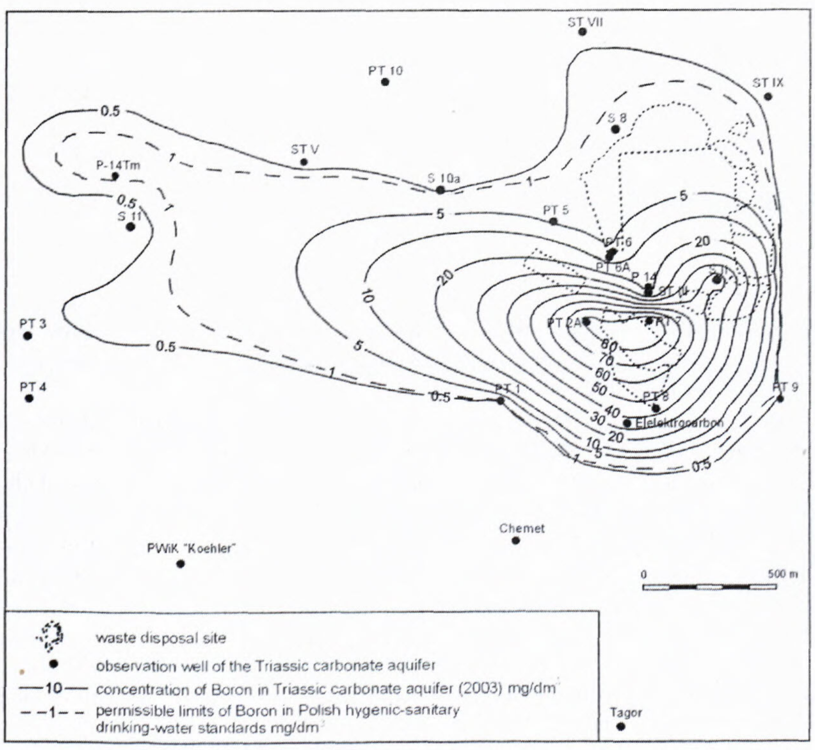

Fig. 7. Spatial distribution of the boron concentration in the Triassic aquifer (based on monitoring data – 2003)

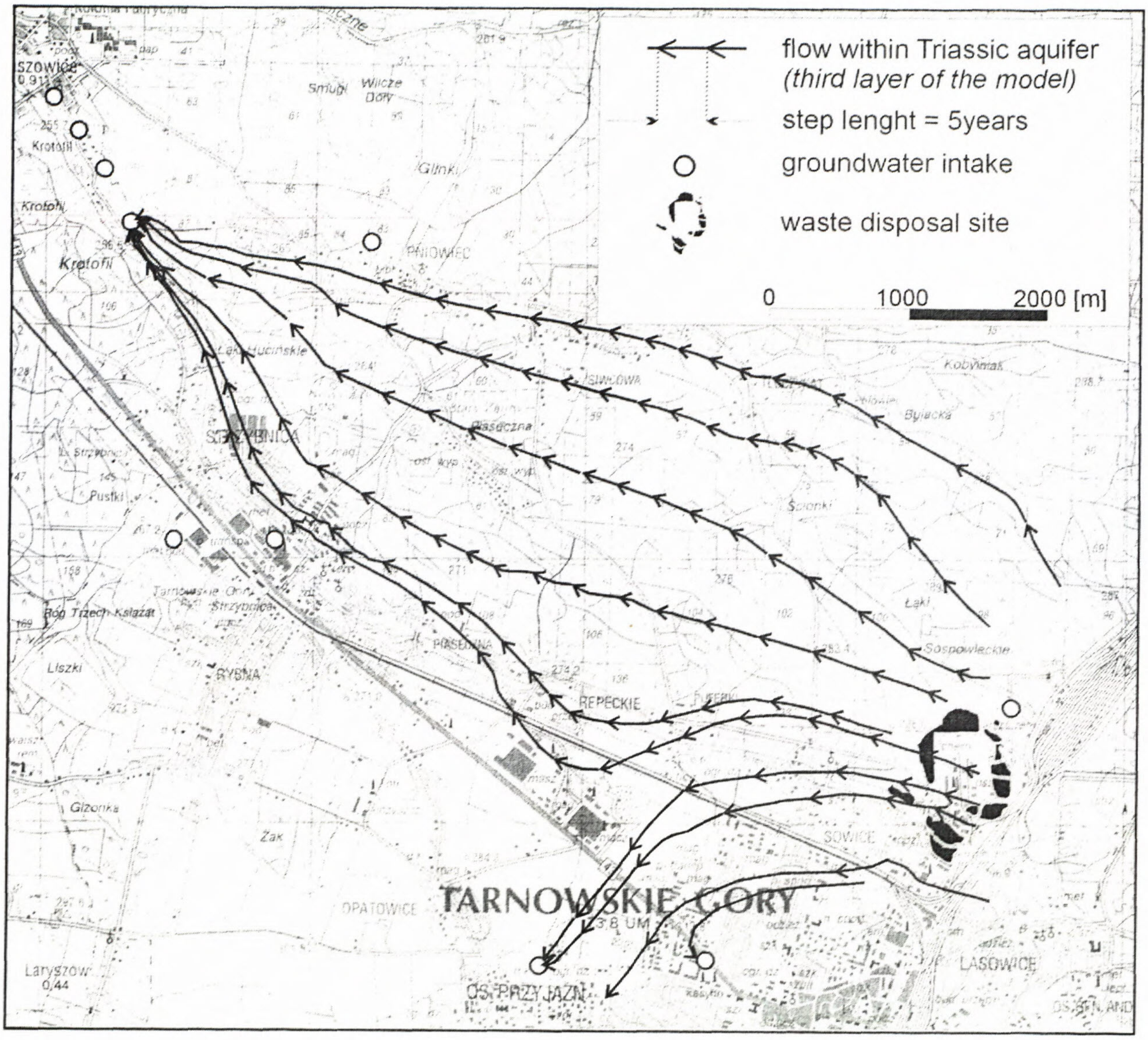

Fig. 8. Groundwater flow pathways according to the numerical modelling.

Groundwater of the fourth, lowest, aquifer (**Roethian**) have been practically uncontaminated by the considered facility (TDS – up to 306 mg/dm^3, Cl – up to 41 mg/dm^3, SO_4 – up to 67 mg/dm^3, B – up to 0.47 mg/dm^3; Fig. 4). The groundwater has a slightly lower and stable temperature ranging from 9 to 10 °C.

Vertical and horizontal differentiation of the boron concentration in groundwater of the considered multi-aquifer system is observed. Maximum content of $H_3BO_3^0$ (major easily migrating boron speciation) in groundwater of Quaternary and Triassic (Muschelkalk) aquifers occurs in the waste dump area (Fig. 5). However the maximum content of boron in groundwater of deepest Roethian aquifer is observed in the area of observation well S10a (about 0.7 km W downgradient from the waste disposal sites) where Muschelkalk and Roethian aquifers are probably hydraulically connected (Fig. 2). Vertical differentiation of boron content in groundwater is very well noticed in nested piezometers (Fig. 6). The mean concentrations of boron in the area of nested piezometers P25, PT6 and PT6A have varied from 0.86 mg/dm^3 (in the deeper part of the Muschelkalk aquifer – piezometer PT6A) up to 28.5 mg/dm^3 (in the shallow Quaternary aquifer – piezometer P25; Fig. 6).

In the course of the five years from 1999 to 2003 a general improvement of groundwater quality of the Quaternary aquifer and some relative stabilization of the groundwater quality of the Triassic aquifer were observed (Fig. 6). The current spatial distribution of the boron concentration within the Triassic aquifer based on monitoring data is shown in Fig. 7.

The hydrodynamic system of the Triassic aquifer shows a practically unlimited boron migration along some privileged flow ways in the NW and SW directions (Fig. 8).

Conclusions

The waste disposal sites under consideration have caused a significant groundwater contamination within the Quaternary and Triassic aquifers. Results of groundwater monitoring as well as numerical modelling indicate that an intensive downward groundwater flow within the first Quaternary aquifer predominates in the area of the waste disposal sites. A downward and locally horizontal flow was observed within the lower Quaternary aquifer. Both the Quaternary aquifers are of the transit type, being a source of recharge of lower Triassic aquifers. The horizontal flow in the Triassic aquifers is predominant while within the upper one (Muschelkalk) some weak downward component is also observed. The natural regional groundwater flow pattern is modified by active wells and old mine workings.

A significant differentiation in migration intensity of boron has been observed within the Quaternary and Triassic aquifers depending on water flow direction. Results of hydrodynamic modelling indicated a practically unlimited water outflow within the Triassic aquifers, which would enable the easily migrating boron to spread along privileged flow pathways without limits. However a limited lateral migration of contaminants within the Quaternary aquifer has been observed. Results of groundwater quality monitoring and simulated groundwater flow and advective transport of boron showed that groundwater of the Triassic aquifers discharging by wells located about 2.5–3 km SW downgradient from the waste disposal sites is possible to be contaminated in 25-30 years. The important, big water intakes situated at a distance of about 5-9 km NW downgradient from the sites are practically safe. Travel time of advecting boron from the waste site to that well field is estimated at about 90 years (Fig. 8).

Current remediation works and natural attenuation processes should result in general improvement of groundwater quality in all aquifers.

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Conceptual geochemical models of groundwater chemistry against aquifer mineralogy (Stephanian-Autunian sedimentary rocks, the Intra-Sudetic basin, SW Poland)

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Abstract. In Carboniferous-Permian aquifer in the vicinity of Sokołowsko and Unisław Śląski (Intra-Sudetic Basin, the Sudetes, SW Poland) the effects of gradual chemical evolution have been found. Groundwater chemistry varies from the fresh bicarbonate–calcium–magnesium water at the recharge area to sulphate–calcium–sodium mineral water downwards the basin. The main aqueous chemistry features are controlled by the dedolomitization process and calcium common–ion effects. Dissolution of gypsum and dolomite favours the calcite precipitation and cation exchange. Geochemical model presented in the paper was chosen after the selection of different variants. The effects of conceptual model assumptions on geochemical modelling results are discussed.

Key words: groundwater chemistry, geochemical modelling, sulphates, the Sudetes, Poland

Introduction

Drinking-water exploration works allowed to recognize the aquifer abound in the groundwater resources in Carboniferous and Permian sedimentary rocks south of Wałbrzych (the Intra-Sudetic Basin, the Sudetes). Waters are abstracted only in the northern part of the aquifer. Groundwaters in the southern part do not comply drinking water standards due to increased level of sulphate, hardness, iron, manganese, and trace elements (e.g. boron, arsenic, cadmium, lead).

Inverse mass balance and mixing geochemical modelling have been used to identify the groundwater quality origin and diversity (Dobrzyński, 2005). The paper presents preliminary modelling results and is focussed on the discussion of the effect of conceptual model assumptions on obtained models.

Methods

Groundwaters were sampled in wells of the intake in Unisław Śląski (wells Nos. 1, 2, 7, and 8) and in the unused borehole 5p in Sokołowsko after performed research pumping test (Fig. 1). Field measurements included SEC, pH, Eh, and T. Water samples were filtered in the field by cellulose-nitrate membrane 0.45 μm filters and stored in LDPE bottles. Anions were determined by spectrophotometric, HPLC or volumetric methods, and cations and trace elements by ICP-AES or FAAS methods. Computer code PHREEQCI v.2.11 (Parkhurst & Appelo, 1999) was used for geochemical modelling.

Geology and hydrogeology outlines

Studied area is located in the Intra–Sudetic Basin (central part of the Sudetes Mts). The basin is filled by the Lower Carboniferous–Lower Permian terrestrial molasse locally overlaid by the thin cover of terrestrial Lower Triassic sandstones and Upper Cretaceous marine deposits (Dziedzic & Teisseyre, 1990). The area of Unisław Śląski-Sokołowsko is built of Upper Carboniferous–Lower Permian sedimentary and volcanic rocks (Fig. 1). Studied groundwaters occur in lithostratigraphic members of Upper Stephanian and Lower Autunian ages (Tab. 1). Sedimentary rocks are deposited in alluvial and lacustrine environments (Bossowski & Ihnatowicz, 1994) and have varied mineral composition (Tab. 1). From the viewpoint of the groundwater chemistry the most important is the presence of reactive phases: gypsum, carbonate minerals (calcite, dolomite and siderite), sulphides (surely mainly pyrite) and dispersed organic matter.

Groundwaters occur mainly in fissured sandstones and mudstones. Total discharge of the intake in Unisław Śląski varied between 123.4 and 154.4 thousands m^3/month. Wells Nos. 1, 2, 7, and 8 give about 85 % of the total intake discharge. Intake is located in the upper part of the Ścinawka river catchment. Borehole No. 5p in Sokołowsko was drilled in 1980, and is unused due to poor water quality. Ścinawka river is the main base level of groundwater drainage in the upper part of catchment, and Sokołowiec – tributary of Ścinawka – is the one in the Sokołowsko valley (Fig. 1). Groundwater abstraction affected the natural hydrologic regime and probably

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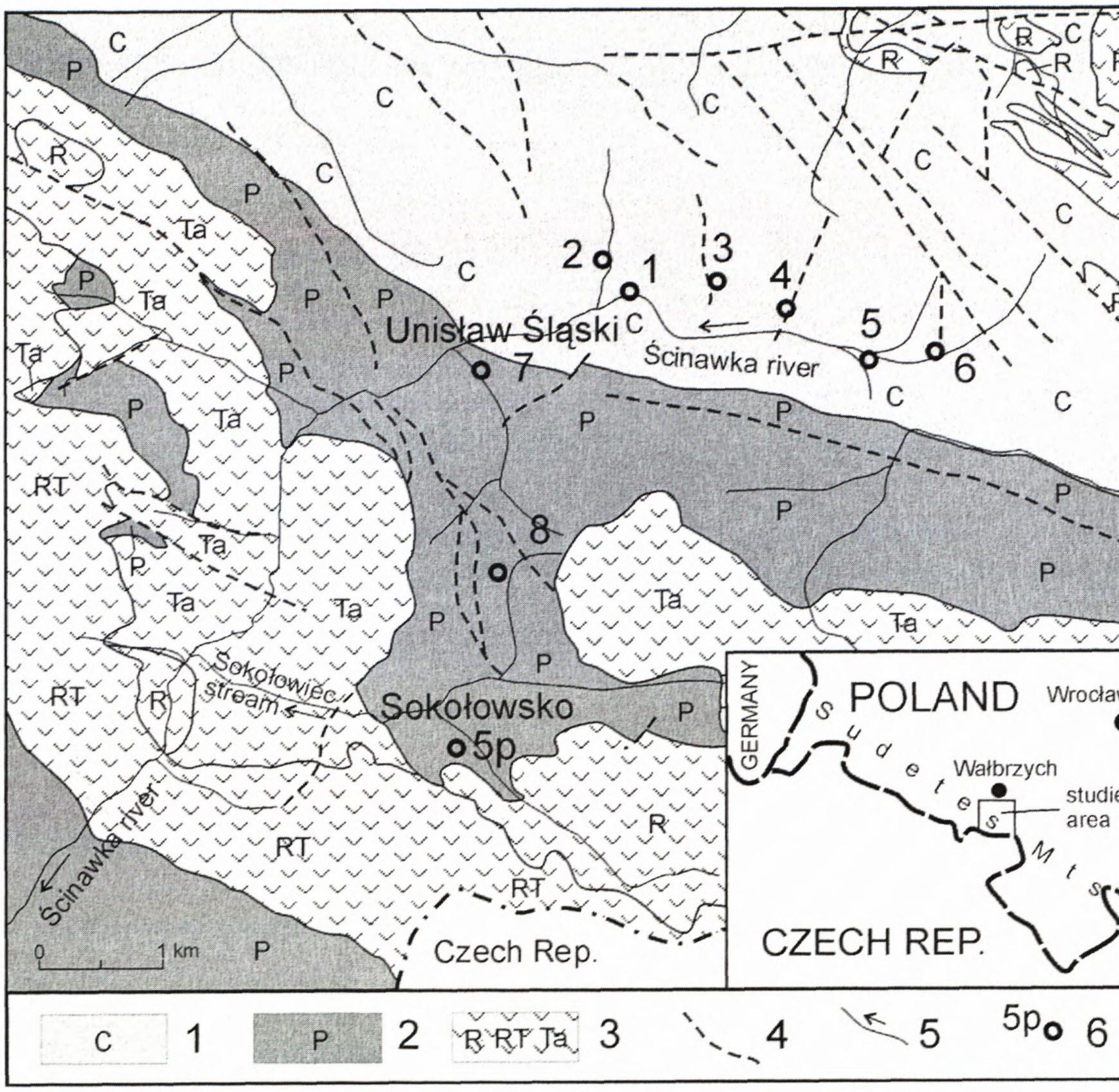

Fig. 1. Geological map of the studied area (after Grocholski, 1971; Bossowski et al., 1994; Awdankiewicz, 1999). 1 – Carboniferous sedimentary rocks, 2 – Permian sedimentary rocks, 3 – volcanic rocks: rhyolites, rhyolite tuffs, and trachyandesites, 4 – faults, 5 – waterways, 6 – wells.

Tab. 1. Mineralogical characteristics of sedimentary rocks in the Unisław Śląski – Sokołowsko area (after Bossowski, ed., 1996, 1997)

Lithostratigraphic units	Lithology	Main features of mineral composition
Zagórzyn Member (Autunian)	Mudstones and claystones with sandstones	Rare fragments of volcanic rocks and feldspars, argillaceous-siliceous and ferrous cement, xenomorphic calcite, dolomite, illite, kaolinite, rare dispersed pyrite and organic matter
Krajanów Member (Autunian)	Sandstones and mudstones with claystones, limestones, calcareous mudstones, bituminous limestones and mudstones at top	Fragments of volcanics and feldspars, chloritized clay schists, gypsum cement and covers, argillaceous-siliceous cement, ferrous pigment, siderite, bituminous mass, illite, calcite veins, dispersed pyrite and organic matter
Ludwikowice Member (Stephanian)	Polymict conglomerate sandstones, rarely mudstones and shales	Numerous fragments of volcanic rocks (rhyolites, trachyties) and feldspars, chloritized biotite, carbonates (mainly calcite), gypsum, sericitized and kaolinitized feldspars, argillaceous-siliceous cement with neogenic calcite, gypsum, and limonite

activated flow of sulphate groundwaters northwards. A first sign of this process was found in the chemistry of groundwater from wells 7 and 1 (Dobrzyński & Mitręga, 2002; Wiśniewska, 2003).

Groundwater chemistry

Fresh groundwaters from wells (Nos. 1, 3-6) located in the upper part of Ścinawka catchment (Fig. 1) present similar composition (Wiśniewska, 2003). They are of low total dissolved solids, usually below 400 mg/L. Bicarbonate-calcium-magnesium and bicarbonate-sulphate-calcium-magnesium hydrochemical types prevail there.

The groundwaters from wells situated along the dip of beds (Fig. 1, Tab. 2) – i.e. from well No. 2 followed by Nos. 1, 7, 8 to well 5p – manifest different chemical features. Chemical composition gradually changes from the fresh water in unconfined part of the aquifer at the recharge area (well 2) to mineral sulphate water southwards (well 5p). The concentration of the most solutes (SO_4, Ca, Mg, Na, Fe, Mn, Sr, B, As, NH_4, Zn, Li, Mo) increases southwards. Only concentration of chloride, fluoride, nitrate and barium increases (Tab. 3). It causes gradual changes of hydrochemical types. Waters from "meridional" set of wells were the subject of geochemical modelling (Dobrzyński, 2005).

Tab. 2. General characteristics of sampled wells

Well	Altitude, m a.s.l.	Well depth, m	Screened intervals (below the surface level, m)
2	582.1	96.5	32.5 - 86.7
1	582.5	88.8	43.5 - 47.5 60.7 - 67.7 75.7 - 77.7 81.0 - 86.0
7	569.8	100.0	60.0 - 85.0
8	620.0	220.0	71.9 - 102.5 160.5 - 197.7
5p	570.0	350.0	49.4 - 60.6 (fresh water) 72.3 - 92.2 (fresh water) 176.15 - 266.6 (sulphate mineral water) 305.6 - 314.3 (sulphate mineral water)

Groundwater chemistry is affected by the solubility products of gypsum (Fig. 2). Deviations from the regular pattern of gypsum dissolution are found both at the lowest and the highest calcium and sulphate concentrations. Bicarbonate and calcium concentration initially increases due to carbonate minerals. However, at the deeper part of the aquifer the inorganic carbon is immobilized (Fig. 3).

Increasing concentration of numerous trace elements (e.g. As, B, Sr, Zn) is interesting feature of the groundwater chemistry. Strontium surely originated by the gypsum/celestite dissolution. Arsenic is probably released from sulphides (pyrite) and also might come from organic matter both deposited in the deep lacustrine reduction environments. Iron and zinc can be related to pyrite and siderite dissolution.

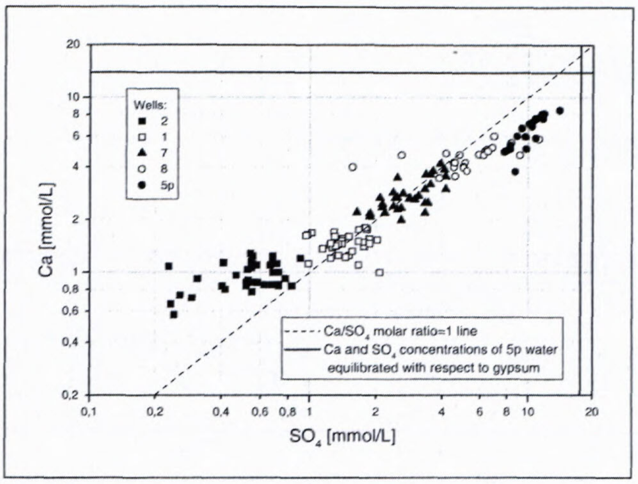

Fig. 2. Calcium vs. sulphate concentration in groundwater (after Dobrzyński, 2005).

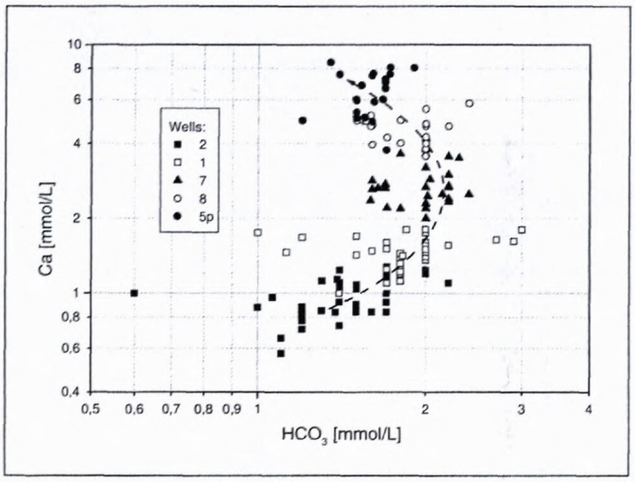

Fig. 3. Calcium vs. bicarbonate concentration in groundwater (after Dobrzyński, 2005).

Mass balance modelling results. Effects of conceptual model assumptions

Groundwaters manifest the effects of gradual chemical evolution. However, one should mention that sampled wells (Nos. 2, 1, 7, 8, and 5p) are not situated in the same flow path. Waters from extreme wells (Nos. 2 and 5p) show the scale of present chemical evolution in the aquifer, and were assumed as the "end-member" waters. Inverse modelling was performed between these two wells. The model included gypsum, celestite, dolomite, siderite, rhodochrosite, smithsonite, pyrite, arsenopyrite, calcite, barite, chlorite, kaolinite, $Fe(OH)_{3(a)}$, CH_2O, gases (CO_2, O_2, N_2), and calcium, sodium, and potassium in cation exchange. The role of particular phases has been discussed by Dobrzyński (2005). Results of speciation-saturation calculation and aquifer mineralogy data were used in constructing conceptual model(s). The saturation state of sulphate minerals (gypsum, celestite, and barite) approaches the equilibrium as sulphate concentration increases downwards the basin. At the same time

Tab. 3. Chemical composition of groundwater (after Dobrzyński, 2005). Concentrations in mg/L

Parameter	Well No. 2	Well No. 1	Well No. 7	Well No. 8	Well No. 5p[1]
T	11.2	9.3	10.1	15.46	15.3
pH	7.73	7.80	7.47	7.74	7.60
pe	6.373	6.151	5.969	5.556	1.278
SEC_{25}[2] [μS/cm]	249	460	598	1230	2070
SiO_2	17.0	18.0	17.3	30.4	19.8
SO_4	38.8	126	205	625	1113
HCO_3	84	111	123	95	116
Cl	7.12	9.5	2.4	<0.5	<0.5
F	0.11	0.10	0.10	0.01	0.01
NO_3	8.11	8.9	4.46	1.94	0.00
Ca	33.5	56.5	98.4	197.7	322.9
Mg	5.8	16.6	9.4	25.9	20.2
Na	6.0	12.6	16.1	54.9	129.5
K	1.1	1.5	1.9	0.3	1.5
Al	<0.01	<0.01	0.02	<0.01	0.001
As	<0.01	<0.01	0.01	0.11	0.14
B[3]	0.02	0.05	0.17	0.45	1.41
Ba	0.127	0.044	0.038	0.017	0.011
Fe	<0.01	<0.01	<0.01	0.06	0.66
Li[3]	0.005	0.011	0.031	0.035	0.121
Mn	0.001	0.001	0.011	0.086	0.126
Mo[3]	0.001	0.001	0.005	0.016	0.022
NH_4	<0.05	<0.05	<0.05	<0.05	0.13
Sr	0.086	0.291	1.045	8.942	7.836
Zn	0.016	0.018	0.054	0.017	1.052
Hydrochemical type	HCO_3-SO_4-Ca	SO_4-HCO_3-Ca-Mg	SO_4-HCO_3-Ca	SO_4-Ca	SO_4-Ca-Na

1 – composition of water from the sulphate horizons in well 5p; 2 – specific electric conductivity compensated to 25 °C; 3 – element not included in geochemical models

Tab. 4. Mole transfers in found geochemical models

Phase	Models with minimum number of phases		Model without minimum number of phases
	1	2	3
CO_2(g)		4.981E-04	
N_2(g)	-6.174E-05	-6.174E-05	-6.174E-05
Gypsum	1.077E-02	1.068E-02	1.075E-02
Celestite	8.861E-05	8.861E-05	8.861E-05
Dolomite	5.669E-04	7.168E-04	7.168E-04
Siderite	6.612E-04		5.747E-04
Pyrite		4.408E-05	5.765E-06
Rhodochrosite	2.279E-06	2.279E-06	2.279E-06
Smithsonite	1.588E-05	1.588E-05	1.588E-05
Arsenopyrite	1.805E-06	1.805E-06	1.805E-06
Calcite	-7.183E-04	-7.050E-04	-7.817E-04
Barite	-8.443E-07	-8.443E-07	-8.443E-07
Kaolinite	-6.199E-05	-4.700E-05	-4.700E-05
Chlorite	6.206E-05	4.708E-05	4.707E-05
$Fe(OH)_{3(a)}$	-6.512E-04	-3.413E-05	-5.705E-04
"Halite"	-1.951E-04	-1.951E-04	-1.951E-04
"Fluorite"	-1.576E-06	-1.576E-06	-1.576E-06
NaX	5.715E-03	5.715E-03	5.715E-03
KX	1.030E-05	1.030E-05	1.030E-05
CaX2	-2.863E-03	-2.863E-03	-2.863E-03
Sum of transfers	1.334E-02	1.391E-02	1.341E-02
Redox mole transfers			
As(3)	9.023E-07	9.023E-07	9.023E-07
Fe(3)	-6.511E-04	-3.407E-05	-5.704E-04
N(-3)	-7.152E-06	-7.152E-06	-7.152E-06
N(0)	-1.235E-04	-1.235E-04	-1.235E-04
O(0)	-3.610E-06	-3.610E-06	-3.610E-06
S(-2)	1.805E-06	8.996E-05	1.334E-05

also calcite and dolomite tends towards equilibrium. Saturation index of the latter minerals does not correlate with bicarbonate and pH (op.cit.).

Calculation by PHREEQCI code gave several mass balance models with minimum number of phases. Two of them were chosen (Tab. 4). The models mainly differ in mole transfer of: (1) gases (CO_2, O_2) dissolution, (2) organic matter oxidation, (3) calcite precipitation, (4) iron source phase (siderite or pyrite), and (5) iron sink phase ($Fe(OH)_{3(a)}$). Gypsum and dolomite dissolution transfers differ slightly.

The models were selected as the ones that probably better describe the real system. Both models differ each other in term of iron source phase. Model No. 1 includes siderite, and model No. 2 – pyrite. In the real geochemical system the dissolution of both siderite and pyrite is surely taking place, what is illustrated by the model without minimum number of phases (model No. 3 – Tab. 4). Released iron can be immobilized at iron hydroxides and/or oxyhydroxides, like $Fe(OH)_{3(a)}$ or goethite. Selected models include decrease of Fe(3) and O(0) forms in redox transfer.

According to modelling results the chemistry of sulphate groundwater in Sokołowsko might be explained by congruent dissolution of gypsum and incongruent dissolution of dolomite with calcite precipitation. Increasing sulphate activity in water favours dolomite dissolution and $MgSO_4^0$ complex formation. It promotes further gypsum and dolomite dissolution and increase of magnesium concentration. Calcite precipitation is enhanced by the calcium common-ion effect among gypsum, dolomite, and calcite. Calcium also depends upon ion exchange with monovalent cations (Na^+, K^+).

In the groundwaters at recharge area (well 2) the sulphate concentration is lower that conforms with gypsum solubility (Fig. 2). Gypsum in bedrock of recharge area is leached out already. Sulphates in fresh waters mainly come from biomass biodegradation and from atmospheric deposition, whereas calcium originates from carbonate minerals dissolution. Next, in sulphate mineral waters (wells Nos. 8 and 5p) the calcium concentration is lower than saturation with gypsum probably due to the cation exchange ($Ca^{2+} \leftrightarrow Na^+$ and K^+).

The barite precipitation causes the barium decrease, whereas celestite dissolution – strontium increase. Gypsum also can be the source of Sr. Mole transfer ratio of celestite to gypsum suggests that gypsum should contain about 0.8 % of Sr, what corresponds with reasonable level of the element content in gypsum.

Arsenic probably originated by the sulphide minerals dissolution. Iron can be released during both the siderite and pyrite dissolution. Sulphide dissolution promotes decrease of gypsum, siderite and calcite transfers. Pyrite oxidation does not bring the water acidification because groundwaters are efficiently neutralized by the carbonate dissolution.

Redox potential drops towards sulphate waters, from 357 mV (well 2) to 73 mV (well 5p). However, redox potential in sulphate groundwater remains still so high to reduce sulphates to sulphides.

The main features of aquifer mineralogy are known. However, some doubts arise during the modelling process because the absence of detailed data on bedrock mineralogy and chemistry.

Calcium geochemistry in groundwater depends upon gypsum dissolution and common-ion effects of several solid phases (gypsum, dolomite, calcite), and is strictly connected with other main solutes, like magnesium, sulphate and sodium.

Magnesium can originate from dolomite or Mg-calcite dissolution, but there is unknown chemical composition of carbonate minerals in aquifer. The former one was taken into account (Dobrzyński, 2005) as magnesium solute source in the presented model. The calcite present in aquifer bedrock can also contain some amounts of magnesium. The application of Mg-calcite of different composition as a source of magnesium instead dolomite, extorts the higher mole transfer of dissolving Mg-calcite in groundwater mass balance than dolomite transfer, as well as increasing transfer of precipitated calcite. The lower content of Mg in incongruently dissolved Mg-calcite, the higher mole transfers (Fig. 4).

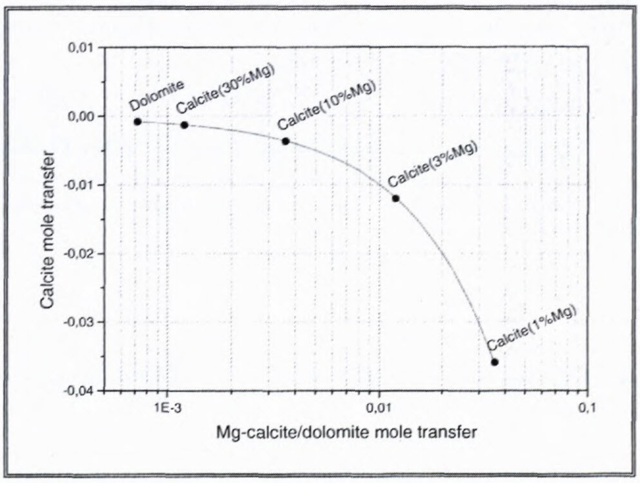

Fig. 4. Effect of magnesium content on Mg-calcite/dolomite and calcite mole transfers.

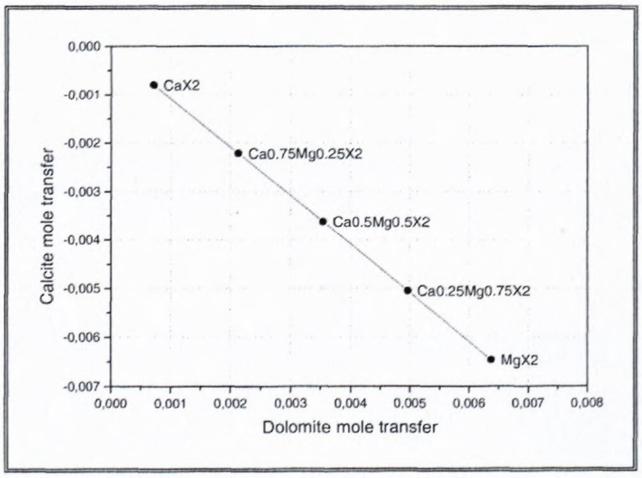

Fig. 5. Effect of magnesium sorption on dolomite and calcite mole transfers.

Magnesium together with calcium can take part in the cation exchange with monovalent cations (Na^+, K^+). It affects transfer of carbonate minerals. Magnesium sorption causes the increased dolomite dissolution and resulting increased calcite precipitation. The higher magnesium adsorption, the higher transfer of dissolving dolomite (or Mg-calcite) as well as the higher calcite precipitation (Fig. 5).

Increase of pyrite dissolution promotes the decrease of siderite and gypsum transfer – source phases of iron and sulphate. Then, calcite precipitation transfer decreases (Tab. 4). Iron immobilizing in (oxy) hydroxides probably can take place mostly at recharge area where oxygen is available but the amount of organic matter is lower.

Obtained models suggest that the role of organic matter is probably negligible in the chemical evolution of the aquifer. Oxidation of organic matter can locally take place in the aquifer. It is more likely in recharge area where oxygen is more attainable.

Presented preliminary geochemical model fits with the main features of aquifer chemistry. Researches of tritium and stable isotopes (δD, $\delta^{18}O$, $\delta^{34}S$, $\delta^{13}C$) in groundwater are in progress (Dobrzyński, 2005). It will allow the verification of the geochemical model. Detailed investigations of reactive minerals chemical composition in the bedrock are also necessary.

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Geochemistry of urban street sediments of Bratislava, Slovakia

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Abstract. Street dust samples in the inner as well as outer parts of the city agglomeration Bratislava were collected to acquire the baseline pattern of their granulometric, mineralogical and chemical composition and its spatial variation.

Grain-fraction analysis pointed out relatively small rate, ca 1–4 %, of the finest, clay fraction (<2μm). The highest amount, ca 85–90 %, was documented for the sand fraction in all samples.

From the point of view of mineralogical composition analysis of clayey fraction the presence of following minerals in street dust samples was observed: illite, chlorite, quartz and feldspar. Other minerals like kaolinite, smectite and calcite were found variably distributed in collected samples. No significant differences were documented when comparing the inner and outer city samples.

Chemical analyses of 2 size fractions (<1 mm and <0.125 mm) revealed significant concentration variations as a function of particle size mainly for Cu, Fe, Mn and Zn which are characterized with the higher content levels in finer fraction. On the other hand, As and Cd feature the very similar concentrations in both analysed fractions.

Comparison of chemical composition of inner and outer city samples did not show any substantial differences in chemical content levels. Markedly higher mean concentrations in inner city samples have been found in the case of Cr (>100 $mg.kg^{-1}$) and Cu (>200 $mg.kg^{-1}$). Following inner city sampling locations are characterized by the higher contents of some metals: Kamenné námestie (Cr, Fe, Ni and Mn), Hodžovo námestie (Cu and Zn) and Nový most (Pb and Zn). Based on concentration data correlations the significant correlation coefficients were determined for Cr and Ni, Cd and Zn, Fe and Mn with Cr and Ni.

Key words: street sediments, chemical composition, mineralogy, Bratislava, Slovakia

Introduction

Street sediments represent specific component of urban environment which chemical composition reflects the character of anthropogenic activities and geogenic processes proceeding in a particular city agglomeration. Thus the urban street sediment geochemistry represents one of the needful investigation fields concerning assessment of urban environment pollution.

Present studies realized worldwide are focused on analysis of metal concentration levels mainly in the finer street sediment fraction (dust particles) and their potential mobility and availability in urban environment (aquatic systems, Charlesworth & Lee, 1999; Li et al., 2001; Ordóñez et al., 2003; Varrica et al., 2003 and others). Their purpose is to acquire basic information on input and distribution pattern of potentially toxic elements in urban ambient in relation to associated potential health and environmental risks.

In the Slovak Republic a regional and local continual monitoring of air quality and pollution, performed by the Slovak Hydrometeorological Institute, is done (SHMU, 2005). It is focused mainly on quantitative analysis of total suspended particles (TSP), particulate matters <10 μm (PM_{10}) and <2.5 μm ($PM_{2.5}$) and to a lesser extent on concentration determination for some metals in TSP (mainly Cd and Pb). No analogous study in relation to geochemistry of road-deposited sediments, representing potential source of contaminated airborne and fine respirable particles, was until realized.

The main aim of this study is to provide the primary basic characteristics of street sediments in one of the busiest industrial cities of Slovakia, a capital Bratislava. It includes granulometric analysis, mineralogical characteristics and chemical content level determination regarding the different particle size as well as the particles spatial distribution (inner / outer samples). The first impulse for performing such a study was a British research project, realized in summer 2003 in Bratislava. Within its frame the chemical composition analyses of some street sediment samples from the major city crossroads were acquired (Robertson, 2004). A relative consistency of both studies (selection of sampling sites, similar range of chemical analyses) allows to achieve the basic information on possible distribution variability of chemical concentration levels at respective sampling locations.

Presented study represents a contribution to the field of urban pollution characterization and assessment based

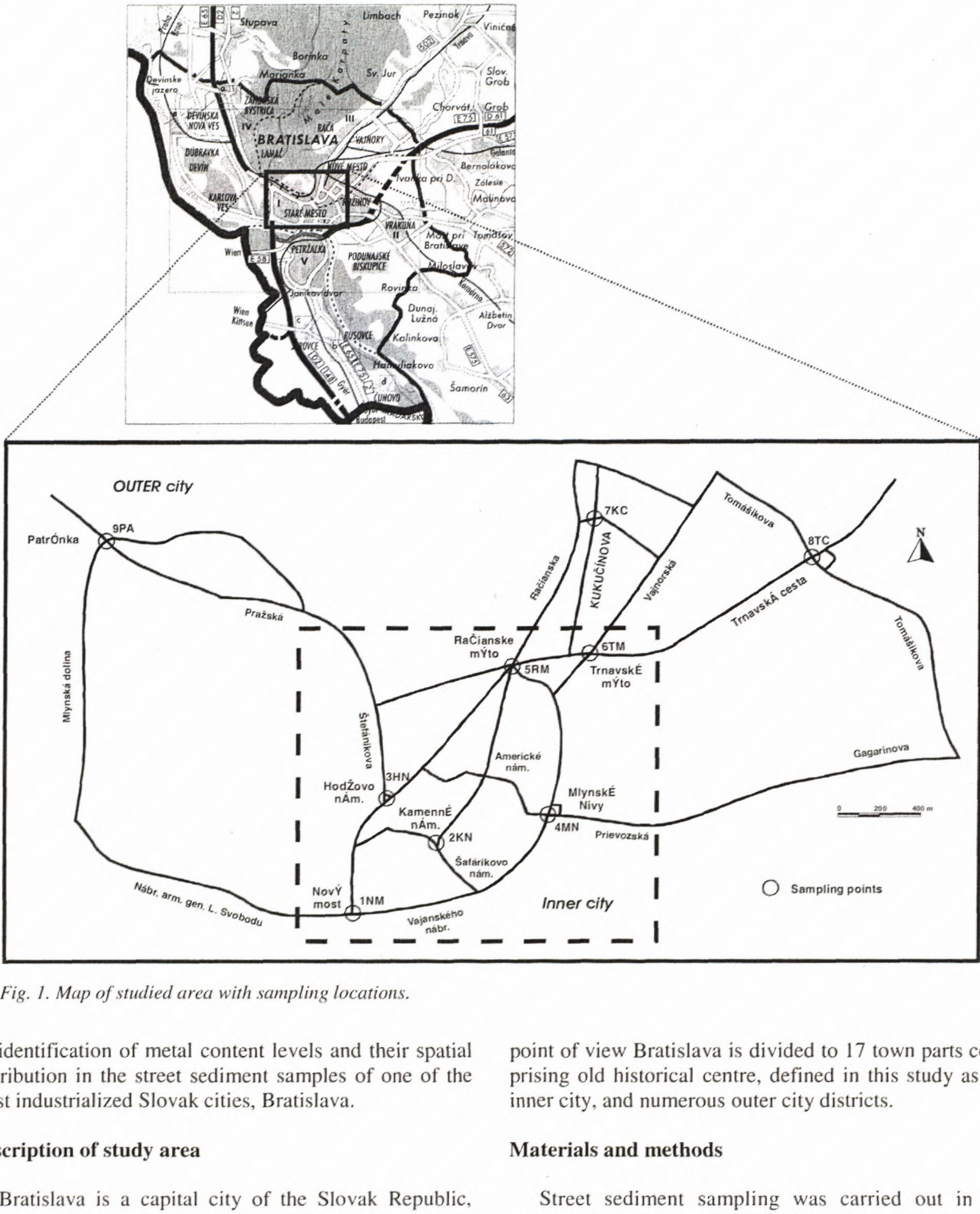

Fig. 1. Map of studied area with sampling locations.

on identification of metal content levels and their spatial distribution in the street sediment samples of one of the most industrialized Slovak cities, Bratislava.

Description of study area

Bratislava is a capital city of the Slovak Republic, situated in the southwestern part of the country. It is spread on both banks on the river Danube on the area ca 370 km^2, at the foot of the Malé Karpaty Mts. and on the boundary of the Danube and Borská lowlands. Bratislava represents the most significant economic and transport centre in Slovakia with population density more than 1,200 inhabitants per km^2 (cca 450,000 inhabitants). Since it is the most industrialized city and the significant traffic junction, it is predisposed to be one of the most polluted regions in the Slovak Republic. Chemical industry, power generation and traffic are defined as the main sources of atmospheric pollution. From the administrative point of view Bratislava is divided to 17 town parts comprising old historical centre, defined in this study as the inner city, and numerous outer city districts.

Materials and methods

Street sediment sampling was carried out in the summer-time (August 2004), in a long-term rainless period. Sampling collection was focused on some major crossroads with the high traffic density in the inner city as well as its outer parts. Overall, 9 samples were collected by the street sweeping at traffic islands on some of the busiest inner/outer city crossroads. The setting of study area and location of sampling sites are shown in Fig. 1. Six of nine samples were located in the central part of the city and three in the outer zone. Inner city samples caught the busiest Bratislava traffic junctions (samples 1KN, 3HN, 4MN, 5RM, 6TM) and marginally also pedestrian zone (2KN). The outer city samples

(7KC, 8TC and 9PA) were situated closely to trunk roads with the big traffic flows.

A plastic dustpan and brush and self-sealing polyethylene bags were used to avoid sample contamination. Sample quantity ranged from 100 to 200 g, depending on the sediment amount accumulated at the site of concern. Collected samples were air-dried at room temperature and screened through a 1 mm aperture metal sieve to exclude large particles, including stones and impurities (e.g. glass, debris). Subsequently, respective sub-samples were acquired in compliance with requirements of further analyses.

Following analytical methods were used within a frame of urban sediment composition analysis:

- Grain-fraction analysis,
- X-ray analysis,
- Chemical analysis.

Grain-fraction analysis

Sub-samples <1 mm of about 60 g undergone the granulometric analysis to provide basic characteristics of collected samples, regarding the composition rate of various grain fractions. Based on using sieves with the different aperture sizes a percentual content of distinct size fractions, sandy (1–0.060 mm), loamy (0.060–0.002 mm) and clayey (<0.002 mm), was determined.

X-ray analysis

The X-ray powder diffraction method was used to provide general information on mineralogical composition of the street sediment samples. A finest, clayey fraction <0.002 mm was analysed since it plays an important role in sorption processes of potentially toxic elements.

Sub-samples <0.002 mm were obtained from suspension consisting of <1 mm fraction and distilled water. Subsequently, the oriented specimens were prepared, both untreated (air-dry) as well as treated with ethylene glycol (EG), and were used for identification of phyllosilicates with expandable layers (e.g. smectite). The X-ray analysis was performed using the DRON – 3 diffractometer (Co anticatode with Fe filter, 15 mA current and 30 kV voltages).

Chemical analysis

Two size fraction chemical composition analyses were carried out for the purpose of chemical content level determination as well as their distribution as a function of particle size. Samples were divided in 2 sub-samples, <1 mm and <0.125 mm, of about 5 g, respectively. The total contents of 10 chemical elements (As, Cd, Cr, Cu, Fe, Hg, Mn, Ni, Pb and Zn) were determined for both particle size fractions, using standard laboratory procedures and analytical methods (see Tab. 1).

Results and discussion

Grain-fraction composition

All samples have similar particle-size composition without any marked differences regarding the inner/outer city sampling site location (see Fig. 2). Sandy fraction predominates with percentage rate corresponding approximately to 85–90 %. Further loamy and clayey fractions are present proportionally in minor quantities, cca 9–11 % and 1–4 %, respectively. Despite of low amount of the finest clay fraction, this still represents, since respirable and relevantly involved in potentially toxic element retention, the most significant particle size fraction with respect to associated potential human health risk.

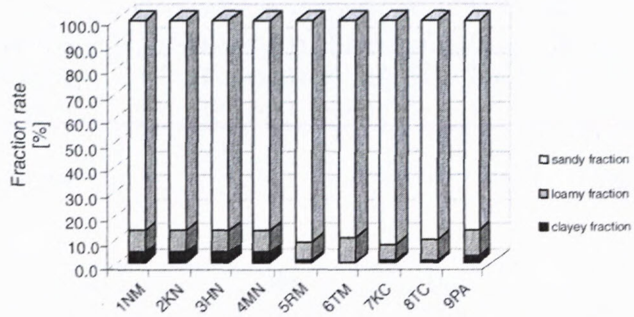

Fig. 2. Percentage rate of grain-size fractions in collected street samples.

Mineralogical composition

In general, the mineralogical composition of clayey sample fraction seems to be rather complex but without any significant differences between inner/outer city sampling sites. Following minerals were determined in all street sediment samples (see Tab. 2): illite, chlorite, quartz and feldspar. Other minerals including kaolinite, smectite and calcite were found to be characterized with variable distribution in collected samples.

Chemical composition

Review of chemical contents, determined in the urban street sediment samples of Bratislava inner and outer city, is shown in Tabs. 3 and 4.

In all of the Bratislava street sediment samples (see Tab. 5) the lowest concentration levels were, in the case of <1 mm fraction, found for As and Cd, ranging from 2.6 to 3.8 $mg.kg^{-1}$ (mean concentration: 3.1 $mg.kg^{-1}$) and 0.6 to 1.2 $mg.kg^{-1}$ (mean concentration: 0.9 $mg.kg^{-1}$). On the other hand, Fe and Mn show the highest concentration levels in a range 19.0-30.6 % (mean concentration: 23.1 %) and 360.8-577.7 $mg.kg^{-1}$ (mean concentration: 428.4 $mg.kg^{-1}$), respectively. Similar trend in chemical content levels was determined also in the case of <0.125 mm fraction.

Generally, data on metal concentration levels in street dust and urban sediments, acquired in analogous studies realized worldwide, are rather variable and often each other inconsistent (different analysed fraction, decomposition methods etc.). Comparing our results with some of existing concentration data on analysed chemical elements (see Tab. 5) we can state similar content range determined for Cd and Zn (Ahmed & Al-Swaidan, 1993; De Miguel et al., 1997; Charlesworth et al., 2003). The significantly lower contents are documented for Pb whereas Fe and Mn concentrations are found to be substantially higher (Robertson et al., 2003; Loredo et al., 2003). Cr,

Tab. 1 Review of analytical techniques and detection limits

Chemical element	Way of decomposition	Analytical method	Analytical instrument	Detection limit	Units
As	HNO_3, HCl	HG-AAS	PE 3100 FIAS 100	0.1	$mg.kg^{-1}$
Cd	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	0.1	$mg.kg^{-1}$
Cr	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	5	$mg.kg^{-1}$
Cu	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	1	$mg.kg^{-1}$
Fe	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	0.01	%
Hg	-	AAS	TMA-254	0.03	$mg.kg^{-1}$
Mn	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	10	$mg.kg^{-1}$
Ni	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	1	$mg.kg^{-1}$
Pb	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	5	$mg.kg^{-1}$
Zn	HF, $HClO_4$, H_3BO_3, HCl	F-AAS	PE 3030B	1	$mg.kg^{-1}$.

Tab. 2 Mineral composition of clayey street sediment sample fraction

Sample	Illite	Kaolinite	Chlorite	Smectite	Quartz	Calcite	Feldspar
1 NM	+	+	+	+	+	+	+
2 KN	+	+	+	–	+	–	+
3 HN	+	+	+	–	+	+	+
4 MN	+	+	+	–	+	+	+
5 RM	+	–	+	+	+	+	+
6 TM	+	+	+	+	+	+	+
7 KC	+	+	+	–	+	–	+
8 TC	+	+	+	+	+	?	+
9 PA	+	–	+	–	+	+	+

Cu a Ni seem to be the most variable parameters with markedly varying content levels in the street sediment samples (Banerjee, 2003; Charlesworth et al., 2003; Loredo et al., 2003).

The wide variability of chemical concentrations in urban street sediments was revealed and documented also by a comparison of our results with the previously realized British study (Robertson, 2004, Fig. 3). In general, the metal concentration data in the street sediment samples of presented study are higher. The most significant differences can be observed in the case of Fe and Mn whereas the slightliest are in the case of Pb and Cu. One of the possible explanations of observed variations is supposed to be the different way of sample decomposition performed in our study using the strong mixed acid digestion in contrast to foreign study proceeding using the weak 10 % nitric acid digestion.

From the point of view of chemical content levels as a function of particle size we can state that higher concentrations are found in finer fraction <0.125 mm. The most significant variations in chemical contents between 2 analysed fractions can be observed in the case of Cu, Fe, Mn and Zn. On the contrary, As and Cd feature very similar concentration levels in both fractions.

Comparing inner and outer city samples, in general no substantial variations can be noticed. Main differences are observed for Cr and Cu, which contents are markedly higher in the inner city samples, exceeding 100 and 200 $mg.kg^{-1}$, respectively. Mean concentration variations of other chemicals result mainly from their increased content levels, determined locally in single inner (Ni, Pb, Fe) and also outer city samples (Zn, see Tabs. 3 and 4). Interpreted spatial trend in chemical content variations is figured in Fig. 4. From the inner city part, following sampling sites are characterized by the higher metal contents: Kamenné námestie (Cr, Fe, Ni and Mn), Hodžovo námestie (Cu and Zn) and Nový Most (Pb and Zn). On the other hand the lowest concentrations of chemicals were determined in the case of Račianske mýto crossroad. From the outer city part sampling locations, Kukučínova is characterized by the slightiest differences in content levels of analysed chemicals (mainly Cr, Ni and Pb) in comparison with inner city samples.

The fact that localities with potentially highest traffic are relatively "clean" (e.g. Račianske mýto) and on the other hand those considered to be "cleaner" (e.g. Kukučínova) are characterized with higher metal contents, points out various genesis and manifold sources of urban street sediment material.

Based on linear correlation of chemical concentration data on urban street sediment samples of fraction <0.125 mm (see Tab. 6), the significant correlation coefficients were determined for following elements: Cr-Ni, Cd-Zn and Fe-Mn with Cr-Ni. No correlations at evaluated significance levels (<0.01 and <0.001) are observed in the case of As, Cu, Hg and Pb.

From the point of view of spatial distribution of analysed chemicals no significant differences in their content levels in the inner and outer city samples were documented. Additional and extended sample collection and analysis of street sediments, but also of other media like urban soils, are required to confirm introduced spatial trends in chemical distribution as well as to catch their concentration variations in time (continual research). Performance of such a research could contribute to identification of the main urban contaminants and possible detection and interpretation of their sources (anthropogenic/geogenic).

Conclusions

Street sediment samples collected in inner as well as outer city parts were submitted to granulometric, mineralogical and chemical composition analyses.

Grain-fraction analysis has revealed the predominance of sandy fraction and on the other hand relatively low rate of the finest, clay particles.

Tab. 3 Chemical concentration data for urban street samples of Bratislava – INNER CITY

Sample	Particle size	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
1NM	<1mm	3.2	0.9	55.2	138.7	21.1	<0.03	378.2	27.5	276.5	366.5
	<0.125mm	3.1	1.4	103.8	215.5	27.5	0.03	593.4	40.5	272.8	367.3
2KN	<1mm	3.8	1.2	341.9	204.2	30.6	<0.03	577.7	150.1	34.4	222.4
	<0.125mm	3.7	1.1	416.2	267.2	42.1	0.05	773.1	185.5	48.0	302.4
3HN	<1mm	2.6	0.9	69.2	214.6	25.6	0.03	461.6	21.9	29.3	322.6
	<0.125mm	3.0	1.4	104.7	401.8	30.0	0.05	604.5	36.3	63.1	463.2
4MN	<1mm	3.0	0.9	51.3	201.2	26.9	<0.03	428.6	21.2	33.6	297.2
	<0.125mm	3.6	1.5	86.8	368.5	29.9	0.05	607.6	32.7	84.4	369.5
5RM	<1mm	3.0	0.6	48.5	278.9	21.8	<0.03	360.8	18.4	25.6	203.1
	<0.125mm	3.5	1.0	86.2	103.3	28.5	<0.03	564.1	32.3	52.7	342.9
6TM	<1mm	3.6	1.0	46.4	143.8	20.0	0.04	373.2	20.7	52.1	241.1
	<0.125mm	3.7	1.5	86.9	218.4	29.4	0.08	571.5	32.0	61.1	377.3
Mean	<1mm	3.2	0.9	102.1	167.6	24.3	0.02	430.0	43.3	75.2	275.5
	<0.125mm	3.4	1.3	147.4	291.7	31.2	0.05	619.0	59.9	97.0	370.4

Note: Concentration units in mg.kg^{-1}, for Fe in %.

Tab. 4 Chemical concentration data for urban street samples of Bratislava – OUTER CITY

Sample	Particle size	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
7KC	<1mm	3.1	0.9	61.4	100.4	23.1	0.1	443.4	23.5	84.0	364.3
	<0.125mm	3.9	1.5	80.6	177.2	29.4	0.1	692.1	38.9	98.6	462.6
8TC	<1mm	2.8	1.0	50.0	88.5	19.0	<0.03	378.6	16.8	32.1	313.8
	<0.125mm	3.2	1.9	76.0	265.7	30.8	0.04	600.3	31.4	72.1	832.4
9PA	<1mm	3.0	1.0	60.1	130.0	19.6	<0.03	453.5	20.5	36.2	313.5
	<0.125mm	4.1	1.2	68.8	146.0	22.0	0.03	572.8	24.7	44.4	265.9
Mean	<1mm	3.0	1.0	57.1	106.3	20.5	0.05	425.2	20.3	50.8	330.5
	<0.125mm	3.7	1.5	75.1	196.3	27.4	0.06	621.7	31.7	71.7	520.3

Note: Concentration units in mg.kg^{-1}, for Fe in %.

Tab. 5 Review of concentration data on urban sediment samples from different studies

Study		Bratislava[1]		Riyadh[2]	Oslo[3]	Madrid[3]	Coventry[4]	Birmingham[4]	Manchester[5]	Mieres[6]
Analysed fraction Analytical method		< 1mm FAAS	< 0.125mm FAAS	< 0.5mm FAAS	< 0.1mm ICP-MS	< 0.1mm ICP-MS	< 1mm AAS	< 1mm AAS	< 1mm FAAS	< 0.147mm ICP-AES
As	Mean	3.1	3.5							68.8
	Min – Max	2.6 – 3.8	3.0 – 4.1							34.0 – 202.0
Cd	Mean	0.9	1.4	1.7	1.4		0.9	1.6		1.6
	Min – Max	0.6 – 1.2	1.0 – 1.9				0.0 – 8.9	0.0 – 13.1		0.7 – 2.3
Cr	Mean	87.1	123.3							41.1
	Min – Max	46.4 – 341.9	68.8 – 416.2							24.0 – 97.0
Cu	Mean	147.2	259.9		123.0	188.0	226.4	466.9	113.0	112.4
	Min – Max	88.5 – 214.6	146.0 – 401.8				49.3 – 815.0	16.4 – 6688.4	32.0 – 283.0	50.0 – 211.0
Fe	Mean	23.1	29.9						0.9	3.2
	Min – Max	19.0 – 30.6	22.0 – 42.1						0.3 – 1.7	1.8 – 6.4
Hg	Mean	0.03	0.05							3.1
	Min – Max	0.02 – 0.12	0.02 – 0.12							0.5 – 9.0
Mn	Mean	428.4	619.9		833.0	362.0			282.0	495.9
	Min – Max	360.8 – 577.7	564.1 – 773.1						49.0 – 433.0	421.0 – 547.0
Ni	Mean	35.6	50.5		41.0	44.0	129.7	41.1		25.8
	Min – Max	16.8 – 150.1	24.7 – 185.5				6.2 – 233.5	0.0 – 636.2		20.0 – 32.0
Pb	Mean	67.1	88.6	257.0			47.1	48.0	265.0	317.5
	Min – Max	25.6 – 276.5	44.4 – 272.8				0.0 – 199.4	0.0 – 146.3	25.0 – 645.0	143.0 – 618.0
Zn	Mean	293.8	420.4		412.0	476.0	385.7	534.0	653.0	420.4
	Min - Max	203.1 – 366.5	265.9 – 832.4				93.0 – 3038.2	81.3 – 3164.8	172.0 – 2183	197.0 – 1077.0

[1]Present study; [2]Ahmed & Al-Swaidan, 1993; [3]De Miguel et al., 1997; [4]Charlesworth et al., 2003; [5]Robertson et al., 2003; [6]Loredo et al., 2003.
Note: Concentration units in mg.kg^{-1}, for Fe in %.

Tab. 6 Correlations for chemical contents in Bratislava street sediment samples < 0.125 mm

	As	Cd	Cr	Cu	Fe	Hg	Mn	Ni	Pb	Zn
As	1.000									
Cd	-0.289	1.000								
Cr	0.041	-0.394	1.000							
Cu	-0.606	0.073	0.090	1.000						
Fe	-0.159	-0.091	0.883*	0.330	1.000					
Hg	0.385	0.388	-0.030	-0.219	0.149	1.000				
Mn	0.182	-0.134	0.829*	-0.022	0.814*	0.418	1.000			
Ni	0.073	-0.372	0.997**	0.050	0.888*	0.014	0.860*	1.000		
Pb	-0.464	0.126	-0.155	-0.167	-0.184	-0.084	-0.107	-0.151	1.000	
Zn	-0.481	0.804*	-0.276	0.168	0.054	0.105	-0.087	-0.254	-0.015	1.000

Note:
* Correlation significance at $p < 0.01$.
** Correlation significance at $p < 0.001$.

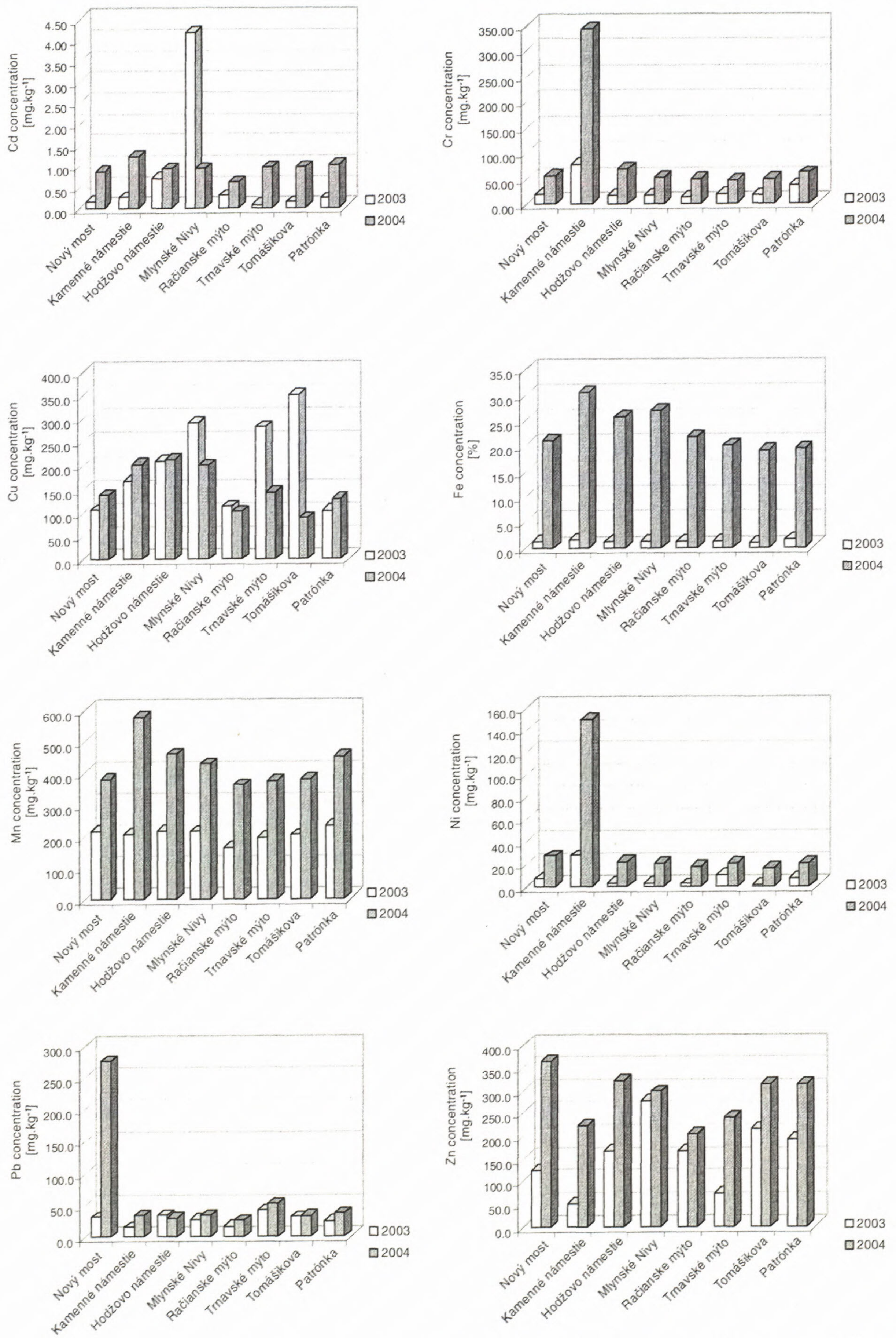

Fig. 3. Comparison of two concentration data sets for <1mm sediment fraction acquired in years 2003 (Robertson et al., 2004) and 2004 (presented study).

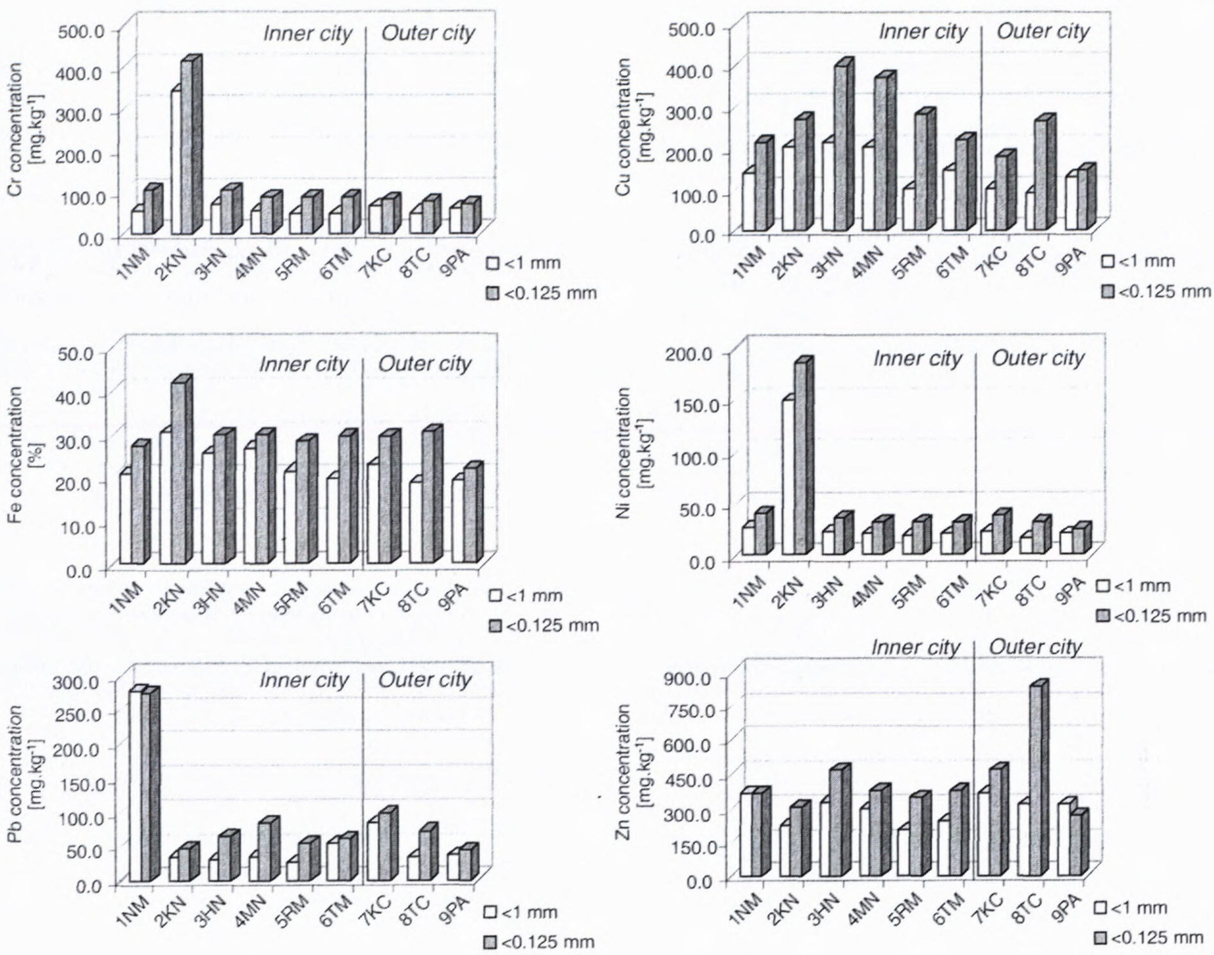

Fig. 4. Concentration variations of selected chemicals in inner / outer city samples.

Based on using X-ray powder diffraction method the following minerals were determined in the clayey fraction of collected samples: illite, chlorite, quartz and feldspar. The presence of other minerals like kaolinite, smectite and calcite is rather variable. No significant differences between inner/outer city samples were observed.

Chemical composition analysis has revealed the significantly lower Pb concentrations and on the other hand higher Fe and Mn contents in comparison with some similar foreign studies.

Higher chemical content levels were found in the finer analysed sediment fraction (<0.125 mm) with the most marked increase in the case of Cu, Fe, Mn and Zn.

Based on comparison of chemical composition determined in the inner and outer city samples, generally no substantial differences were documented. The higher concentrations in the inner city samples have been found mainly in the case of Cr and Cu. From the point of view of sampling locations the following inner city sites are characterized by the higher contents of some metals: Kamenné námestie (Cr, Fe, Ni and Mn), Hodžovo námestie (Cu and Zn) and Nový most (Pb and Zn).

The statistical concentration data evaluation has revealed the significant correlation of Cr with Ni, Cd with Zn and Fe and Mn with Cr and Ni. The least significant correlation has been documented for As, Cu, Hg and Pb.

Urban street sediments in Bratislava show increased concentration levels of some metals, e.g. Fe and Mn, together with relatively high variability in concentration levels of various potentially toxic elements (e.g. Cr, Cu). In the areas, at first sight looking as those most environmentally loaded, such as big junctions with the high traffic density, the highest metal concentrations were not always found there. On the other hand the relatively "clean" areas near pedestrian zone or in the outer city parts show the higher metal contents. This fact reveals a genesis variability of street sample material including local, regional and long-distance sources. Acquired first results point out those contents of potentially toxic elements in the urban street sediments in Bratislava which are not so high in comparison with those found in some other industrial centres and cities (e.g. Manchester).

The urban street sediments still should be the object of future study since they represent an important medium for assessment of quality of urban environment.

Analysis of their chemical composition provides basic information on character and level of urban pollution. However, from the point of view of related potential health risk assessment and its objective interpretation, the chemical analyses of fine, airborne and respirable particles, being potentially present in the road deposited sediments, are necessary.

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Lower/Middle Badenian foraminiferal associations from the Vienna Basin (Slovak part) and Carpathian Foredeep: Biostratigraphy and paleoecology

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Abstract: The benthic and planktonic foraminiferal fauna have been analysed from the Middle Miocene sedimentary sequences. We present statistical, biostratigraphical and paleoecological results. The studied material was taken from the Slovak part of Vienna Basin and represents the borehole cores Dúbrava 47 and 48 and samples from two outcrops in the vicinity of Oslavany (Lower Badenian holostratotype) and Židlochovice (Lower Badenian faciostratotype) localities in the Carpathian Foredeep. The standard laboratory methods were used for the fossils separation. The material was processed by the few statistical methods as diversity (Simpson index), equitability, P/B ratio and cluster analyses (Ward's methods). Foraminiferal associations from the Vienna Basin have supported the Lower/Middle Badenian age (*Praeorbulina - Orbulina* biozone). In the Carpathian foredeep the Lower Badenian *Praeorbulina* biozone was determined. Foraminiferal assemblages indicate the outer shelf/upper bathyal depositional area. Benthos dominated nearly in all samples and is well preserved. The preservation of planktonic forms is not very good; the tests are rather small and misshapen. The occurrence of the warm and cool planktonic indices together can suppose temperature stratification of the water column. According to preservation of the foraminiferal fauna and species diversity and equitability, we can assume not appropriate life conditions in the investigated part of the Vienna Basin. Foraminifers in the Carpathian Foredeep are well developed and individuals have a good proportion. The presence of the stress-tolerant species which can tolerate low-oxygen supply may indicate partial restriction of the oxygen supply near the sedimentation basin ground in the both, Vienna Basin and Carpathian Foredeep areas.

Key words: Miocene, Badenian, *Foraminifera*, paleoecology, biostratigraphy, Vienna Basin

Introduction

In this paper we present the results based on planktonic and benthic foraminiferal assemblages study from the Lower and Middle Badenian stage sediments. The investigated sections are located in the Vienna Basin and Carpathian Foredeep within the Central Paratethys area (Fig. 1).

First papers, dealing with this area and describing found fossils were written in the second half of the 19. century (Czjzzek 1848, Orbigny 1846, Hoerness 1859-1870, Reuss 1851, 1860). Later papers were focused on the stratigraphy of the sediments and using foraminiferal assemblages the age of the rocks was determined (Grill 1941, 1943, Cicha et al, 1983, Papp & Schmidt 1971). Paleoecological studies based on foraminifera did not appear until the 1950s (Molčíková 1962, Šutovská 1991, Hudáčková 1995, Hudáčková & Kováč 1993, Kováč & Hudáčková 1997).

Geological settings

The Vienna Basin represents a typical pull-apart basin situated within the Alpine-Carpathian mountain belt, between the Eastern Alps and Western Carpathians (Kováč, 2000). It is one of the most explored sedimentary basins in Europe with a numerous boreholes and seismic data.

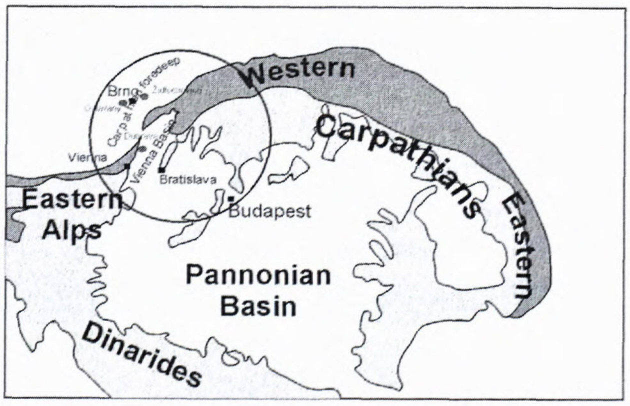


Fig. 1. Localization of the studied material.

The basin was filled by Neogene to Quaternary deposits with maximal thickness up to 5500 m in its central part (Killényi & Šefara, 1989). The Carpathian Foredeep can be classified as a peripheral foreland basin (Allen et al., 1986). The depositional history here started in the Egerian/Eggenburgian period and finalized during the Early Badenian. The biostratigraphic ages of the investigated sections have been determined by means of planktonic and benthic foraminifers, using the zonation of Grill (1941, 1943) and Cicha et al. (1975). These zonations have been correlated with the nannoplankton zones following Martini (1971) and with a timescale of Berggren et al. (1995). This paper represents a part of the paleoecological and stratigraphic studies of the Slovak part of Vienna basin.

Materials and methods

The studied material deriving from the Vienna Basin area (Slovak part) represents the borehole cores Dúbrava 47 and Dúbrava 48. In Carpathian Foredeep the samples derive from two outcrops in Oslavany (Lower Badenian holostratotype) and Židlochovice (Lower Badenian faciostratotype) localities (Fig. 2a). Poor foraminiferal assemblages were observed in Dúbrava 48 borehole. There are present only the allochthonous individuals and therefore they are not involved into statistical analyses. Borehole Dúbrava 47 is located between Dúbrava and Láb villages in the Záhorská nížina lowland. The boreholes for the petroleum research were deep in the range of 800-1800 m, penetrating the Neogene bedding sequence of the Vienna Basin. Their lithology consists of dark-grey sandy siltstone and medium-grained sandstone with micas (Fig. 2b).

The Oslavany sandpit (Fig. 2a) is situated to SSE part of the Oslavany area, SW from Brno (Czech Republic). This locality represents the Lower Badenian holostratotype (Morav) and contains autochthonous as well as redeposited micro- and macrofaunas. Sediments consist of Brno sands member containing fine- to coarse-grained polymict calcareous sands and sandy gravels. There are frequent clay lumps with Ottnagian and rare Karpatian microfauna. Rich macro and micro fauna was documented here: *Braarudosphaera bigelowi, Holodiscus macroporus, Coccolithis miopelagicus, Orbulina suturalis, Uvigerina macrocarinata, Myrtea spinifera, Ervilia pusilla, Rzehakia socialis, Cardium moravicum* (Zimák, 1997).

The studied material deriving from the Židlochovice locality was collected from the old brickyard situated at the north of Židlochovice village and in the lower part of the Výhon hill. This locality is defined as a Lower Badenian faciostratotype (Morav) and belongs to Carpathian Foredeep area. Sediments consist of light algae limestones and carbonatic grey, blue-grey micaceous clays with lenses and beds of light algae limestones to calcareous sands (Fig. 2a). Rich fossil fauna and flora were recorded here including Foraminifera (*Spiroplactammina carinata, Spiroloculina arenaria, Lenticulina Cultrata, Uvigerina macrocarinata, U. grilli, Globigerinoides trilobus, Globorotalia mayeri, Orbulina bilobata, O. suturalis* and other, lot of Radiolaria – *Hexastylus* sp., *Hexacontium* sp., Spongodiscidae and other, Anthozoa – *Tarbellastrea reussiana, Trochoczathus plicatus* as well as lot of other forms: Bryozoa, Mollusca, fish otolits, Ostracoda, rich calcareous nannoplankton assemblage and Rhodophyta (Zimák, 1997). The uppermost part of the profile consists of loess, which has been exploited for brick production in the past.

Standard laboratory methods were used for the fossil separation. Approximately 200 gr of the sediment for each sample were soaked in diluted hydrogen peroxide, washed under running water and wet sieved over the two sieves, which upper one had meshes 0.71 mm in diameter and the bottom one 0.071 mm. Occasionally there was added the sodium pyrophosphate for the entire removal of clay components. Coarse and fine fractions, including macroperforate, microperforate and agglutinated taxa were further processed separately. The material was dried at room temperature and studied with a binocular stereomicroscope for planktonic and benthic foraminifera content. In the case of agglutinated species the transmitted light microscope was used, enabling better study of the inner shell structures and individuals set in immersion oil. Foraminiferal assemblages were analysed by a few statistical methods and therefore to pick out minimum 250 specimens from each sample was necessary. Variable numbers of specimens were picked up from the each analysed sample to provide a reference collection for more detailed studies. The individuals were conserved to the chapman's cells for later retention. The statistical methods used for foraminifers analyses comprised the diversity (Simpson's index), equitability, P/B ratio and cluster analysis (Ward's methods).

The values of diversity (H) were calculated using the Simpson's index (Buzas 1979, Magurran 1991) based on the formula $D = 1/ \sum n_i (n_i - 1)/N (N - 1)$, where i is the number of species in association and N is the number of all association. Equitability (E) means the evenness distribution of an assemblage: $E = e^H / S$, where H is diversity from the Simpson index and S is the number of genera in an assemblage. Foraminifers were also counted in order to calculate the plankton to benthos ratio. The plankton/benthos ratio (%) is the percentage of planktonic foraminifers in an assemblage: $P/B = N_p/N$, where N_p is the number of planktonic foraminifers and N is the total number of foraminifers in the sample.

Biostratigraphy

Foraminiferal associations from D47 borehole (Vienna Basin) supported the Lower/Middle Badenian (Morav/Velic) age, which present the Upper lagenide Biozone and *Spiroplectammina carinata* Biozone boundary (according to Grill 1941, 1943) or CPN7 *Praeorbulina / Orbulina* Zone (according Cicha et al. 1975). This period is defined by the presence of index species *Orbulina suturalis* Brön. and abundance of rich occurrence of *Spirorutilus carinatus* d'Orb., characterizing the Middle Badenian onset. Berggren et al. (1995) recorded the first occurrence of *Orbulina suturalis* at 15.1 Ma and used it to mark the base of the upper Lower Badenian in the Vienna Basin. *Globigerina druryi* Akers and *Globigerina decoraperta* Tak. & Saito indicate a little bit higher period according to Cicha et al. (1975), ranged to the Zone CPN8. This interval is equivalent to the nannoplankton Zone NN5 (Martini, 1971) and the Lower/Middle Badenian boundary is situated approximately on 15 Ma (Rögl, 1998; Fig. 3).

Considerably similar foraminiferal composition is marked in both, Židlochovice and Oslavany localities from the Carpathian Foredeep. The presence of *Praeorbulina glomerosa circularis* Blow (without genus *Orbulina*) indicates the *Praeorbulina* Zone (Zone CPN 6 sensu Cicha et al., 1975) and characterizes the base of the La-

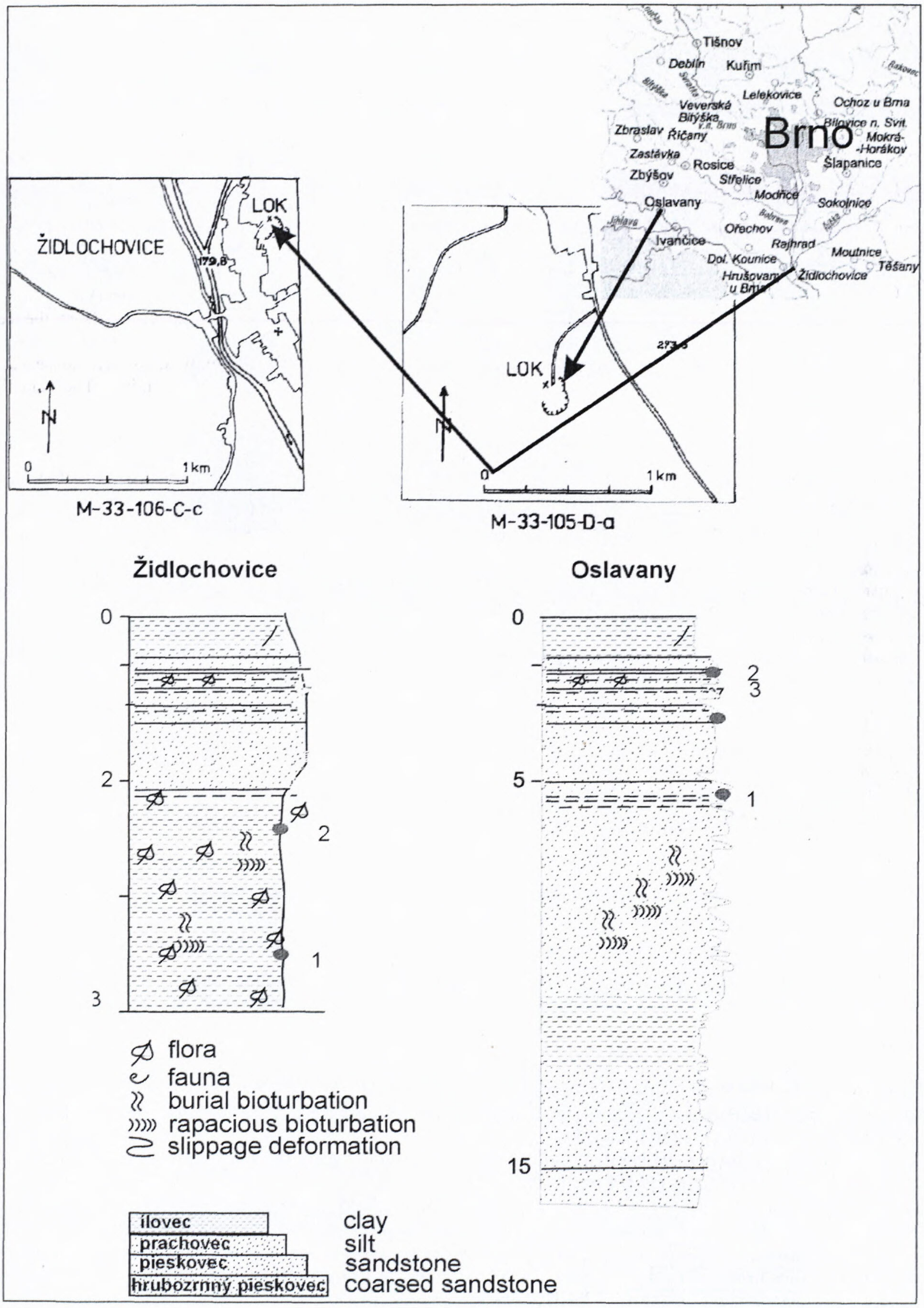


Fig. 2a. Lithological columns of the studied profiles – Židlochovice and Oslavany. 2b. Dúbrava 47.

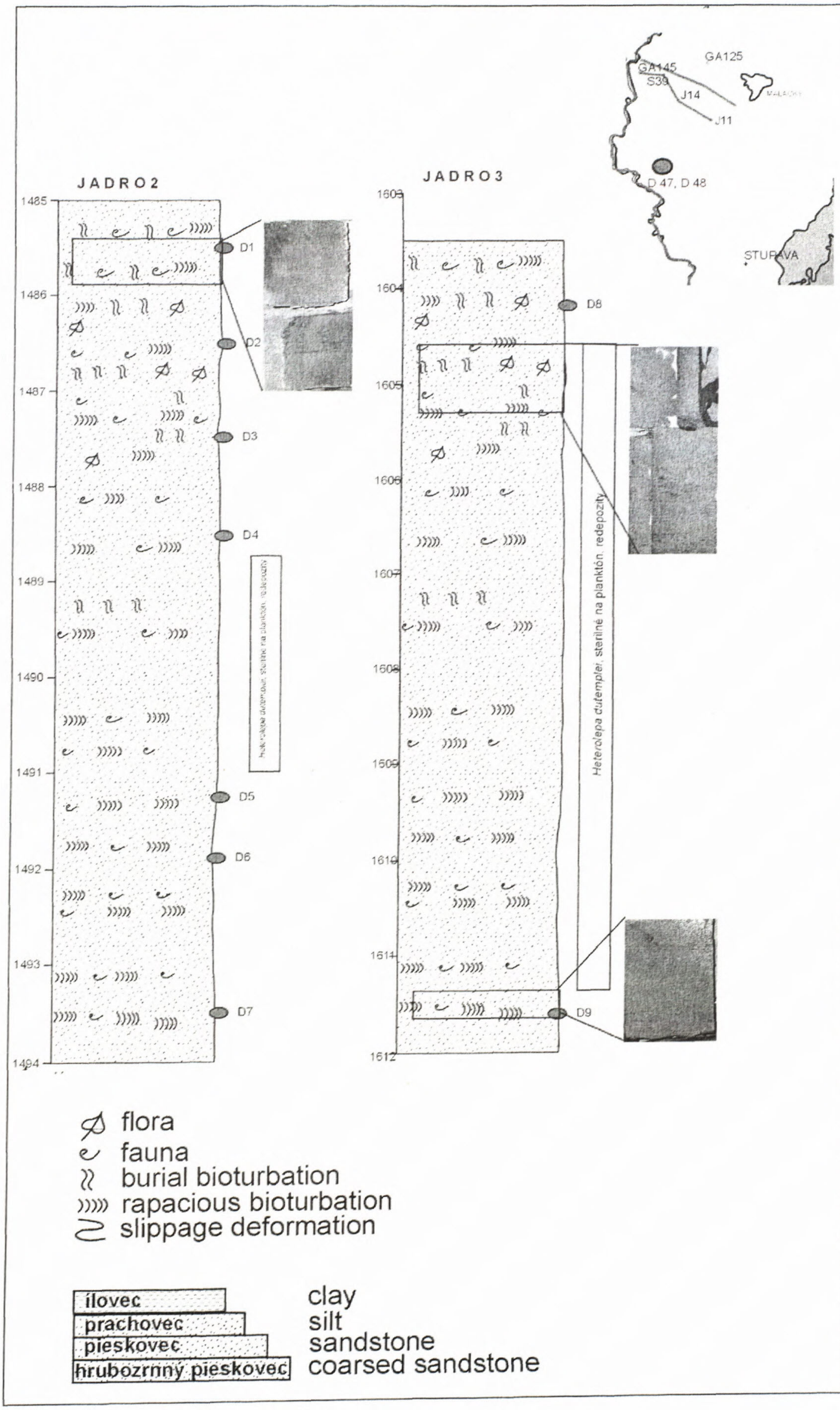


Fig. 2b. Lithological columns of the studied profiles – Dúbrava 47.

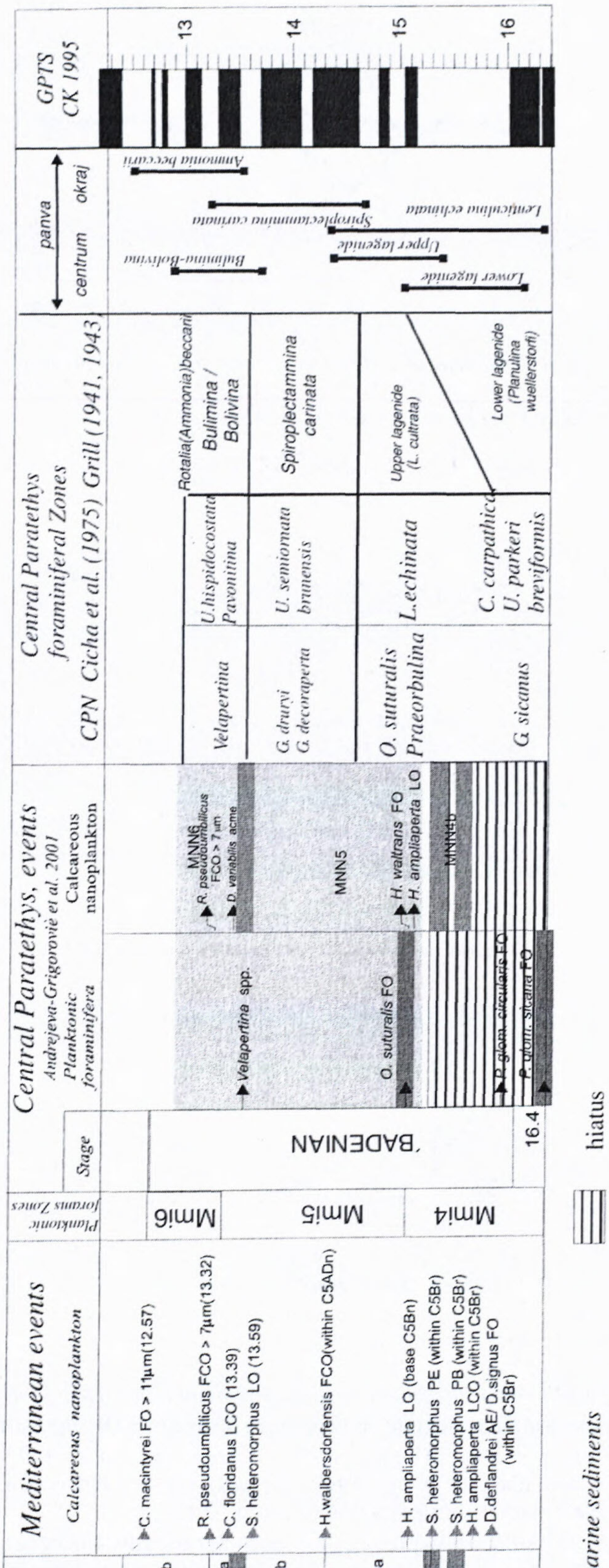


Fig. 3. Correlation of the used zonation with the foraminiferal and calcareous nannoplankton events

genide Zone in the Lower Badenian stage. The deposits with preorbulinas from the Carpathian Foredeep were described by Cicha (1995) and assigned to Karpatian/Badenian boundary period. The occurrence of *Globigerinoides bisphericus* Todd, as a typical Upper Karpatian taxa (Rögl, 1986) indicates, that the sedimentation ranged during the Lower Badenian beginning in the time period from 16.8? to 15.1 Ma (Berggren et al., 1995). According to Cicha et al. (1998) Karpatian overlaps into the Lower Badenian stage. The studied sediments can be attributed to the upper part of the nannoplankton Zone NN4 of Martini (1971). This is contrasting with new data by Spezzaferri (2004), which was undertaken to solve the debate about the age of the sediments from the Grund Formation and to propose an environmental interpretation based on benthic and planktonic foraminiferal assemblages. The studied sediments can be attributed to the Lower Lagenidae Zone in the Badenian (Langhian, Middle Miocene) on the basis of the presence of index fossils like *Praeorbulina glomerosa circularis* and *Uvigerina macrocarinata*. In agreement with Andrejeva Grigorovič et al. (2001) the Židlochovice samples are classified into the NN5a nannoplankton Zone and Oslavany locality is ranked to the NN5b/c nannoplankton Zone.

Foraminiferal assemblages

A total of 135 taxa were determined in the studied samples, including 29 planktonic and 106 benthic species. Foraminiferal assemblages are moderately to well preserved and small-sized in the case of planktonic species. Well preserved benthic assemblages are dominated nearly in all samples from the Vienna Basin. Planktonic forms are generally moderately to poor preserved, tests are rather small and misshapen, what is probably related to tectonic processes during the fossilization.

Dúbrava 47

Foraminiferal assemblages from the Vienna Basin are moderately to well preserved. Planktonic foraminiferal assemblages are scarce (0.4–15 %) and consist of dominant *Globigerinoides triloba*, *Globigerina praebulloides* and *Globigerinella obesa*. The accompanying taxa includes *Globigerina bulloides*, *Globigerinoides quadrilobatus* and *Globoquadrina altispira*. Benthic foraminiferal assemblages represent a majority in these samples and consist mainly of *Bulimina subulata*, *Heterolepa dutemplei*, *Spirorutilus carinatus*, *Pullenia bulloides*. Different composition of foraminiferal taxa is observed in the sample D3, where the planktonic taxa comprise 76 % of the total sample. Sample D3 contains dominant planktonic assemblages *Globigerina* aff. *decoraperta*, *Globorotalia mayeri* and *Globigerina* aff. *woodi*. They are associated with *G.* aff. *nepenthes* and *Globorotalia bykovae*. Benthic elements are rare and dominated mainly by *Heterolepa dutemplei*.

Židlochovice

Foraminiferal assemblages are generally well preserved and are dominated by planktonic forms such as *Globigerina praebulloides*, *Globigerinoides triloba*, *Globorotalia* *mayeri* with accompanying taxa *Globigerina bulloides*, *G. falconensis*, *Globorotalia challengeri* and *Globigerinoides quadrilobatus*. Planktonic taxa represent 60–72 % of samples. Benthic fauna is rare and includes moderately abundant *Cibicidoides ornatus*, *Nonion commune*, *Sphaeroidina bulloides* and *Stilostomella adolphina*.

Oslavany

Foraminiferal assemblages are well preserved and consist of dominant planktonic forms *Globigerinoides triloba*, *Globigerina praebulloides*, *G. quinqueloba*, *G. bulloides*, *G. falconensis*. Planktonic fauna is represented by 40–60 %. Benthic assemblages are not very abundant and the most frequent species are *Bulimina striata*, *Heterolepa dutemplei* and *Nonion commune*.

Statistical analyses and paleoenvironment

Abundance of foraminiferal fauna widely ranges. The most abundant were the samples D4, D5, D7 from Dúbrava and Z1, Z2 from Židlochovice. Diversity and equitability are distinctively shown in Fig. 4 for planktonic and in Fig. 5 for benthic species. Both values are reciprocally related and they are influenced by various factors, such as oxygen content and nutrient availability (Murray, 1991; Van der Zwaan et al., 1995). High values of equitability and diversity represent well-balanced associations living in the ideal life-conditions. Decrease of both, diversity and equitability values and the predominance of one or several taxa demonstrate stress settings acceptable only for the dominant species (Pokorný et al., 1992; Legendre & Legendre, 1983; Murray, 1991).

The cluster analyses were carried out respecting ecological claims of the single or grouped species. According to species abundance at low, middle and high latitudes reported in literature (Spezzaferri & Premoli Silva, 1991; Spezzaferri, 1995; 1996) the planktonic taxa were divided to: 1. warmer indices (*Globorotalia* s.s. groups, *Globigerinoides*, *Dentoglobigerina altispira*, *Orbulina suturalis*, *Praeorbulina glomerosa circularis*); 2. warm-temperate indices (*Globorotalia mayeri*, *Globorotalia siakensis*, *Globigerina quinqueloba*); 3. cool-temperate indices (*Globigerina woodi*, *Globigerina druryi*) and 4. cooler indices (*Globorotaloides*, *Globigerina* s.s. groups). Distribution of the paleoclimatic indices is shown in Fig. 6. Sample D5 from Vienna Basin was excluded from planktonic cluster analysis, because the planktonic fauna was not present in this sample.

Benthic forms were divided to 1. uvigerinas (*U. semiornata*, *U. accumminata*, *U. acculeata*, *U. grilli*, *U. venusta*, *U. pygmoides*, *U. graciliformis*), 2. buliminas (*B. pyrula*, *B. elongata*, *B. subulata*, *B. striata*), 3. bolivinas (*B. antiqua*, *B. dilatata*, *B. scalprata*), 4. epiphyte dwellers (*Elphidium*, *Nonion*, *Lobatula lobatula*, *Cibicides boueanus*, *Ammonia vienensis*, *Asterigerinata planorbis*), 5. agglutinated species (*Martinottiella karreri*, *Martinottiella communis*, *Reophax* sp., *Spirorutilus carinatus*, *Semivulvulina*, *Textularia*) and 6. outer shelf/slope dwellers (*Pullenia bulloides*, *Melonis pompilioides*, *Hansenisca soldanii*, *Valvulineria akneriana*, *Sphaeroidina bulloides*, *Fontbotia wuellerstorfi*, *Favulina hexagona*, *Cibicidoides*, *Dentalina*, *Lenticulina*). Benthic indices were viewed on the basis of literature (e.g. Murray, 1991; Yassini & Jones, 1995; Kouwenhoven et al., 1999; Bartakovics & Hudáčková, 2004) and their distribution is shown in Fig. 7.

The P/B ratio curve is not even but broadly fluctuated (Fig. 8). The predominance of plankton taxa was recorded only in the sample D3 from the Vienna Basin. Mostly all samples from Carpathian Foredeep correspond with these results. The sample D3 contains planktonic species not present or rare in the other samples such as *Globigerina* aff. *decoraperta*, *Globorotalia mayeri* and *G. bykovae*. Planktonic assemblages in Carpatian Foredeep samples show relatively high abundance. Dominant

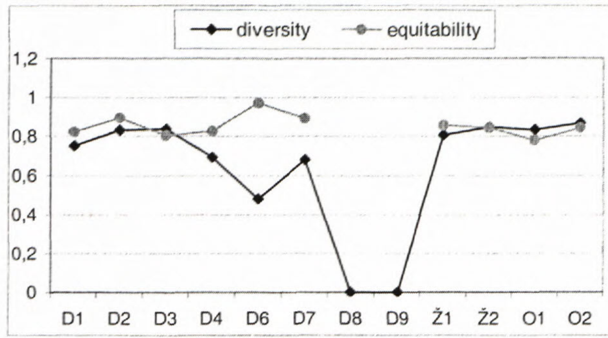


Fig. 4: The Simpson's diversity and equitability for planktonic foraminiferal groups (D1 - D9 Vienna Basin samples, Ž 1,2 Židlochovice samples, O1,2 Oslavany samples).

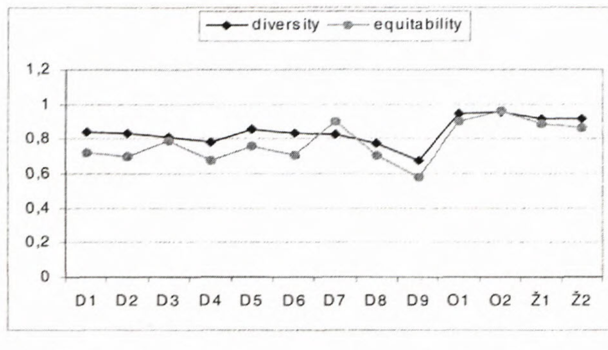


Fig. 5: The Simpson's diversity and equitability of the benthic foraminiferal groups (D1 - D9 Vienna Basin samples, Ž 1,2 Židlochovice samples, O1,2 Oslavany samples).

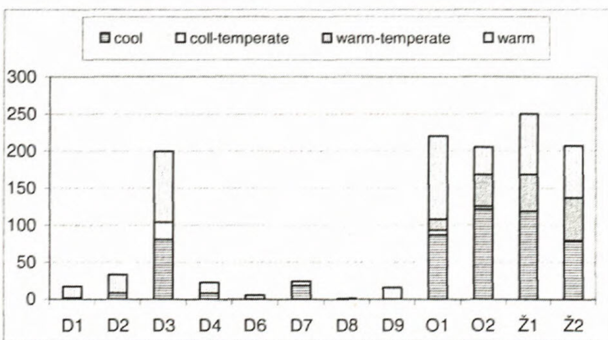


Fig. 6: Planktonic foraminifera indices according to temperature demands. Divided according to Spezzaferri & Premoli Silva (1991), Spezzaferri (1995; 1996).

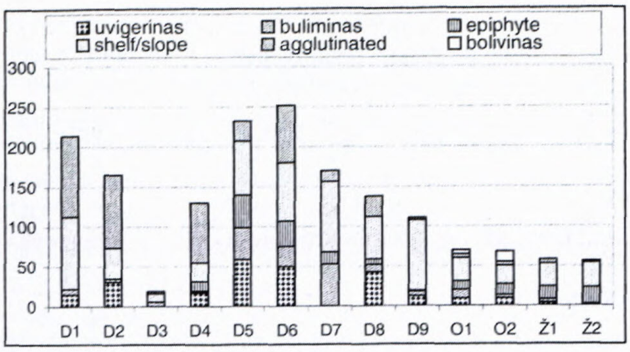


Fig. 7: Ecological groups of benthic foraminifera dwellers in the studied samples.

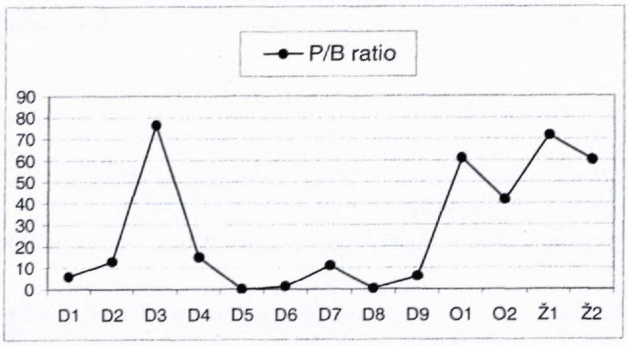


Fig. 8: Plankton/benthos ratio.

species are *Globigerinoides triloba, Globigerina praebulloides, G. quinqueloba* and *G. mayeri*. High planktonic values of equitability and diversity have been observed in the samples D2, Ž1, Ž2, O2 what support well developed and balanced associations with the most favourable life conditions from all studied samples. Planktonic associations in the samples O1 and D3 show the lowest values of equitability, but the diversity is relatively high. Warmer and cooler indices are present in both samples equally, with small-sized warm-water species as is a typical sign. These associations are not balanced adequately but diversity is high, thus we can assume adequate life conditions with temperate surface-water temperature. The occurrence of both, warm and cool indices together indicates probably temperature stratification of the water column. In the other samples the planktonic taxa are poorly represented with the low species diversity. Planktonic assemblages imply lack of nutrient supply or early transgression, what may support also bad preservation of individuals.

Abundance of the benthic associations is the most distinct sign in the Carpathian Foredeep samples what is in good accordance with the plankton diversity in these samples and indicates presentable conditions. The lowest diversity is observed in the Vienna Basin (samples D4, D7, D8 and D9) and it is conformable to plankton data. Low values can be attributed with a stressful factor, which lead to rapid aggravation of ecological conditions. Predominant benthic forms including species *Pullenia bulloides, Melonis pompilioides, Heterolepa dutemplei, Spirorutilus carinatus* together with uvigerinids, indicate a relatively deep environment of about 150-200 meters corresponding to the outer neritic/upper bathyal area. This depth attribution agrees with many paleoecological works (e.g. Murray, 1991; Šutovská-Holcová et al., 1993; Yassini & Jones, 1995; Spezzaferri, 2004). According to ecological demands of this species the surround deepening can be predicted.

In some samples there are present the shallow water dwellers like *Nonion, Elphidium, Lobatula lobatula, Ammonia vienensis* and *Asterigerinata planorbis*. They may indicate shallower depth. Nevertheless, shells of these taxa appear broken in contrast to the better preserved deep-water dwellers. Accordingly, combining the shallow-water species and deeper-water benthic foraminifers indicates the redeposition of the upper shelf sediments into the deeper parts of the sedimentary area with anoxic environments. This assumption intensifies the fact that the shallow water species were strongly compressed and deformed.

The stress-tolerant taxa *Uvigerina, Bulimina, Bolivina, Spirorutilus, Melonis, Pullenia* (e.g. Van der Zwaan, 1982; Murray, 1991; Van Marle, 1991; Šutovská-Holcová et al., 1993; Kouwenhoven et al., 1999; Spezzaferri et al., 2002) which can tolerate low-oxygen supply, may imply a partial restriction of the oxygen supply near the sedimentation basin ground. These species are characterized as suboxic indicators, characteristic for oxygen contents of 0.3 to 1.5 ml/l (Kaiho, 1994). Among the low-oxygen taxa belongs *Heterolepa dutemplei* also (Šutovská, 1990), representing the current species in the Vienna Basin. Under conditions without any oxygen, the benthic foraminifera are absent (Murray, 1991).

Clusters analysis of planktonic ecological groups shows highermost diversity cluster composition in D3, Ž1, Ž2, O1 and O2 samples (Fig. 9), which have very similar species representation with different temperature demands. These cluster associations developed in comparative ecological conditions and indicate temperature stratifications of water column. These samples have the highermost P/B ratio what indicates the deepening environment (Van der Zwaan et al., 1995; McGowran & Li, 1997; Gonera, 1994). The Carpathian Foredeep samples contained species *Praeorbulina glomerosa circularis, Globigerinoides quadrilobatus, G. triloba* which described Kováč & Zlinská (1998) in the Lower Badenian sediments from the East Slovakian basin and assume neritic open sea area. The second cluster encompasses the Vienna Basin planktonic assemblages with similar warm and cool indices abundance without temperate species. Cluster analyses results of plankton are comparable with the values of benthic groups analyses (Fig. 10). Two clusters were formed according to ecological demands of the benthic taxa. First cluster includes samples from the Carpathian Foredeep and one the Vienna Basin sample. Samples Ž1, Ž2 and D3 have low representation of stress-tolerant species and a high contribution of deepwater dwellers, what indicates cold and high-oxygen contents environment. Representation of euryoxibiont species is relatively high in Oslavany and it should suggest the short suboxic periods in this area. Second cluster combine the samples with a high contribution of agglutinated forms like *Spirorutilus carinatus, Textularia gramen abbreviata, Martinottiella communis*, which represent euhaline neritic Vienna Basin backgrounds deposition of Jakubov Formation (Špička, 1969).

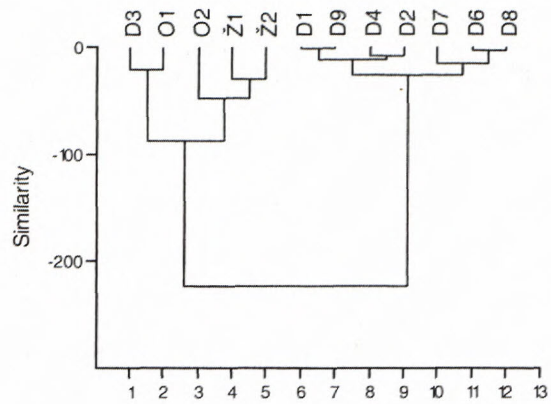


Fig. 9. Cluster analysis of ecological groups for planktonic forms.

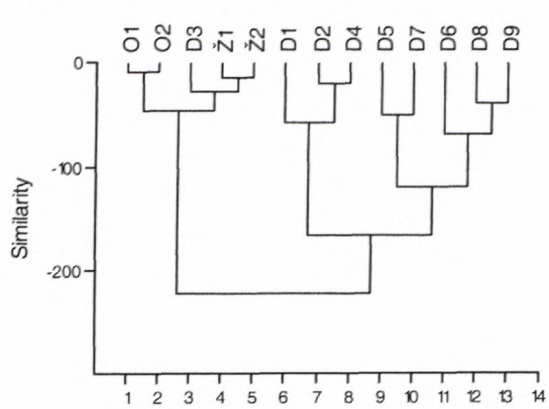


Fig. 10. Cluster analysis of ecological groups for benthic forms.

Conclusions

In the Vienna basin samples the Lower/Middle Badenian age was supported, representing the upper lagenid Biozone and *Spiroplectammina carinata* Biozone boundary (Zone CPN8, NN5).

In both, Židlochovice and Oslavany localities from the Carpathian Foredeep, the presence of *Praeorbulina glomerosa circularis* Blow confirmed the *Praeorbulina* Zone (Zone CPN 6-7) and marked base of the lagenid Biozone in the Lower Badenian stage. The studied sediments can be attributed to the upper part of the nannoplankton Zone NN4 of Martini (1971) or to the NN5a and NN5b/c Zones of Andrejeva Grigorovič et al. (2001).

The foraminiferal associations in the Carpathian Foredeep are well developed. Individuals have broadly good proportions which show almost ideal conditions for the test formation. Temperature demands of the present species imply temperature stratification of the water column with the cooler and warmer flows zones. Židlochovice and Oslavany associations are developed in the good aerated areas; in Oslavany there was recorded the episodic low-oxygen content.

Because the extreme low plankton content in majority of the Vienna Basin samples, it is not possible to interpret the life environment certainly. Planktonic associations are not well developed and probably they had not appropriate life conditions here. The main stress factors could be deepening of background and not sufficienty nutrient-supply.

During the sedimentation the higher temperature prevailed with moderate cooling periods. In both, Vienna Basin and Carpathian Foredeep, the predominant benthic forms suggest the sedimentation area at neritic/upper bathyal boundary (about 150-200 m). Species composition supports episodic reduced oxygenation in the ground, which could be caused by circulation changes and reduced supply of the fresh water.

Systematic part

The systematic part comprises only planktonic taxa determined in the investigated sections. The taxonomic classification used here is based on several available studies. The species are discriminated following Loeblich & Tappan (1987; 1992) and Kennett & Srinivasan (1983).

Phyllum: *Granoreticulo s a* (LEE, 1990)
Class: *Foraminifera* (LEE, 1990)
Order: *Globigerinida* (DELAGE et HERONARD, 1896)
Superfamily: *Globigerinacea* (CARPENTER, PARKER et JONES, 1862)
Family: *Globigerinidae* CARPENTER, PARKER et JONES, 1862

Genus: *Globigerina* D'ORBIGNY, 1826

This genus includes all trochospiral species with single, large, open umbilical aperture. It is characterized by hispid surface, penetrated by cylindrical pores.

***Globigerina quinqueloba* NATLAND 1938**
Plate 1, Fig. 1a, b, c

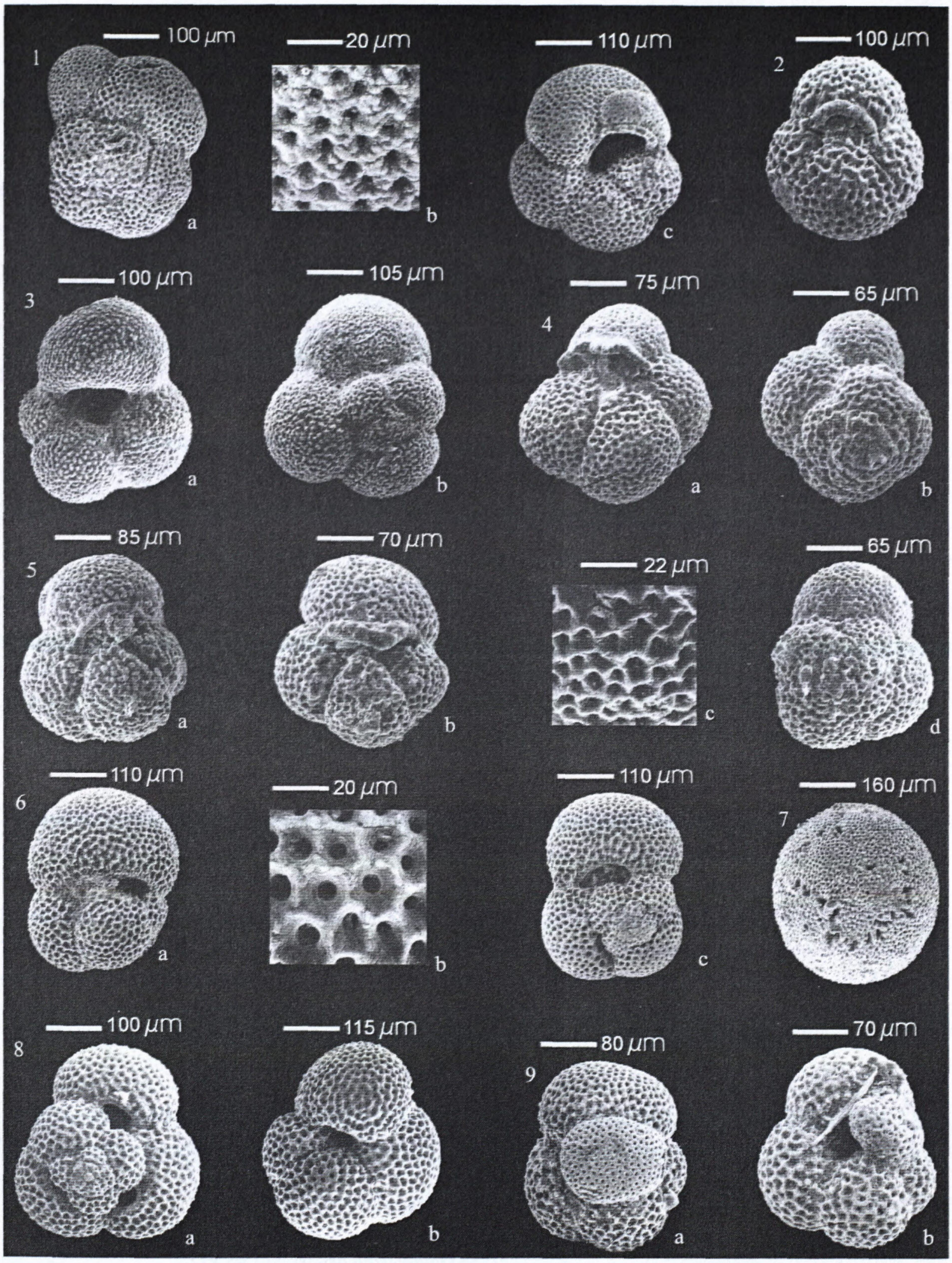
1938 *Globigerina quinqueloba* NATLAND, p. 149, pl. 6, Fig. 7
1938 *Turborotalita quinqueloba* NATLAND, pl. 31, Figs. 7-10
1957 *Globigerina angustiumbilicata* BOLLI, p. 109, pl. 22, Figs. 12-13

Diagnosis: Test small, trochospiral, slightly compressed, five chambers in the final whorl; chambers inflated, subglobular; final chamber spinose; aperture with an elongate slit. Final chamber is atypically developed in contrast with the previous.
Remarks: This species has a few morphological variants – final chamber can be smaller or larger than the others; can shield an umbilical area; bordered by a lip (it is not regular). Determined individuals from Oslavany have a final chamber smaller and without lip.
Stratigraphic distribution: Lower Miocene to Recent.

***Globigerina praebulloides* BLOW 1959**

1959 *Globigerina praebulloides* BLOW, p. 180, pl. 8, Fig. 47a – c, pl. 9, Fig. 48

Diagnosis: Test medium, trochospiral, elongate, four chambers in the final whorl, umbilicus small; aperture small, umbilical low to moderate asymmetric arch; final chamber is largest.



Pl. 1. 1 - *Globigerina quinqueloba* NAT., Oslavany, Upper Badenian, a - dorsal side, b - detail of dorsal area, c - ventral side, 2 - *Globigerina druryi* AKERS, Vienna Basin, Upper/Middle Badenian, ventral side, 3 - *Globigerina bulloides* D´ORB., Židlochovice, Upper Badenian, a - ventral side, b - dorsal side, 4 - *Globigerina* aff. *nepenthes* TODD, Vienna Basin, Upper/Middle Badenian, a - ventral side, b - dorsal side, 5 - *Globigerina* aff. *woodi* JENK., Vienna Basin, Upper/Middle Badenian, a - ventral side, b - ventral side, c - detail of dorsal area, d - dorsal side, 6 - *Globigerinoides triloba* REUSS, Židlochovice, Upper Badenian, a - ventral side, b - detail of ventral area, c - dorsal side, 7 - *Praeorbulina glomerosa circularis* BLOW, Oslavany, Upper Badenian, 8 - *Globigerinoides quadrilobatus* D´ORB., Židlochovice, Upper Badenian, a - dorsal side, b - ventral side, 9 - *Globorotaloides suteri* BOLLI, Oslavany, Upper Badenian, a - lateral side, b - ventral side.

Remarks: G. praebulloides is ancestral to *G. bulloides*, from which it differs with smaller test, elongate equatorial profile and less arched aperture.
Stratigraphic distribution: Upper Eocene to Upper Miocene (Lower Sarmatian) in the Central Paratethys.

Globigerina bulloides D´ORBIGNY 1826

Plate 1, Fig. 3a, b

1826 *Globigerina bulloides* d'ORBIGNY, p. 227

Diagnosis: Test low-trochospiral, four chambers in the final whorl; chambers spherical; surface densely perforated with simple spines; aperture umbilical, high symmetrical arch.
Remarks: G. bulloides shows large variation in the size of the aperture. Observed species from investigated areas have aperture developed variously. Large and open apertures are frequent, but we observed also smaller and constricted apertures.
Stratigraphic distribution: Middle Miocene to Recent, most frequent in Badenian.

Globigerina falconensis BLOW 1959

1959 *Globigerina falconensis* BLOW, p. 177, pl. 9, Fig. 40

Diagnosis: Test low trochospiral, slightly compressed, four chambers in the final whorl; chambers spherical, the last chamber smaller than the penultimate; surface with small regular pores and thin spines; aperture an elongate narrow arch, umbilical.
Remarks: It differs from *G. praebulloides* and *G. bulloides* in final chamber with well-developed imperforate lip. Obtained species have the last chamber turned to umbilicus and umbilicus is not overlapped. The lip is less distinct and thinner, in some cases not visible.
Stratigraphic distribution: Lower Miocene to Recent.

Globigerina diplostoma REUSS 1850

1850 *Globigerina diplostoma* REUSS, p. 373, pl. 47, Fig. 9a-b, 10, pl. 48, Fig. 1

Diagnosis: Test medium, trochospiral, four chambers in the final whorl; aperture large, open, central; surface regularly perforated with small dense pores; the test wall is thick; the last chamber is often identical or smaller than penultimate.
Remarks: It differs from *Gg. bulloides* in final smaller chamber. Several authors regard it as a younger synonym of *G. bulloides*.
Stratigraphic distribution: Lower Karpatian to Upper Badenian in the Central Paratethys.

Genus: ***Globigerina* D´ORBIGNY 1826**
Subgenus: ***Zeaglobigerina* KENNETT and SRINIVASAN 1983**

It icludes species characterized by a cancellate suface with regular subhexagonal pore pits with pores at the centers. The suface is clearly cancellate in contrast to the hispid appearance of *Globigerina (Globigerina)*.

Globigerina woodi (JENKINS 1960)

Plate 1, Fig. 5a, b, c, d

1960 *Globigerina woodi* n. sp. - JENKINS, p. 352, pl. 2, Fig. 2a – c
1998 *Globoturborotalia woodi* (JENKINS)–CICHA-RÖGL-ČTYROKÁ-RUPP et al., pl.35, Figs. 14-16

Diagnosis: Test medium, low trochospiral; chambers spherical, four in the final whorl; surface with rough subhexagonal pits; umbilicus open; aperture umbilical, highly arched, bordered with a thick rim.
Remarks: Several individuals from Dúbrava 47 have been determined as *Globigerina* aff. *woodi*. The aperture was deformed and overlapped into the umbilical area. In some cases the thicked rim converted to thick lip.
Stratigraphic distribution: Upper Oligocene to Upper Pliocene (to Upper Badenian in the Central Paratethys).

Globigerina aff. *nepenthes* TODD 1957

Plate 1, Fig. 4a, b

1957 *Globigerina nepenthes* TODD, p. 301, pl. 78, Fig. 7a–b

Diagnosis: Test compact with high spire; chambers indistinct, inflated, four in the final whorl; surface cancellate with pore pits; aperture suborbiculate, umbilical, usually bordered by a thickened rim.

Remarks: The last chambers of the determined individuals have a large morphological variability. Some have conical form, another are more rounded. The remaining chambers are more inflated and aperture is turned to side.

Stratigraphic distribution: Middle Miocene to Lower Pliocene.

Globigerina decoraperta TAKAYANAGI et SAITO 1962

1962 *Globigerina druryi* AKERS *decoraperta* TAKAYANAGI et SAITO, p. 85, pl. 28, Fig. 10a–c
1965 *Globigerina decoraperta* TAKAYANAGI et SAITO – CITA, PREMOLI SILVA and ROSSI, p. 246, pl. 23, Fig. 6a–c, pl. 31, Fig. 2a–c
1978 *Globigerina decoraperta* TAKAYANAGI et SAITO – PAPP et al., p. 272, pl. 8, Figs. 37–39

Diagnosis: Test compact, low to medium trochospiral; chambers spherical to subspherical, four in the final whorl; aperture large, umbilical, bordered by a broad rim.
Remarks: Determined species as a *G.* aff. *decoraperta* had broadly deformed aperture without a distinct rim. From *G. woodi* is dinstinguished by higherpired test.
Stratigraphic distribution: Middle Miocene to Upper Pliocene.

Globigerina druryi AKERS 1955

Plate 1, Fig. 2

1955 *Globigerina druryi* AKERS, p. 654, pl. 65, Fig. 1

Diagnosis: Test compact, low to medium trochospiral; chambers spherical, four in the last whorl; surface thick, cancelate, coarsely pited; umbilicus deep; aperture small, umbilical, bordered by a distinct lip.

Remarks: Obtained individuals were small-sized with a distinct coarsenly lip. *G. druryi* evolved from *G. woodi* and is ancestral to *G. nepenthes*
Stratigraphic distribution: Lower to Middle Miocene (Lower to Upper Badenian in the Central Paratethys).

Genus: *Globigerinoides* CUSHMAN 1927

Globigerinoides is distinguished from *Globigerina* by its supplementary sutural apertures. Surface can have cancellate or spinose character with large, distinct, regular pores.

***Globigerinoides triloba* (REUSS 1850)**
Plate 1, Fig. 6a, b, c

1850 *Globigerina triloba* REUSS, p. 374, pl. 47, Fig. 11a–d
1957 *Globigerinoides triloba* (REUSS) – BOLLI, p. 112, pl. 25, Fig. 2a–c, text Fig. 21/1a–b, Figs. 1a–b, 2a–b, 3a–b, 4a–b, pl. 31, Fig. 4a - b
1969 *Globigerinoides quadrilobatus trilobus* (REUSS) – BLOW, p. 326
1970 *Globigerinoides trilobus* (REUSS) – DREMEL, p. 63, text Fig. 41a – c

Diagnosis: Test trochospiral; chambers spherical; three in the final whorl; surface distinctly cancellate; primary aperture wide, umbilical; on the spiral side one to three supplementary apertures.
Remarks: Observed individuals exhibited great variation of a size and morphology. Some test are large with less rounded profile, another are smaller and more orbiculate.
Stratigraphic distribution: Lower Miocene to Pleistocene (Upper Egerian to Upper Badenian in the Central Paratethys).

***Globigerinoides quadrilobatus* (D´ORBIGNY 1846)**
Plate 1, Fig. 8a, b

1846 *Globigerina quadrilobata* D´ORBIGNY, p. 164, pl. 9, Fig. 7-10
1970 *Globigerinoides quadrilobatus* (D´ORBIGNY) – DREMEL, p. 58, text Fig. 40a-c

Diagnosis: Test low trochospiral; chambers distinctly rounded, three and a half to four in the final whorl; surface distinctly cancellate; primary aperture umbilical, elongated, bordered by a rim.
Remarks: Determined species have more open aperture, chambers more rounded and spherical profile.
Stratigraphic distribution: Lower Miocene to Recent (Lower to Upper Badenian in the Central Paratethys).

***Globigerinoides bisphericus* TODD 1954**

1954 *Globigerinoides bispherica* TODD, p. 681, pl. 1, Fig. 1

Diagnosis: Test spherical to subspherical, two and one-half to three chambers in the final whorl; surface distictly cancellate; primary aperture umbilical, supplementary apertures irregular, along spiral sutures.
Remarks: *Gs. bisphericus* is different from *Gs. triloba* in having smaller pores and more spherical profile. *Gs. bisphericus* developed from *Gs. triloba* and is the direct ancestor of *Praeorbulina*.

Stratigraphic distribution: Late Lower Miocene to early Middle Miocene (Upper Karpatian to Lower Badenian in the Central Paratethys).

Genus: *Praeorbulina* ÓLSSON 1964

***Praeorbulina glomerosa circularis* (BLOW 1956)**
Plate 1, Fig. 7

1956 *Globigerinoides glomerosa circularis* BLOW, p. 65, text Figs. 2.3-2.4

Diagnosis: Test nearly spherical; last chamber almost globular, enveloping the earlier part of the test for more than 75 percent; surface densely perforated; apertures numerous, circular, in the sutures between the last penultimate and earlier chamber.
Remarks: It differs from *O. suturalis* in lacking areal apertures.
Stratigraphic distribution: Late Lower Miocene to early Middle Miocene (early Upper Badenian in the Central Paratethys).

Genus: *Orbulina* D´ORBIGNY 1839

***Orbulina suturalis* BRÖNNIMANN 1951**

1951 *Orbulina suturalis* n. Sp. – BRÖNNIMANN, p. 135, text Fig. II, Figs. 1-2, 58, 9, Text-fig. III, Figs. 3-8, 11, 13-16, 18, 20-22, text Fig. IV, Figs. 2-4, 7-12, 15, 16, 19-22

Diagnosis: Test spherical; final chamber enveloping the early part of the test; surface densely perforated; supplementary apertures along sutures separating the final and earlier chambers.
Remarks: *Orbulina* was derived from *Praeorbulina.*
Stratigraphic distribution: Lower Miocene to Recent (late Lower to Upper Badenian in the Central Paratethys).

Family: *Globorotaliidae* CUSHMAN 1927
Genus: *Globorotalia* CUSHMAN 1927
Subgenus: *Jenkinsella* KENNETT et SRINIVASAN 1983

The subgenus *Jenkinsella* represents phylogenetically the group from the latest Paleogene to Neogene, usually referred as *Turborotalia* (BLOW, 1969). However, according to Srinivasan & Kennett (1981), *Turborotalia* is a Paleogene lineage and is phyletically unrelated to forms, which KENNETT & SRINIVASAN (1983) included in *Jenkinsella*. The main diagnostic features common to all species included within *Jenkinsella* are the rounded periphery lacking a distinct carina, globular to subglobular chambers arranged in a compact, low trochospire, umbilical-extraumbilical aperture bordered by a rim, cancellate surface, dense pores.

***Globorotalia acrostoma* WEZEL 1966**

1966 *Globorotalia acrostoma* WEZEL, p. 1298, pl. 101, Fig. 1-12, text Fig. 1

Diagnosis: Test small, trochospiral with low spiral; chambers subquadrate to oval, four to four and one-half

in the final whorl; surface covered with dense pores, cancellate texture; aperture large, bordered by a rim, umbilical – extraumbilical.
Remarks: This species closely resembles *Gr. mayeri* but is easily distinquished by its four to four and one-half chambers in the final whorl and larger and higher-arched aperture. *Gr. acrostoma* evolved during the earliest Miocene from *Gr. mayeri* by a reduction in number of chambers in the final whorl and by developing a larger and higher aperture (Srinivasan & Kennett, 1981).
Stratigraphic distribution: Lower Miocene to Middle Miocene (Lower Eggenburgian to Middle Badenian in the Central Paratethys).

***Globorotalia bykovae* (AISENSTAT 1960)**

1960 *Turborotalia bykovae* AISENSTAT in SUBBOTINA - PISHVANOVA-IVANOVA, p. 69, pl. 13, Figs. 7-8
1978 *Globorotalia bykovae minoritesta* PAPP in PAPP et al., p. 278, pl. 7, Figs. 1-3

Diagnosis: Test trochospiral, planoconvex, periphery broadly angled; aperture curved medium high, umbilical-extraumbilical arch with a small lip; the wall is thin, nonspinose; surface smooth finely perforated with a normal perforation; five or six chambers in the final whorl.
Remarks: The determined species were small-sized with four to four and one-half chambers in the final whorl.
Stratigraphic distribution: Upper Karpatian to the end of the Badenian.

***Globorotalia mayeri* CUSHMAN et ELLISOR 1939**

1939 *Globorotalia mayeri* n. sp. – CUSHMAN et ELLISOR, p. 11, pl. 2, Fig. 4a-c

Diagnosis: Test low trochospiral, slightly lobulate, broadly rounded, the final chamber depressed; chambers inflated, five in the final whorl; sutures depressed; surface perforate with large pores and ridges; umbilicus narrow; aperture high, bordered with a distinct rim, umbilical-extraumbilical.
Remarks: Gr. mayeri is distinquished from *Gr. siakensis* by its distinctly curved spiral sutures, more closely appressed and embracing chambers in the final whorl. *Gr. mayeri* is dominant in the temperate areas, while *Gr. Siakensis* is more dominant in equatorial and warm subtropical sites (Kennett & Srinivasan, 1983). Generally, the studied individuals were small sized with less distinct rim as is usually.
Stratigraphic distribution: Uppermost Oligocene to Middle Miocene (Upper Karpatian to Upper Badenian in the Central Paratethys).

***Globorotalia siakensis* LE ROY 1939**
Plate 2, Fig. 13a, b

1939 *Globorotalia siakensis* LE ROY, p. 39, pl. 3, Figs. 30-31
1969 *Globorotalia (Turborotalia) siakensis* BLOW, p. 356, pl. 10, Figs. 7-9; pl. 11, Figs. 4-5

Diagnosis: Test large, low trochospiral, broadly rounded; chambers subspherical, inflated, six to seven in the final whorl; sutures nearly radial, depressed; surface coarsely perforate with ridges and large pores; umbilicus wide, deep; aperture umbilical-extraumbilical, bordered by a distinct rim.
Remarks: Gr. siakensis is distinguished from *Gr. mayeri* by more than five chambers in the final whorl and wide, open and deep umbilicus. *Gr. siakensis* is evolved from *Gr. opima* and is ancestral to the *Gr. mayeri* (Kennett & Srinivasan, 1983). Determined individuals are characterized by a more fine perforation and by six to six and half-one chambers in the final whorl.
Stratigraphic distribution: Upper Oligocene to Middle Miocene.

Genus: *Globorotalia* CUSHMAN 1927
Subgenus: *Menardella* BANDY 1972

The subgenus *Menardella* is characterized by lenticular, trochospiral tests, a prominent keel and smooth, perforate surfaces.

***Globorotalia archeomenardii* BOLLI 1957**

1957 *Globorotalia archeomenardii* BOLLI, p. 119, pl. 28, Fig. 11

Diagnosis: Test low trochospiral, compressed, equatorial periphery slightly lobate, five to five and one-half chambers in the final whorl; sutures strongly curved, depressed; surface smooth, very finely perforated; umbilicus small; aperture low-arched with a distinct lip, umbilical-extraumbilical.
Stratigraphic distribution: Lower Miocene to Lower Middle Miocene.

Genus: *Globorotalia* CUSHMAN 1927
Subgenus: *Globoconella* BANDY 1975

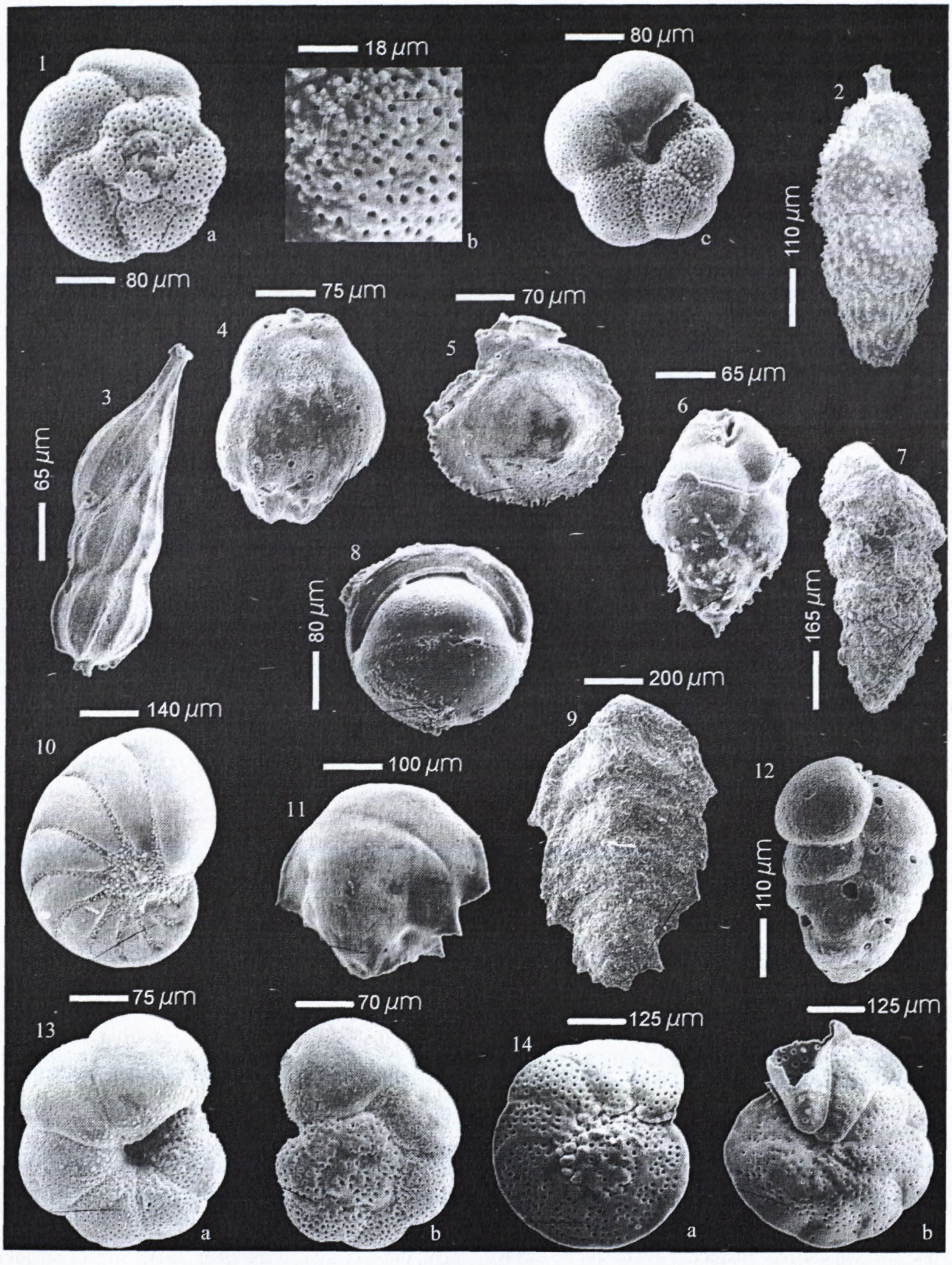
Subgenus *Globoconella* is a major lineage in temperate areas and includes keeled and nonkeeled, inflated and compressed forms with a thick walls and high-arched apertures.

***Globorotalia praescitula* BLOW 1959**

1959 *Globorotalia praescitula* BLOW, p. 221, pl. 19, Fig. 128a-c
1969 *Globorotalia (T.) scitula praescitula* BLOW, p. 356, pl. 4, Figs. 21-23; pl. 39, Fig. 9

Diagnosis: Test low trochospiral, biconvex, not keeled; chamber four to four and one-half in the final whorl; sutures strongly curved and depressed on the spiral side; surface perforated, smooth; umbilicus small; aperture umbilical-extraumbilical with a thin lip.
Remarks: This species is ancestral to the *Gr. zealandica* and is distinguished by an increase in number of chambers in the final whorl from four to four and one-half and a low-arched aperture.
Stratigraphic distribution: Lower to Middle Miocene.

Genus: *Globorotalia* CUSHMAN 1927
Subgenus: *Hirsutella* BANDY 1972



Pl. 2. 1 - *Globorotalia challengeri* SRIN. & KENN., Židlochovice, Upper Badenian, a - dorsal side, b - detail of dorsal area, c - ventral side, 2 - *Uvigerina aculeata* D´ORB., Židlochovice, Upper Badenian, 3 - *Nodosaria sp.*, Oslavany, Upper Badenian, 4 - *Uvigerina uniseriata* JEDL., Oslavany, Upper Badenian, 5 - *Siphonina reticulata* CZJZEK, Oslavany, Upper Badenian, 6 - *Bulimina subulata* CUSH.. & PARK., Vienna Basin, Upper/Middle Badenian, ventral side, 7 - *Textularia mariae* D´ORB., Vienna Basin, Upper/Middle Badenian, 8 - *Pullenia bulloides* D´ORB., Vienna Basin, Upper/Middle Badenian, ventral side, 9 - *Spirorutilus carinatus* D´ORB., Vienna Basin, Upper/Middle Badenian, 10 - Nonion commune D´ORB., Židlochovice, Upper Badenian, lateral side, 11 - *Ehrenbergina serrata* REUSS, Židlochovice, Upper Badenian, dorsal side, 12 - *Kareriella chilostoma* REUSS, Židlochovice, Upper Badenian, lateral side, 13 - *Globorotalia siakensis* LE ROY, Židlochovice, Upper Badenian, a - ventral side, b - dorsal side, 14 - *Cibicidoides ungerianus ungerianus* D´ORB., Židlochovice, Upper Badenian, a - dorsal side, b - ventral side.

Subgenus *Hirsutella* includes sharp-edged to keeled forms and inflated to compressed forms. Most of the species are thin walled with smooth and densely perforate tests. *Globorotalia (Globoconella) praescitula* is the ancestral form for the *Hirsutella* lineage.

Globorotalia challengeri SRINIVASAN et KENNETT 1981

Plate 2, Fig. 1a, b, c

1981 *Globorotalia challengeri* SRINIVASAN et KENNETT, n. 6, p. 499-533, pl. 1

Diagnosis: Test is a fairly low trochospiral, biconvex, equatorial periphery lobate; surface thin, coarsely perforated, smooth; chambers twelve to fifteen, five to five and one-half in the final whorl; sutures on spiral side curved, depressed; aperture has a distinct arch with a prominent lip, umbilical-extraumbilical.
Remarks: This species is morphologically similar to *Gr. mayeri* but differs being less elongated in equatorial profile and low-arched aperture. From its ancestor Gr. praescitula differs by exhibiting five to five and one-half chambers in the final whorl, more inflated chambers and more rounded periphery.
Stratigraphic distribution: Middle Miocene.

Genus: *Globorotaloides* BOLLI 1957

The genus *Globorotaloides* includes forms with a trochospiral test, ovate to spherical chambers. The final chamber is often smaller than the penultimate and may cover part of the umbilicus and appear a bulla. The surface is distinctly cancellated, aperture is umbilical-extraumbilical, later becoming umbilical.

Globorotaloides suteri BOLLI 1957

Plate 1, Fig. 9a, b

1957 *Globorotaloides suteri* BOLLI, p. 117, pl. 27, Figs. 9a-13b

Diagnosis: Test low trochospiral, periphery lobulate; chambers spherical to ovate, four to five in the final whorl, the final chamber often smaller than the penultimate and overlap the aperture; sutures depressed; surface punctate; aperture a low arch, umbilical-extraumbilical, often covered by a bulla-like final chamber.
Stratigraphic distribution: Middle Miocene to Lower Miocene.

Genus: *Globoquadrina* FINLAY 1947

Genus *Globoquadrina* includes trochospiral forms with a quadrate to subquadrate equatorial profile. Aperture is umbilical-extraumbilical with one or more tooth-like projections.

Globoquadrina venezuelana (HEDBERG 1937)

1937 *Globigerina venezuelana* HEDBERG, p. 681, pl. 92, Fig. 72b

Diagnosis: Test large, equatorial periphery slightly lobulate; chambers spherical to ovate, inflated, four in the final whorl; final chamber usually irregular; sutures slightly curved and depressed; surface densely perforate, distinctly cancellate; aperture umbilical with umbilical teeth.
Stratigraphic distribution: Middle Eocene to Early Pliocene.

Genus: *Dentoglobigerina* BLOW 1979

The genus *Dentoglobigerina* includes the morphotypes with umbilical teeth over an umbilically restricted aperture. *Dentoglobigerina* is morphologically intermediate between *Globigerina* and *Globoquadrina* (KENNETT & SRINIVASAN, 1983).

Dentoglobigerina altispira altispira CUSHMAN et JARVIS 1936)

1936 *Globigerina altispira* CUSHMAN et JARVIS, p. 5, pl. 1, Fig. 13a-c

1998 *Globoquadrina altispira* (CUSHMAN et JARVIS) - CICHA-ROGL-ČTYROKA-RUPP et al., pl. 41, Figs. 3-5

Diagnosis: Test large, highly trochospiral; four to five chambers in the final whorl; sutures depressed; surface distinctly cancellated; umbilicus wide, open; aperture umbilically restricted with umbilical teeth projecting into the umbilicus.
Stratigraphic distribution: Lower Miocene to Upper Pliocene.

Superfamily: *Candeinacea* (CUSHMAN 1927)
Family: *Candeinidae* CUSHMAN 1927

Genus: *Globigerinita* BRONNIMANN 1951

The genus *Globigerinita* is characterized by a microperforate surface with extremely small, irregularly distributed perforations. Pore pits are absent, surface is smooth. A bulla is present like *Catapsydrax* but is distinguished by its cancellated surface with large pores. *Catapsydrax* probably evolved from *Globorotaloides* suteri during the late Middle Eocene and is phylogenetically unrelated to *Globigerina* (KENNETT & SRINIVASAN, 1983).

Globigerinita uvula (EHRENBERG 1861)

1861 *Pylodexia uvula* EHRENBERG, pl. 2, Figs. 24-5

1983 *Globigerinita uvula* (EHRENBERG) – KENNETT et SRINIVASAN, p. 224, pl. 56, Figs. 6-8.

Diagnosis: Test small, high trochospiral; chambers spherical, three to four in the final whorl; surface smooth, microperforate, covered with small tubercles; aperture interiomarginal, umbilical, low arch, bordered by a thin lip.
Remarks: Globigerina bradyi WIESNER is a junior synonym (Kennett & Srinivasan, 1983).
Stratigraphic distribution: Upper Oligocene to Recent.

Genus: *Globigerinella* CUSHMAN 1927

Genus *Globigerinella* is characteristic by the forms with an initial test that later becomes nearly planispiral in the adult stage. Chambers are globular to ovate, umbilical aperture and fine spines covered the test. The genus *Globigerinella* evolved from *Globigerina praebulloides* through *Globigerinella obesa*. *Globigerinella* resemble *Jenkinsella* but is distinguished by its spinose surface ultrastructure (Kennett & Srinivasan, 1983).

Globigerinella obesa (BOLLI 1957)

1957 *Globigerinella obesa* BOLLI, p. 119, pl. 29, Figs. 2a-3b
1969 *Globigerina obesa* (BOLLI) – ROGL, p. 93, pl. 6, Fig. 5, pl. 7, Figs. 1 and 4
1987 *Globorotalia obesa* BOLLI – WENGER, p. 324, pl. 24, Figs. 13-14, 19

Diagnosis: Test low trochospiral, equatorial periphery strongly lobulate; chambers spherical, inflated, four to four and one-half in the final whorl; sutures radial, depressed; surface densely perforated; umbilicus wide, deep; aperture has a low to medium arch without lip or rim.
Remarks: Ge. obesa evolved from *Globigerina praebulloides* and is ancestral to *Globigerinella praesiphonifera* (Kennett and Srinivasan, 1983).
Stratigraphic distribution: Upper Oligocene to Recent (Early Egerian to Early Badenian in the Central Paratethys).

Globigerinella regularis (d´ORBIGNY 1846)

1846 *Globigerina regularis* D´ORBIGNY, p. 162, pl. 9, Figs. 1-3

Diagnosis: Test trochospiral to planispiral; chambers rouded, four to five in the final whorl; last chamber is the biggest; aperture umbilical; surface densely perforated with a fine spines; aperture without lip, highly arched.
Remarks: Determinated individuals from Oslavany are characterized by the five chambers in the final whorl. From *Ge. obesa* is distinguished by a bigger-size and more superficial form.
Stratigraphic distribution: Upper Karpatian to the end of the Badenian in the Central Paratethys.

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Paleocene reef limestones near Veľký Lipník (Pieniny Mts., NE Slovakia): Facial environments and biogenic components

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Abstract: The important Paleocene reef complex of small dimensions is situated near the state frontiers of Slovakia with Poland in the Pieniny Mts. above the village Veľký Lipník. It is Lower Thanetian in age (57-58 Ma) and belongs into the Myjava-Hričov Group. In contrast to many other Paleocene reefs of Slovakia, this complex probably lies in situ below the deposits of the Early Eocene (Ilerdian). The reef complex at Veľký Lipník originated on the muddy substrate and this fact limited its size. After Höfling ´s typology (1997) the deposits of reef frameworks belong to the category of reef mounds (patch-reefs) and back-reef and fore-reef sediments to the muddy mounds. Very favourable life conditions in the area of the outer shelf, protected of waves and strong currents with abundance of nutrients and with tropical climatic conditions enabled development of many interesting elements of fauna and flora (Plates 1-8). They participated in constructor, binding, dweller and bioeroder communities. The main constructors of reef buildups were corals, crustose algae and encrusting foraminifers.

Key words: Paleocene, Thanetian, reef complex, reef mounds, muddy mounds, Pieniny Mts., NE Slovakia.

Introduction

There are not many regions on the Earth where the Paleocene reef complexes have been presented. They have been discovered mostly in the last 40 years, but in Slovakia the Paleocene reef limestones have been known more then 60 years (at first with incorrect age determination, for example "Middle to Upper Lutetian if not Lower Priabonian", cf. Lemoine, 1933).

In present 5 regions with occurrences of Paleocene reef complexes (Malé Karpaty Mts., Myjavská pahorkatina Upland, Middle Váh Valley, Orava and Eastern Slovakia, cf. Köhler, 1995) are known in Slovakia.

From the territory of Eastern Slovakia the most important Paleocene reefs are known from the Pieniny Mts. Scheibner (1968) described in the frame of zone Myjava-Hričov-Haligovka the reef framework 10 x 8 x 10 m in size above the settlement Paluby (NW margin of the village Haligovce) formed of grey algal-coral limestone.

Only four km east of this well-known Paleocene reef body another reef complex is well developed.

The presence of limestones of reef origin near the village Veľký Lipník (27 km north of the town Kežmarok, near the Slovak–Polish frontiers) was firstly noted by Nemčok & Kullmanová (1988) in the excursion guide for the national paleontological conference. Mentioned authors assumed that they are "marginal reefs" or "isolated patch reefs" in a shallow open environment, separated from each other by channels, trough which clastic material from the source area was brought into the sedimentation environment. Potfaj & Rakús (in Janočko et al., 2000b) stated that Paleocene limestones of the Pieniny Mts. area belong to Paleogene of the Klippen Belt. This locality is also described by Köhler (1995) in unpublished report of IGCP/ UNESCO project N° 286 "Early Paleogene Benthos".

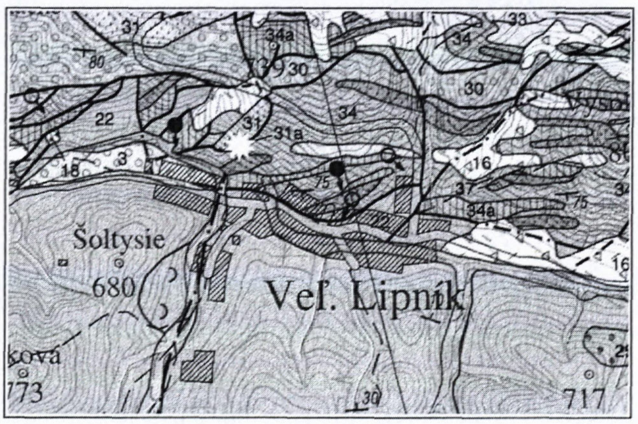


Fig. 1a. Location of the locality Veľký Lipník in Geological map of the Spišská Magura region 1:50 000 (Janočko et al., 2000a).

Very similar Paleocene reef limestones are known also from the Bavarian Alps (Moussavian, 1984) and from the Northern Calcareous Alps (Tollmann, 1976; Kambühel Limestone). Moussavian (l. c.) assumed the existence of so-called "Alpine-Carpathian reef belt". In the last time the Kambühel limestones were studied by Tragelehn (1996). From this point of view the comparative studies of Alpine and Carpathian Paleocene basins are very topical and desirable.

Description of locality and geological setting

The locality is located north of the village of Veľký Lipník below the elevation point 635 m a.s.l. (below the outlook at the road from Veľký Lipník to Lesnica – Fig. 1).

Fig. 1b. Panoramatic view on the Paleocene reef limestones in the locality Veľký Lipník.

The belt of disintegrated blocks of grey reefal limestones has a length up to 200 m. Its width does not exceed 30-40 m. Separate blocks reach the size from 50 cm up to 10 m.

Below the lowermost blocks above the Lipník brook the red marlstones of Púchov Formation outcrop (Janočko et al., 2000a, b). They are Cretaceous in age. The immediate underlying beds of reef blocks are built by soft claystones and marlstones of Early Paleocene age. Near the road Veľký Lipník-Lesnica above the reef occurrences the outcrop of fine-grained sandstones is located, containing *Operculina azilensis* TAMBAREAU, *Assilina yvettae* SCHAUB, *Nummulites* sp. and *Discocyclina* sp. (Plate 7, Fig. 6). These sandstones belong to lowermost Early Eocene (Ilerdian). From the viewpoint of their linear occurrence, size of bodies and stratigraphic position below the deposits of lowermost Eocene, it is very probable that the reef bodies are located at the place of their origin. Their present appearance is caused by the recent erosion and karstification of limestones.

After Golonka et al. (2004) in the Pieniny belt the Paleocene carbonate forms olistoliths in the Zlatna (Myjava) unit. From this viewpoint the reef complex at Veľký Lipník appears as extraordinary one.

All Paleocene reef occurrences in the Slovak territory are closely connected with the Klippen Belt. After the opinion of presenting authors the reef complex originated in the shallow parts of the basin bordering the Klippen Belt from the inner side. Deposits of this basin are connected with the Myjava-Hričov Group (Late Cretaceous – Middle Eocene; Buček et al. in Mello et al., 2005).

From the Paleocene locality Veľký Lipník 20 reef blocks have been sampled and 122 thin sections were prepared. Samples and thin sections are stored in the Geological Survey of Slovak Republic, Bratislava.

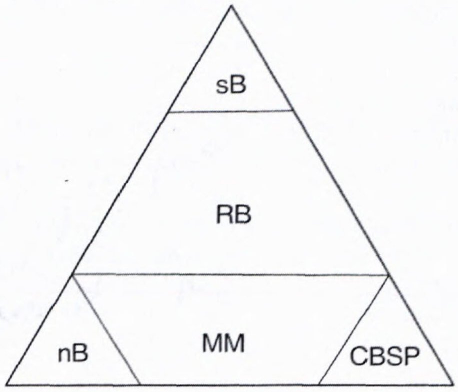
Lithology

Lithology depends on the position of rocks in the reef complex.

All environments have very typical high content of micrite matrix; 20.5-39 % in back-reef environments, 19.5-35 % in reef frameworks, 28-35 % in fore-reef deposits and more than 80 % in channel deposits. The micrite consists of disseminated fragments of Mesozoic carbonates (up to 3.5 mm), grains of quartz (to 0.3 mm) and very scarce fragments of mica plates. Primary cavities in buildups were filled by micrite of second generation, by sparite (often with geopetal textures) or by siltstones. Micrites locally pass into siltstones. Substantial part of rock is formed by organic remnants. Despite the anorganic component of rock is more or less stable, the content of organic components is very variable.

The back-reef environment is predominated by packstones, wackestones and bindstones. For the reef framework the boundstones are typical, locally also bindstones (foralgal crusts). In fore-reef environment the wackestones and packstones originated and in channel deposits the mudstones formed.

2a



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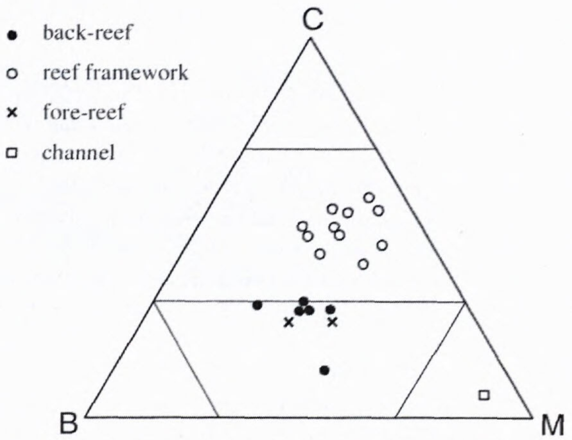

Fig. 2a. Schematic quantitative display of bioconstructions and their transition into non-reefal deposits (Höfling, 1997). Bioconstructions: sB – skeletal bioherm and biostrome, nB – non skeletal stromatolite bioherm and biostrome, RB – reef mounds, MM – mud mounds. Non-reefal deposits: C- cluster, B – bank, S – Schill-horizonte, P – pseudobioherm.
Fig. 2b. Place of samples from the Veľký Lipník locality in Höfling´s triangle.

The high content of micrite matrix demonstrates the quiet protected environment without strong activity of waves and currents. The transport of terrigenous material from the sea-shore was minimal.

Biogenic components

Favourable conditions for organic life in the Pieniny area caused that the reef complex inhabited much diversified association of organisms. They are briefly described in the next pages. For the limited scope of this article the presenting authors abandon the detailed description of taxons.

F l o r a
Cyanobacteria (Pl. 3, Fig. 2)

In several thin sections with crustal coralline algae there are present also the light-grey crusts not displaying any structural signs. These crusts 50-550 μm thick were the product of organisms having the structure so fine that it has not been preserved. The inorganic origin of these covers may be excluded since they are copying the undulated course of algal crusts on which they were lying and they were again covered by algal layers.

Coralline algae
Division *Rhodophyta*

Owing to poor description and different valuation of diagnostic criteria the status of most fossil species of red algae is unclear in present time. The main problem consists of the conflict between traditional identification of fossil species and modern neontological taxonomic concepts (Rasser & Piller, 1999). The original diagnostic characters of many fossil taxa are meaningless according to the modern criteria. In present time many authors attempt to apply the criteria, used for identification of Recent species, also for fossil coralline algae. It appears that practically all descriptions of fossil algae before 1990 are unusable in the sense of new neotological view. As the result of this state the authors of modern articles,

Tab. 1. Volume % of the main components in samples from the reef complex at Veľký Lipník.

Sample N°	Thin section N°	algae Corallinaceae	algae - Solenoporaceae	algae - Peyssonneliaceae	corals	sessile forams	other forams	other fossils	matrix	environment
2	VL9	23		9	4	6	10	9	39	back-reef
6	VL28	13	9		3	34	9	8	24	back-reef
7	VL31	29				27,5	1	15	27,5	back-reef
15	VL72	28,5	16		3	10,5	8.5	3	30.5	back-reef
19	2024	34	12			10	3	10	31	back-reef
20	2036	33	2.5		5	25	7	7	20.5	back-reef
1	VL4	11.5	23	5.5	2	11.5	6	5	35.5	back-reef to
5	VL22	8.5	47.5			7.5	2.5	2.5	31.5	framework
8	VL35	8	28			9	12	6	37	detto
18	1873	18	38.5		11	3.5	3.5	6	19.5	detto
3	VL12	5			47.5	2	7.5	5.5	32.5	framework
9	VL42	13	6.5		35	10	5	6	24.5	framework
10	VL45	13.5	5.5		35.5	7.5	3.5	5	29.5	framework
11	VL49	12.5	7	2	23.5	15	5	7	28	framework
13	VL60	18			31	14	6	2	29	framework
16	VL74	9			46.5	1	6.5	8	29	framework
17	1866	12			37.5	12	3	5	30.5	framework
12	VL58	28	2		8	12	5	9	36	fore-reef
14	VL68	31	8.5	4.5	10	7	7	4	28	fore-reef
4	VL20	4			1	7	3	3	82	channel

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employ only generic designations without concrete species determination. This way is followed also in the presented paper.

It is necessary to mention that many Paleocene red algae were firstly described from Slovakia, but from the other area (Middle Váh valley; Lemoine, 1933). Modern revision of these well-known taxa is very desirable and it is also the aim of presenting authors in the future.

Genus *Sporolithon* HEYDRICH, 1897
***Sporolithon* sp.** (Pl. 2, Figs. 5-6)

It is the most important genus in the algal communities at the Veľký Lipník reef complex.

This genus is characterized by a great variability of growth forms, but the encrusting, layered and foliose growth forms are the most common. This genus is characteristic with its reproductive organs. The numerous simple sporangia are arranged in rows (sori) (Pl. 2, Fig. 5) or in lenses (Pl. 2, Fig. 6) on the peripheral filaments. Several zones of sporangia may be observed within one thallus (buried in the deeper parts of tissue). Sporangia are 30-50 μm high and 15-30 μm in diameter.

This genus is the main element of bindstones in the back-reef environment, but it lived also in the coral communities of reef frameworks. So, it is not only binding element, but also constructer of reefs.

Similar forms of the genus *Sporolithon* described Rasser & Piller (1994) from Paleocene deposits of Austria.

Genus *Lithoporella* (FOSLIE) FOSLIE, 1909
Lithoporella sp. (Pl. 2, Fig. 2)

This genus is characterized by thin thalli and multiple overgrows of large primigenous filaments composed of palisade cells. Filaments are 30-40 μm thick, cells are very narrow (10-15 μm). This genus is present only rarely in thin sections.

Genus *Mesophyllum* LEMOINE, 1928
Mesophyllum sp. (Pl. 2, Fig. 3)

Thalli of this genus are present in encrusting but also in warty and lumpy growth forms. These plants have a dorsiventral nomonerous thalli with a coaxial core and well developed peripheral region. The conceptacules are multiporate, they measure 130-180 μm in diameter and 60-90 μm in height.

Non-oriented sections of this genus can be very easily confused with the genera *Lithothamnion* and *Lithophyllum*.

Genus *Mesophyllum* belongs to common binding algae in the back-reef environment.

Genus *Pseudoamphiroa* MOUSSAVAN, 1999
***Pseudoamphiroa propria* (LEMOINE, 1933)** (Pl. 2, Fig. 4; Pl. 3, Fig. 1)

The Paleocene limestones of Slovakia frequently contain algae with a very characteristic structure of thalli. They may be identified with the species *Pseudoamphiroa propria*, found by Lemoine (1933) on the basis of material from the locality Hričovské Podhradie (Middle Váh valley). Doubts about the correctness of this genus classification were led by Schaleková (1964) to the reclassification of species into the genus *Archaeolithothamnium* (present *Sporolithon*). It does not appear to be a good solution since the structure of the core of both genera is quite different.

In the studied thin sections *Pseudoamphiroa propria* (LEM.) forms 1-2 mm large nodules displaying characteristic bent cell rows sharply separated from each other by the dark walls. Thalli are monomerous with coaxial cores. Dubious sporangia in the peripheral part of thalli are arranged irregularly under the surface of this plant, their diameter does not exceed 50-70 μm (Pl. 3, Fig. 1).

This genus is mentioned in the literature of Paleocene algae only rarely (for example by Johnson, 1964).

Genus *Distichoplax* PIA, 1934
***Distichoplax biserialis* (DIETRICH) PIA, 1934** (Pl. 2, Fig. 1)

Pia (1934) described in detail so far little known species from Paleocene reef bodies near the village Hričovské Podhradie (Slovakia, Middle Váh valley) and he also gave it a genus name.

Sections of fragments of *D. biserialis* (DIETRICH) PIA are rare in thin sections from Veľký Lipník (back-reef and fore-reef environment). The thalli may reach length 1 mm, their diameter varying between 90-110 μm. The typical arrangement of the cells corresponds to that described by Pia (1934).

D. biserialis (DIETRICH) PIA was considered as a marker for Paleocene time, but Schaleková (1964) demonstrated its time span as Paleocene-Middle Eocene. Despite, this species is one of the most characteristic Paleocene algae.

Genus *Elianella* PFENDER et BASSE, 1947
***Elianella elegans* PFENDER et BASSE, 1947** (Pl. 4, Figs. 1-3)

Nodules and fragments of this species are one of the most frequent components of some samples from Veľký Lipník.

This species reaches size up to 12 mm and have an various outer morphology. The most typical one is the cauliflower-like structure. Thallus consists of parallel filaments 30-45 μm thick. A barrel-like shape of the cells is very characteristic. The height of cells is very variable – 20 to 60 μm. The cells in tangential sections are circular to polygonal in outline.

In the literature the contradictory opinions concern the systematic position of these forms. Some authors (Moussavian, 1984; Poignant, 1991) accepted the existence of the genus *Elianella*. The other authors (Segonzac, 1962; Stockar, 2000) claim that it is a synonym of long known genus *Parachaetetes* DENINGEN, 1907. The fundamental criteria for the differentiation of both genera are in the shape of cells in filaments: *Elianella* has an irregular structure of thalli and the horizontal partitions of cells are bent and irregularly distributed, while *Parachaetetes* has a regular structure and the partitions of cells are arranged in regular rows. The barrel-like shape of cells has only *Elianella*. Moussavian (1989) and Stockar (l. c.) affirm that both structural types may occur in the same thallus (the regular and irregular structure), so the differentiation of mentioned genera is not justified and *Elianella* is a young synonym of *Parachaetetes*.

The presenting authors know from the Veľký Lipník locality only forms with the very irregular structure of cells in filaments with distinctly barrel-shaped cells. After their opinion in the Paleocene lived both genera (*Elianella* and *Parachaetetes*) together in some reef complexes.

E. elegans PFENDER et BASSE was found in more than 80 % of thin sections. Locally it forms large accumulations and participates in the composition of frameworks. The present authors suppose that the best conditions for the life of these algae were on the back sides of coral frameworks or in protected back-reef environments.

Genus *Polystrata* HEYDRICH, 1905
***Polystrata alba* (PFENDER) DENIZOT, 1968** (Pl. 3, Figs. 5 and 7)

The thalli are usually well preserved with easily distinguishable details of the structure. The growth form is layered to foliose; layers are to 100-200 μm thick. Thalli are often twisted (Pl. 3, Fig. 5). The thalus consists of primigenous and postigenous filaments. They are very thin – 5 to 10 μm. Very interesting are roundish cavities in the dorsal side (15-110 μm in diameter). After Aguirre & Braga (1999) and Stockar (2001) they are interpreted as reproductive structures buried within the thalus.

This species was described from the Slovak Paleocene under the name *Pseudolithothamnium album* PFENDER by Andrusov (1938, 1950) and as *Ethelia alba* (PFENDER) by Samuel et al. (1972).

Species does not display any special dependence on the environment and occurs in the whole range of environments. Despite, it flourished in the shallow protected environments mainly during the Thanetian.

P. alba (PFENDER) DENIZOT was found in 50 % of thin sections, but specimens are very rare.

Genus *Acicularia* D'ARCHIAC, 1843
***Acicularia* sp.** (Pl. 3, Figs. 3 and 4)

The generic name *Acicularia* is employed for the fertile ampullae of algae of which thalli have not been preserved. They are common in all Paleocene reefs in Slovakian territory.

The circular sections 200-250 μm thick in diameter are known from 68 % of thin sections from all environments of the reef complex.

Genus *Neomeris* LAMOUROUX, 1816
***Neomeris* sp.** (Pl. 3, Fig. 6)

Rare specimens of these dasycladal algae lived only in protected back-reef environment.

Fauna

Foraminiferida
Genus *Alveolina* D'ORBIGNY, 1826
***Alveolina (Glomalveolina) primaeva* REICHEL, 1936** (Pl. 6, Fig. 1)

One of the most important species of undoubtedly Thanetian age is *Alveolina (Glomalveolina) primaeva* REICHEL. Tests of this tiny spherical form are very rare in thin sections from Veľký Lipník (only in 5 thin sections – 4 %) and all lived in the back-reef environment.

The tests are spherical with diameter 300-600 μm; the protoconch has a diameter of 50-60 μm. At the diameter 150-200 μm there are 3 whorls.

This small form is comparable with subspecies *A.* (*G.*) *primaeva ludwigi* REICHEL (in Reichel, 1936) and testify to lower part of Thanetian (typical species *A.* (*G.*) *primaeva* REICHEL is common in Upper Thanetian).

Genus *Discocyclina* GÜMBEL, 1868
***Discocyclina seunesi* DOUVILLÉ, 1922** (Pl. 6, Fig. 2)

Only 3 sections of this species were distinguished in samples from Veľký Lipník. The tests are flat, 1.3-1.6 mm in diameter; the embryonic apparatus (only one measurement) has a diameter 150 μm. It seems that our specimens belong to primitive stage of *D. seunesi* DOUV. (after Less, 1998, diameter of deuteroconch is < 260 μm).

Genus *Miscellanea* PFENDER, 1935
***Miscellanea* cf. *primitiva* (RAHAGHI, 1983)** (Pl. 6, Fig. 3)

We know only 6 sections of this form. The tests are small (diameter 1.0 mm), inflated, with slightly rounded margin. The spherical protoconch has 80 μm in diameter (only one measurement). The chambers increase gradually to the last whorl. The wall of test is expressively perforated.

Similar form was described by Leppig (1988) and Sirel (1998) also from Paleocene.

***Miliolidae* EHRENBERG, 1839** (Pl. 7, Fig. 4)

Miliolid foraminifers are very frequent in the shallow and protected back-reef deposits. The tests are dispersed in micrite or silty matrix. The precise determination on the generic and species level in thin sections is impossible. They certainly include representatives of such genera as *Triloculina* and *Quinqueloculina*, but surprising is the absence of the genus *Idalina* which is common in other Paleocene reefs in the Slovak region.

The sections are circular to oval, thick 300-400 μm in diameter, protoconch is thick 50-90 μm in diameter. In many aspects these forms are similar to unidentified miliolid genera in the monograph by Sirel (1998).

Genus *Solenomeris* DOUVILLÉ, 1924
***Solenomeris ogormani* DOUVILLÉ, 1924** (Pl. 5, Figs. 1 and 2)

Very common tests were distinguished in 45 % of thin sections. Tests are lamellar, encrusting, comprising of numerous layers. They are coalescent with algae and coating solid substrate or (rarely) build macroids. Very interesting is a juvenile part with true nepiont stage having 250-300 μm in diameter (protoconch has 50-60 μm in diameter).

This species was a long time classified as algae, but in present time there is no doubt of its foraminiferal nature. Many authors employed the genus name *Acervulina* or *Gypsina*, presenting authors agree with Bassi (2003) and prefer the original name *Solenomeris* (details see in Bassi, l. c.).

Genus *Smoutina* DROOGER, 1960
***Smoutina* sp.**

Among rotalid foraminifers the most characteristic are the lenticular tests having 600-900 μm diameter with heavy pillars in the central part. The protoconch is 50-90 μm in diameter.

Sections of this form are very similar to *Smoutina* sp. in Sirel (1998, Pls. 37 and 68).

Smoutina sp. belongs between rare dwellers of the reef complex at Veľký Lipník.

Genus *Miniacina* GALLOWAY, 1933
***Miniacina multicamerata* (SCHEIBNER, 1968)** (Pl. 6, Figs. 4 and 5)

This species was originally described by Scheibner (1968) from the Pieniny area (reef framework Paluby – Haligovce). His description is accompanied only by drawings (l. c., p. 84, textfigs. 9-13).

Tests were attached to various solid substrates. Proloculus is spherical (Pl. 6, Fig. 4 right) 50-70 μm in diameter, the walls are 150 μm thick and perforated. Chambers of this species form irregular clusters and they have diameter 40-150 μm.

This species is not as common as *M. multiformis* SCHEIBNER. Long time was *M. multicamerata* known only from Paleocene rocks, but Bosselini & Papazzoni (2003) mentioned this species also from the Late Eocene deposits in northern Italy. Samuel et al. (1972) determined this species from the Paleocene rocks of the Middle Váh valley (Slovakia).

***Miniacina multiformis* SCHEIBNER, 1968** (Pl. 6, Figs. 6-8; Pl. 8, Fig. 6)

Encrusting tests form thin layers repeated densely or lose one another. The layers are 90 to 250 μm thick, very irregular, their calcite walls are 20-40 μm thick. In some samples from the Veľký Lipník these layers are so common that they take part in the construction of reef framework.

Scheibner described this genus (1968) from the reef framework at Paluby – Haligovce near our locality. Bosselini & Papazzoni (2003) mention *M.* aff. *multiformis* from the Late Eocene of northern Italy. Samuel et al. (1972) mentioned this species from the Paleocene limestones of the Middle Váh valley (Slovakia).

Described species is present in 75 % of all thin sections.

Genus *Planorbulina* D´ORBIGNY, 1826
***Planorbulina cretae* (MARSSON, 1878)** (Pl. 5, Figs. 3-6)

The tests are either attached to firm substrates or they have been broken away. The shape of the tests was determined by a relief of the substrate (very often substrate consists of layers of coralline algae). The protoconch is 60 to 100 μm thick in diameter. The adult tests reach 1.5-2.5 mm in diameter. Chambers are arranged irregular in position. The adult chambers are arcuate, their diameter reaches 150-250 μm and walls of chambers are 20-60 μm thick.

This species is very common in protected shallow back-reef environment and with coralline algae binds the soft muddy sea bottom (foralgal crusts).

Family *Placopsilinidae* RHUMBLER, 1913
Genus *Placopsilina* RHUMBLER, 1913
***Placopsilina* sp.**

The agglutinated tests of this genus were attached on various substrates but especially on algal crusts and in the cavities of organic structures. They reached to 3 mm in diameter. Chambers grow usually in one row and attached 700 μm in height. Thick arched walls are composed of calcite and quartz grains.

Genus *Acruliammina* LOEBLICH et TAPPAN, 1946
***Acruliammina praeheissigi* (SAMUEL, KÖHLER et BORZA, 1977)** (Pl. 7, Figs. 1 and 3)

Agglutinated tests are attached on substrate by their initial parts, the adult parts are free and erected. Specimens are 2-7 mm high. Archieved walls are 150-350 μm thick, agglutinated and composed by one layer from calcite and quartz grains. Common presence of quartz grains is surprising, since the quartz grains in micrite matrix are very rare or nearly absent.

These specimens differ of the genus *Haddonia* CHAPMAN by walls from only one layer (e. g. *Haddonia heissigi* HAGN has walls from two layers; cf. Hagn, 1968). *Acruliammina robusta* BIGNOT from Montian reef complex in Vigny (France) is smaller (up to 2 mm in diameter) and is known only from Bignot ´s drawings (Bignot, 1991, textfig. 6 and 7).

Samuel et al. (1972) presented this species on numerous plates under the name *Haddonia* sp. and *Reophax* sp. from Montian-Thanetian reef limestones of the Middle Váh valley (Slovakia). As a new species *Haddonia praeheissigi* SAMUEL, KÖHLER et BORZA these authors (Samuel et al., 1977) described this form again from the Middle Váh valley area but as locus typicus they designated the Late Senonian locality Pod Húštim (to SW of the town Považská Bystrica).

Family *Eoglobigerinidae* BLOW, 1979
Genus *Eoglobigerina*, MOROZOVA, 1959
***Eoglobigerina pseudobulloides* (PLUMMER, 1926)** (Pl. 7, Fig. 2)

This species is present only in samples of fore-reef part of reef complex or from the outer sides of reef buildups.

Sections of free tests (determined by J. Salaj[1]) have 500-900 μm in diameter, coiling is trochospiral, composed by 2-2.5 whorls. Walls are calcareous, perforated.

After Samuel & Salaj (1968) this species in Slovak Paleogene occurs in the stratigraphic range Danien-Thanetian (l. c., textfig. 27).

Other small foraminifers

Very sporadically in thin sections also sections of other foraminifers are present belonging to the genera *Anomalina, Cibicides, Spirobulimina* (Pl. 7, Fig. 5) and to undermined agglutinated genera.

Metazoa

Phyllum *Porifera*

Spines of Porifera belong to the very scarce elements in some thin sections.

Phyllum *Coelenterata*
Class *Anthozoa*
Order *Scleractinia* (Pl. 1, Figs. 3-6; Pl. 8, Figs. 1-2)

The fragments of corals are present in 83 % of thin sections, but they are common only in 36 thin sections (29 %) from samples of reef framework, building these frameworks.

The determination of scattered small fragments of corals is uncertain. These fragments are obviously broken and bored, their structures are recrystallized. Only in 7 samples corals play an important role as constructers of reef buildings. After comparison with description and illustrations of Turnšek (in Drobne et al., 1988) and Turnšek & Drobne (in Hottinger & Drobne, 1998) from these samples the following species were determined: *Actinacis* sp., *Aastrocoenia* sp., *Dendrophyllia* sp., *Litharaea* sp., *Rhizangia* sp. and *Stylocoenia* sp.

Firm frameworks could be built by genera *Actinacis* (Pl. 1, Fig. 5; Pl. 8, Fig. 2), *Dendrophyllia* (Pl. 1, Fig. 4), *Litharaea* (Pl. 1, Fig. 6) and *Aastrocoenia* (Pl. 8, Fig. 1). These frameworks have a large cavities filled mostly by the marine micrite. The initial diagenesis was not intensive. It rather appears that the frameworks were exposed to intensive bioerosion. Only colonies cemented by crusts of coralline algae were resistant.

The structures containing bodies of *Pieninia oblonga* BORZA et MIŠÍK are very interesting. Mišík (1998) mentions that there are different opinions on the nature of skeletons obtaining *Pieninia oblonga* (Pl. 4, Figs. 4-6). After some authors they represent the fragments of corals, after others the bodies of Keratose sponges. Presenting authors regard the coral genus *Litharaea* MILNE EDWARDS et HAIME as a "host" of *Pieninia oblonga.*

Phyllum *Annelida* (Pl. 8, Fig. 6)

Typical tubes with the dark inner and light outer layer can be found only occasionally. Worms were rare dwellers of the reef complex.

Phyllum *Bryozoa* (Pl. 8, Fig. 7)

Bryozoa are present only in small fragments, whole zoaries are very exceptional (Pl. 8, Fig. 7). Study in thin sections does not enable their classification. All specimens belong to the order *Cyclostomata.*

Cyclostomata prefer shallow protected waters and so they lived prevailingly in back-reef environment.

Phyllum *Mollusca*
Class *Bivalvia*

Small fragments of shells occur in almost all studied thin sections, but whole shells are a great rarity. Their more accurate determination is not possible (order *Dysodonta*).

Class *Gastropoda* (Pl. 8, Figs. 3 and 4)

Shells of gastropods are present in some samples but they are not common. The sections do not enable the determination on the level of genus or species.

The gastropods lived in protected back-reef environment and also in the cavities in reef frameworks.

Subphyllum *Crustacea*
Class *Ostracoda* (Pl. 8, Fig. 5)

Whole unbroken shells of ostracods are found relatively rarely in thin sections. Ostracods occur mostly in the back-reef environment. The determination of genera and species in thin sections is so far not possible.

Phyllum *Echinodermata*
Class *Crinoidea*

Dispersed crinoidal segments and their fragments are rare in studied samples and the importance of these animals in the construction of reef communities is negligible.

Class *Echinoidea*

Echinoid spines belong to very rare organic remnants in reef complex at Veľký Lipník.

Vertebrata
Fish teeth

Only in one thin section was determined one fish tooth (sample 2, thin section 10 VL/K).

Incertae sedis
Genus *Pieninia* BORZA et MIŠÍK, 1976
***Pieninia oblonga* BORZA et MIŠÍK, 1976** (Pl. 4, Figs. 4-6)

The genus *Pieninia* with a very unclear systematic position was defined in 1976 by Borza and Mišík. These authors suggested the affinity of *Pieninia* to algae (probably *Codiaceae*). Only one species was described – *Pieninia oblonga.*

[1] The authors wish to thank Dr. Joseph Salaj for identification of planktonic foraminifers.

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In 1998 Mišík returned to the problem of *Pieninia oblonga* on the basis of the new material (also from Veľký Lipník). He mentioned opinions of some specialists about taxonomic position of this fossil. He stated that *Pieninia* was found in fragments of *Coelenterata* or *Sponge* skeletons in Paleocene biohermal limestones. Skeletal fragments were not definitely determined. Problematic bodies often occur not in the cavities but inside of the calcified skeletons. The question remains whether bodies of *Pieninia* are unusual sclerites or parasites because the way of their loosening from the skeletons was not observed.

The presenting authors refer to article of Mišík but in their opinion at the locality Veľký Lipník the genus *Pieninia* is endoparasite in the skeletons of corals (see Pl. 4, Figs. 4-6).

The sections are circular, oval or irregularly angular. Bodies with a diameter of 150 to 250 μm with more or less marked central channel are distinguishable in 39 % of thin sections but only in 10 thin sections (8 %) they are common.

Species *Pieninia oblonga* BORZA et MIŠÍK is known from stratigraphic time span Barremian – Late Eocene.

Age of the reef complex

The age of the reef complex at Veľký Lipník locality is unambiguous. For age determination the most useful are foraminifers, first of all *Alveolina* (*Glomalveolina*) *primaeva* REICHEL, *Discocyclina seunesi* DOUVILLÉ, *Miscellanea* cf. *primitiva* (RAHAGHI) and *Eoglobigerina pseudobulloides* (PLUMMER). This association situates reef complex into Thanetian SBZ 3 zone (in the terminology of Shallow Benthic Zones, see Serra-Kiel et al. 1998) (= P4 and NP 5-8 zones). This age determination coincides also with the composition of all organic remnants in 20 rock samples at Veľký Lipník and with the age determination of overlying Ilerdian (Early Eocene) beds.

The Thanetian has duration about 2 million years (56-58 Ma, see table in Serra-Kiel et al., l. c.).

Since in association the alveolinids and discocyclinids are represented by primitive forms (Alveolina (*G.*) *primaeva ludwigi* REICHEL and primitive *Discocyclina seunesi* DOUVILLÉ) the age of this reef complex is contracted into the interval 57-58 Ma, i. e. lower part of the Thanetian.

Composition of communities in the Veľký Lipník reef complex

Each reef system is characterized by a specific composition of the community of its fauna and flora. Community consists of numerous mutually interacting species. As wrote Fagestrom (1987, pp. 172-173) "The complex interactions of factors and processes are biologically expressed as communities and subcommunities. Because these interactions vary from place to place and reef to reef, no two reefs should be expected to have precisely the same subcommunities arranged in precisely the same patterns". In the sense of Fagestrom (l. c.) and Höfling (1997) in reef complex there is possible to distinguish some characteristic members of communities (guilds in sense Fagestrom, l. c.). The main reef complex communities are: constructor, binding, dweller and bioeroder community.

These communities were distinguished also in Veľký Lipník reef complex.

a) Constructor community

This community build the reef framework. The members are colonially living forms having large, strong and heavy skeletons. Their upward growth is more intensive than the growth sideward and the growth of the skeletons is more rapid than sedimentation.

Typical representatives of constructor community in the Tertiary are corals – *Scleractinia*. On the table 1 with volume % of the main reef components is possible to see that also at the Veľký Lipník locality corals are the main constructors of reef framework. Their surfaces are bearing also encrustings of coralline algae and sessile foraminifers, but their volume portion on the construction of rigid reef buildups is small.

A peculiar role is played by genus *Elianella*. Its accumulations are connected with back-reef environment but chiefly with the back sides of coral buildings. Present authors attribute genus *Elianella* also as a constructor of inner parts of reef frameworks (Table 1).

b) Binding community

When we take into consideration that sea-bottom at Veľký Lipník was muddy and underlying beds consisted of claystones and marlstones of Late Cretaceous-Early Paleocene age, the role of binding community in the stabilization of the substrate was enormous. Only on the relatively firm bottom there arised the conditions for life of colonial large forms as corals. The binding forms were the pioneers and owing to their activity the reef complex has arised in such inconvenient place.

The main components of binding community are coralline algae (chiefly *Corallinaceae* and in the first place genus *Sporolithon*), perhaps also cyanobacteria and some sessile foraminifers (genera *Acruliammina, Miniacina, Solenomeris*). These taxa have heavily calcified structures.

The authors connect binding and baffling communities into one unit because the activity of waves was minimal (micrite matrix without traces of washing).

c) Dweller community

It is the most variable part of reef organic life. It includes the forms living on the sea bottom, being active in reef buildups, or inhabiting the shallow sea water.

This community includes:

- some algae as *Distichoplax biserialis* (DIETRICH) PIA and dasycladal algae,
- foraminifers as miliolids, anomalinids, larger foraminifers and in the fore-reef deposits also planktonic foraminifers,
- bryozoans, ostracods, bivalvia, gastropods, echinoids, fishes.

d) Destroyer community

It left traces in the form of various borings and the breaking of corals branches. On the destructive activity there participated the boring (endolits) algae and sponges, rasping bivalvia and gastropods, polychaete worms and fishes grazing the reef surfaces.

An important factor in the destruction of coral tissue was *Pieninia oblonga* BORZA et MIŠÍK, that is considered as endoparasite in coral colonies.

Classification and typology of the reef complex

The terminology and classification of fossil reef structures is very complicated with many vague terms. The critical review of various opinions gave Höfling (1997). This author defined various bioconstructions of the reefal and non-reefal nature with many examples from the geological history of the Earth. For the unification of typology he proposed the triangle presentation of the main biostructures (Höfling, 1997, p. 40, Fig. 2). The terminal points of his triangle are "constructors in situ" (C), "binding organisms" (B) and "micrite and clasts (M), see Fig. 2a.

For the classification of Veľký Lipník reef complex all collected samples (20) were analysed. One (rarely 2-3) thin section was selected and analysed in details from each sample. The composition of rock was studied by putting a grid with a cell side 4 mm² over the 20 x 20 mm plane. In spite of great variability of reef composition the obtained data render valuable information of composition of reef complex (Table 1).

The studied samples can be divided into 4 categories:

1. Back-reef deposits

are characterized by packstones, wackestones and bindstones with a high percentage of crustose coralline algae, dasycladal algae, sessile and benthic foraminifers (especially miliolids and large foraminifers) with small amount of corals. This environment is preferred also by bivalvia, gastropoda and cyclostomate bryozoa (samples Nos. 2, 6, 7, 15, 19 and 20).

2. Reef frameworks

are built up by boundstones, locally also bindstones (foralagal crusts). In the organic composition there dominate corals (35-47.5 volume %) in association with algae (5-19.5 %), benthic foraminifers (8-14.5 %) and various dwellers (mainly in cavities).

The common presence of alga *Elianella* (23-38.5 volume %) is characteristic for the back side of reef buildups. This alga lived also in protected back-reef environment, but main accumulations of thalli are on the back sides of frameworks. The samples Nos. 1, 3, 5, 8, 9, 10, 11, 13, 16, 17 and 18 belong into this group.

3. Fore-reef environment

consists of wackestones and packstones with algae, fragments of corals, benthic but also planktic foraminifers (*Neoglobigerina*). We have studied only two samples, Nos. 12 and 14.

4. The special case is the sample No. 4 with 82 % volume % of micrite (mudstone) and clasts and with small amount of fragments of corals, algae and benthic foraminifers. According to authors of presented article this sample represented original muddy sediment between the reef buildups (channel deposit).

The data from table 1 after adaptation were substituted into Höfling ´s triangle (Fig. 2b). Deposits of back-reef and fore-reef environment are placed into field MM (muddy mounds), the sample from channel into CBCP field (non-reef deposits).

The most interesting are samples from the reef construction. All samples are placed into the field of reef mounds. This arrangement coincides with the idea of authors that in the space of Veľký Lipník originated only patch reefs with very limited dimensions (up to 10 m). These patch reefs were surrounded by muddy channels with fragments of reefs. In the protected shallow area beyond the reef constructions the favourable conditions for the very diverse life occurred. The fore-reef deposits are conserved only in small rests. In all environments the traces of intensive bioerosion of carbonates were observed.

Conclusions

At the locality Veľký Lipník (Pieniny area, NE Slovakia) the separate reef complex originated on the muddy sea bottom during the lower part of Thanetian (57-58 Ma).

After the stabilization of soft muddy sediment by encrusting algae and foraminifers the very restricted reef constructions have originated. With respect to Höfling ´s categorization (1997) they belong to the category of reef mounds. These frameworks had very limited dimensions (to 10 m). Simultaneously with the growth of reefs also back-reef and fore-reef environments have developed with characteristic elements of fauna and flora. The corals and algae were the main constructors of reef buildups.

Reef complex originated in the very shallow quiet environment relatively distant of sea shore, protected from waves and currents (in outer part of shelf) and without traces of washing (well preserved internal sediment in reef frameworks). Only reduced transport of silty material was recorded.

Bioerosion was the main agent of the destruction of reef constructions.

The organic content indicates the high taxonomic diversity in comparison with adjacent non-reef areas.

In 20 studied samples (122 thin sections) we were able to define the back-reef, reef and fore-reef deposits with characteristic composition of fauna and flora.

The great taxonomic diversity confirms the normal salinity of sea-water, abundance of nutrients and tropical climatic conditions during the growth of the reef complex.

The growth of reef complex had only small duration (under one million years) and extincted during the Thanetian. The reasons of its extinction are various: deepening of sea-bottom and filling of surface of reefs by

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muddy material (the deepening was due to rising of the sea level or by subsidence of bottom owing the tectonic movements). The other possibility is that due to the heavy weight frameworks their rigid foundation was broken and they buried into the soft substrate.

Peculiarity of this locality consists from the fact that deposits of reef complex are probable in situ on the place of their origin (under the deposits of Early Eocene) and they were not transported into younger deposits as is a rule in other Paleocene reef deposits of Slovakia.

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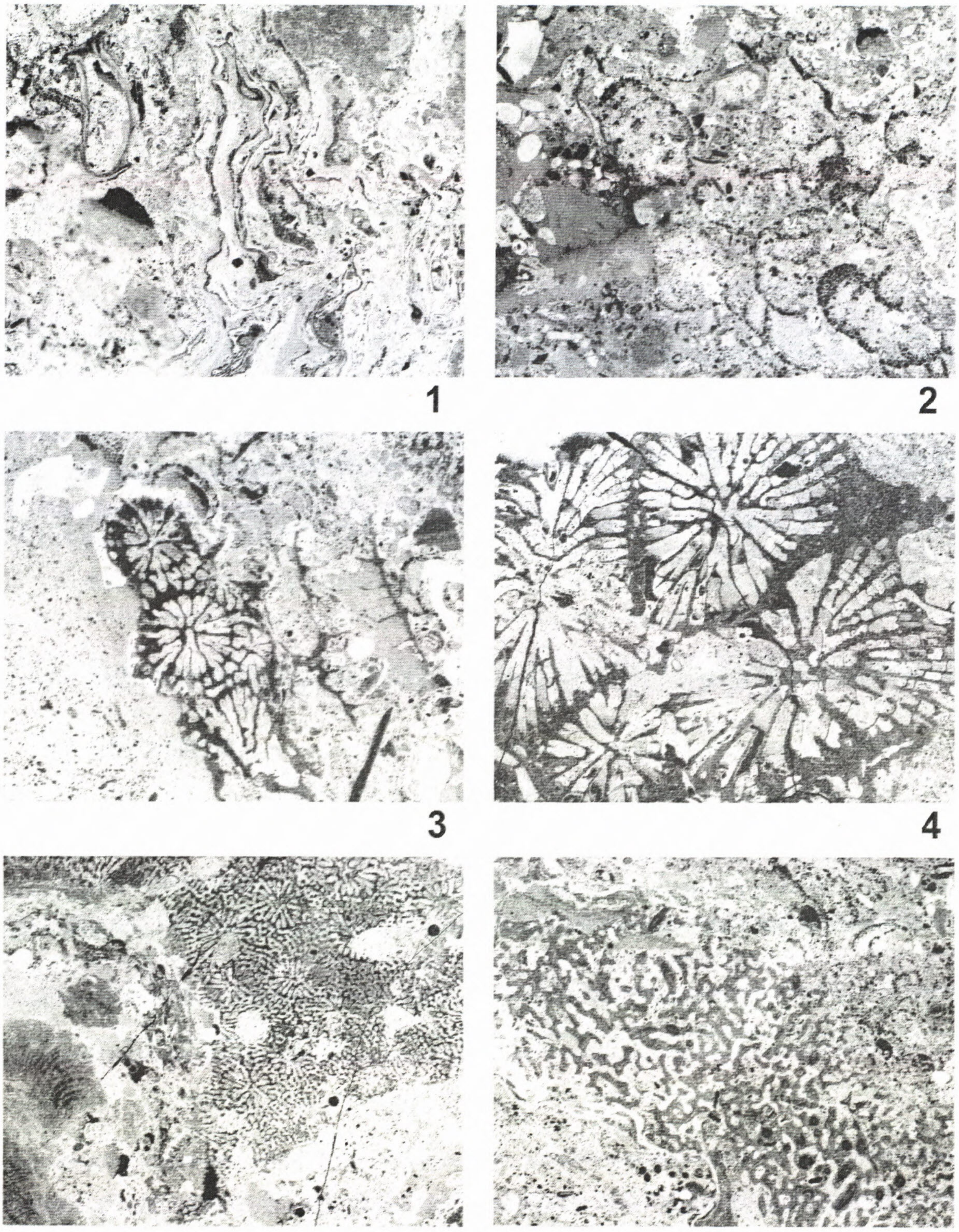

Plate 1

Fig. 1. Crusts of coralline algae (with dominance of *Sporolithon* sp.). Sample 19, thin section 2034/92, magn. 5x; Fig. 2. Crusts of coralline algae with tests of *Acruliammina praeheissigi* (SAMUEL, KÖHLER et BORZA). Sample 8, thin section 28 VL/K, magn. 7x; Fig. 3. Crusts of coralline algae with sections of *Rhizangia* sp. Sample 16, thin section 76 VL/K, magn. 7x; Fig. 4. Sections of *Dendrophyllia* sp. Sample 16, thin section 74 VL/K, magn. 5x; Fig. 5. Sections of *Actinacis* sp. Sample 10, thin section 45 VL/K, magn. 7x; Fig. 6. Sections of *Litharaea* sp. Sample 9, thin section 40 VL/K, magn. 7x. Photo by the authors.

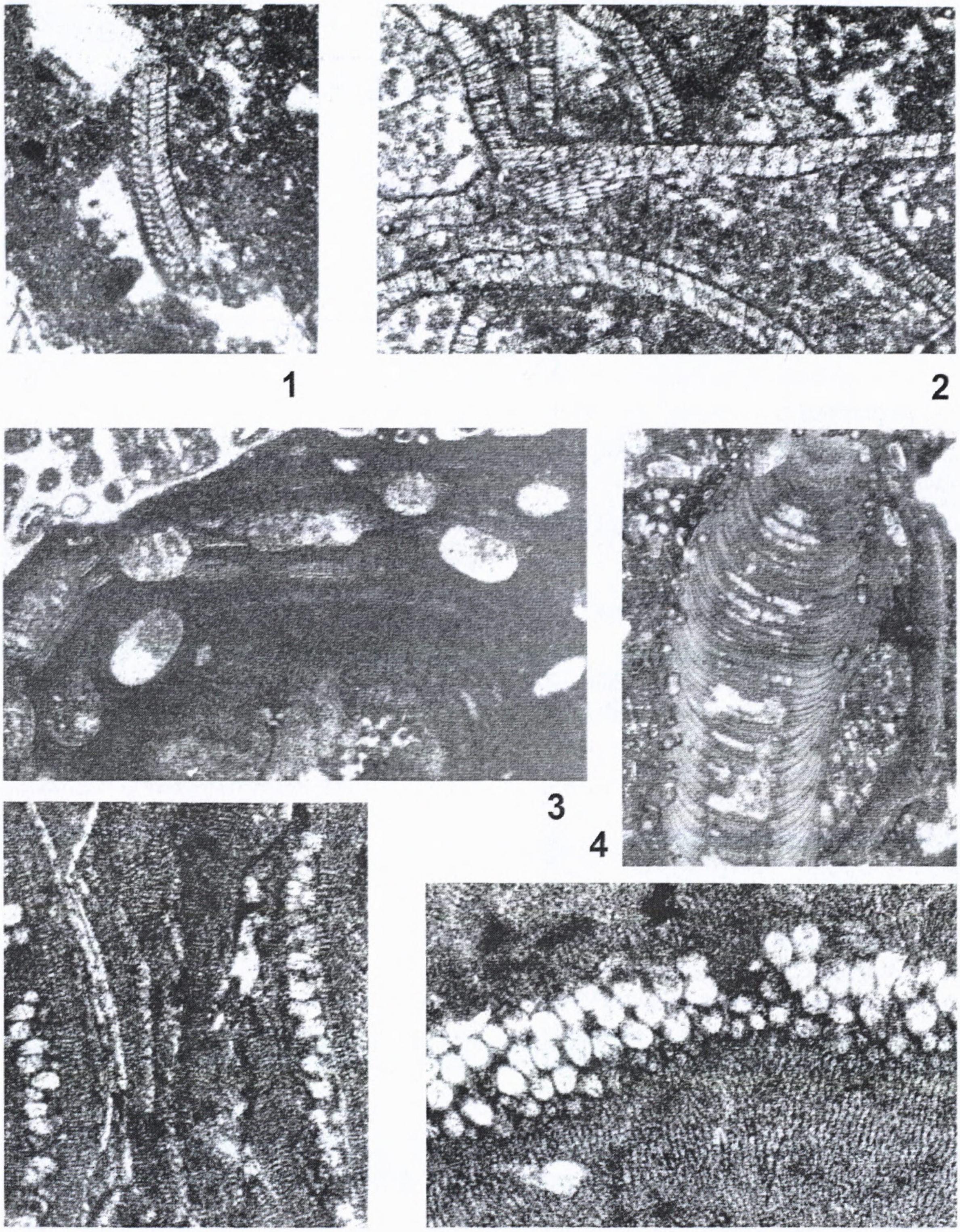

Plate 2

Fig. 1. *Distichoplax bisierialis* (DIETRICH) PIA, fragment of tissue. Sample 18, thin section 1879/91, magn. 50x; Fig. 2. *Lithoporella* sp. Sample 6, thin section 30 VL/K, magn. 80x; Fig. 3. *Mesophyllum* sp., thalus with conceptacules. Sample 19, thin section 3044/92, magn. 50x; Fig. 4. *Pseudoamphiroa propria* (LEMOINE). Sample 9, thin section 42 VL/K, magn. 30x; Fig. 5. *Sporolithon* sp., part of the thallus with sporangia. Sample 10, thin section 45 VL/K, magn. 80x; Fig. 6. Sporangia of *Sporolithon* sp. Sample 1, thin section 3 VL/K, magn. 80x. Photo by the authors.

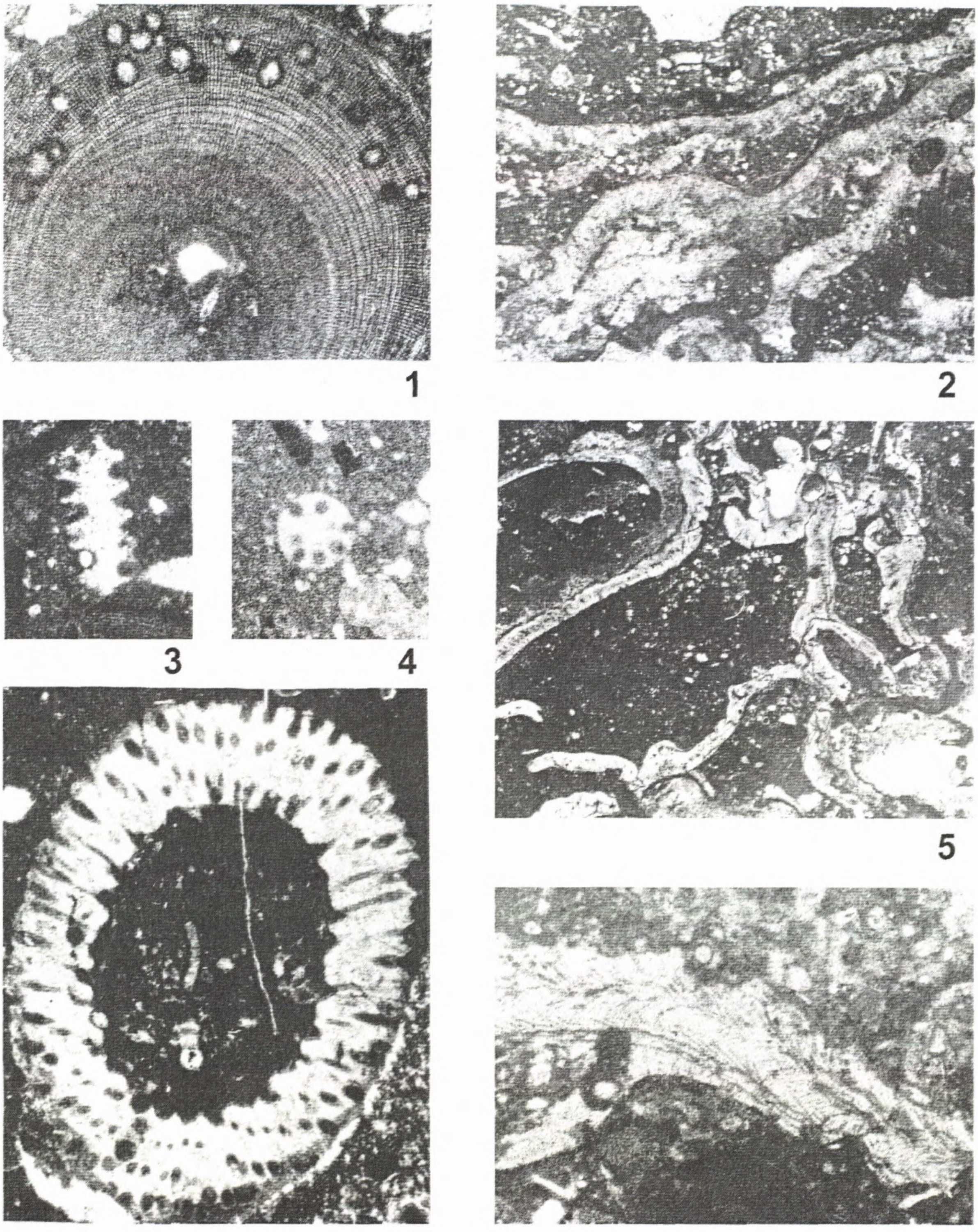

Plate 3

Fig. 1. *Pseudoamphiroa propria* (LEMOINE). Sample 12, thin section 54 VL/K, magn. 50x; Fig. 2. crusts of *Cyanobacteria*. Sample 13, thin section 61 VL/K, magn. 20x; Fig. 3. *Acicularia* sp., longitudinal section. Sample 5, thin section 24 VL/K, magn. 50x; Fig. 4. *Acicularia* sp., transverse section. Sample 5, thin section 25 VL/K, magn. 50x; Fig. 5. *Polystrata alba* (PFENDER) DENIZOT, tangle of thallii. Sample 17, thin section 1862/91, magn. 10x; Fig. 6. *Neomeris* sp. Sample 6, thin section 26 VL/K, magn. 30x; Fig. 7. *Polystrata alba* (PFENDER) DENIZOT, thallus in longitudinal section. Sample 1, thin section 2 VL/K, magn. 50x. Photo by the authors.

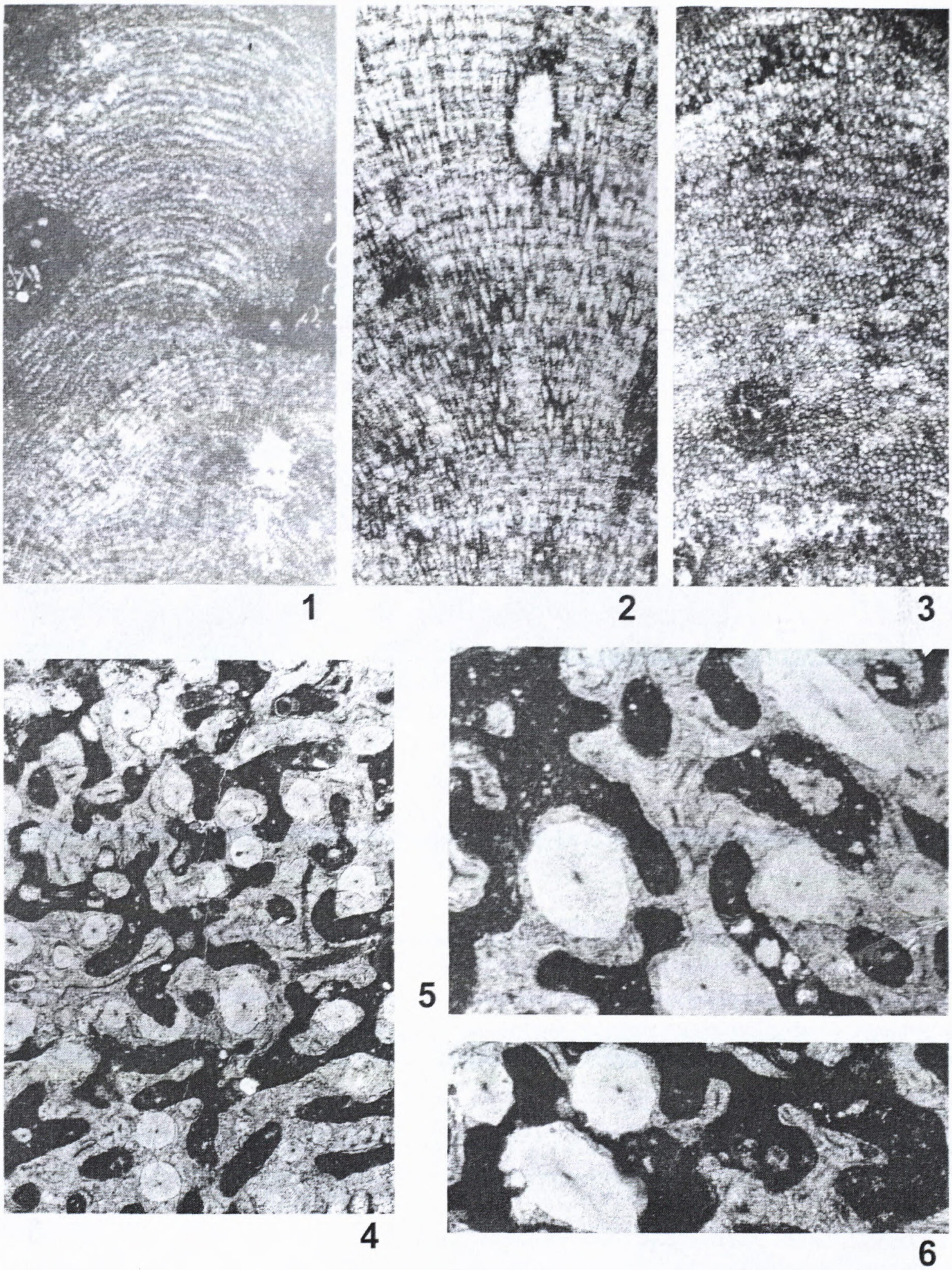

Plate 4

Fig. 1. *Elianella elegans* PFENDER et BASSE. Sample 15, thin section 71 VL/K, magn. 15x; Fig. 2. *Elianella elegans* PFENDER et BASSE. Sample 10, thin section 45 VL/K, magn. 30x; Fig. 3. *Elianella elegans* PFENDER et BASSE, tangential section. Sample 1, thin section 2 VL/K, magn. 30x; Fig. 4. *Pieninia oblonga* BORZA et MIŠÍK in coral structure. Sample 9, thin section 43 VL/K, magn. 30x; Figs. 5-6. *Pieninia oblonga* BORZA et MIŠÍK in coral tissue. Sample 9, thin section 44 VL/K, magn. 50x. Photo by the authors.

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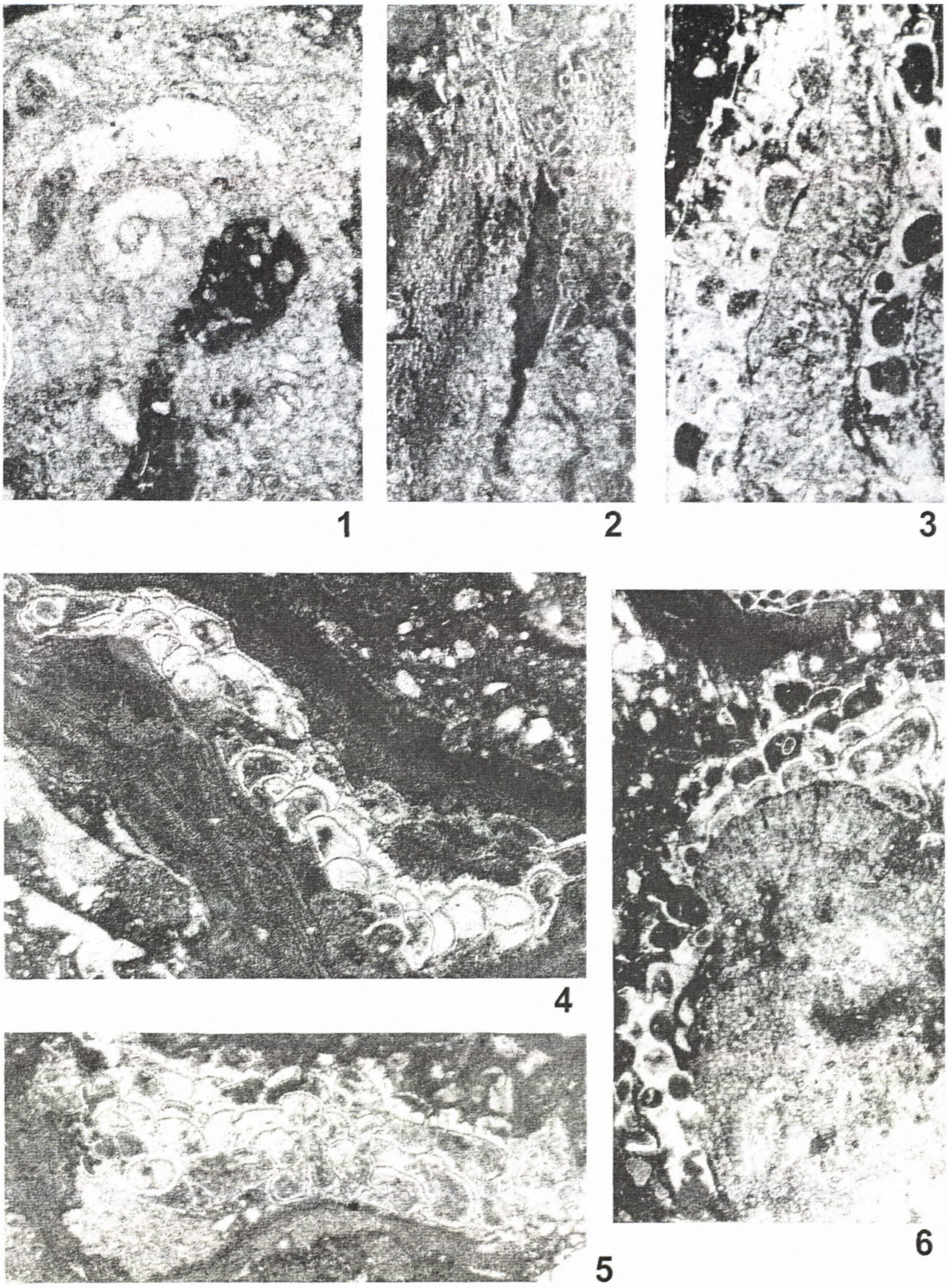

Plate 5

Fig. 1. *Solenomeris ogormani* DOUVILLÉ, central part of test. Sample 14, thin section 38 VL/K, magn. 50x; Fig. 2. *Solenomeris ogormani* DOUVILLÉ, crustose form. Sample 13, thin section 59 VL/K, magn. 50x; Fig. 3. *Planorbulina cretae* (MARSSON). Sample 2, thin section 7 VL/K, magn. 30x; Fig. 4. *Planorbulina cretae* (MARSSON). Sample 16, thin section 76 VL/K, magn. 50x; Fig. 5. *Planorbulina cretae* (MARSSON), embryonal part in left side. Sample 12, thin section 56 VL/K, magn. 50x; Fig. 6. *Planorbulina cretae* (MARSSON) encrusting the thallus of *Elianella elegans* PFENDER et BASSE. Sample 15, thin section 70 VL/K, magn. 30x. Photo by the authors.

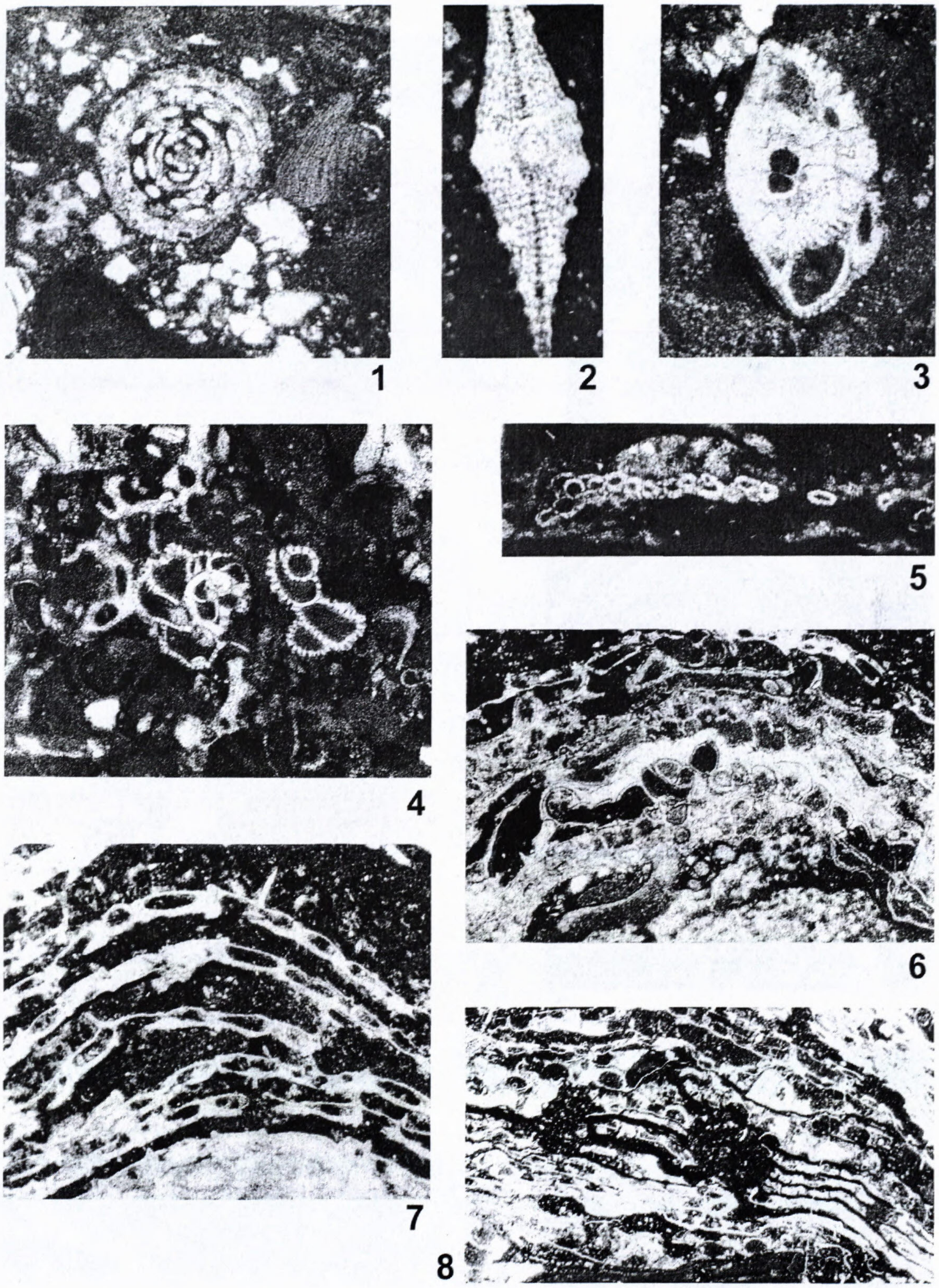

Plate 6

Fig. 1. *Alveolina* (*Glomalveolina*) *primaeva* Reichel, oblique equatorial section. Sample 15, thin section 72 VL/K, magn. 80x; Fig. 2. *Discocyclina seunesi* Douvillé, axial section. Sample 18, thin section 1877/91, magn. 50x; Fig. 3. *Miscellanea* cf. *primitiva* (Rahaghi) in oblique axial section. Sample 6, thin section 26 VL/K, magn. 50x; Fig. 4. *Miniacina multicamerata* (Scheibner), embryonal part in right. Sample 15, thin section 71 VL/K, magn. 80x; Fig. 5. *Miniacina multicamerata* (Scheibner). Sample 20, thin section 2045/92, magn. 50x; Fig. 6. *Miniacina multiformis* Scheibner in crust with *Planorbulina cretae* (Marsson). Sample 2, thin section 8 VL/K, magn. 50x; Fig. 7. *Miniacina multiformis* Scheibner. Sample 7, thin section 31 VL/K, magn. 30x; Fig. 8. *Miniacina multiformis* Scheibner. Sample 7, thin section 31 VL/K, magn. 30x. Photo by the authors.

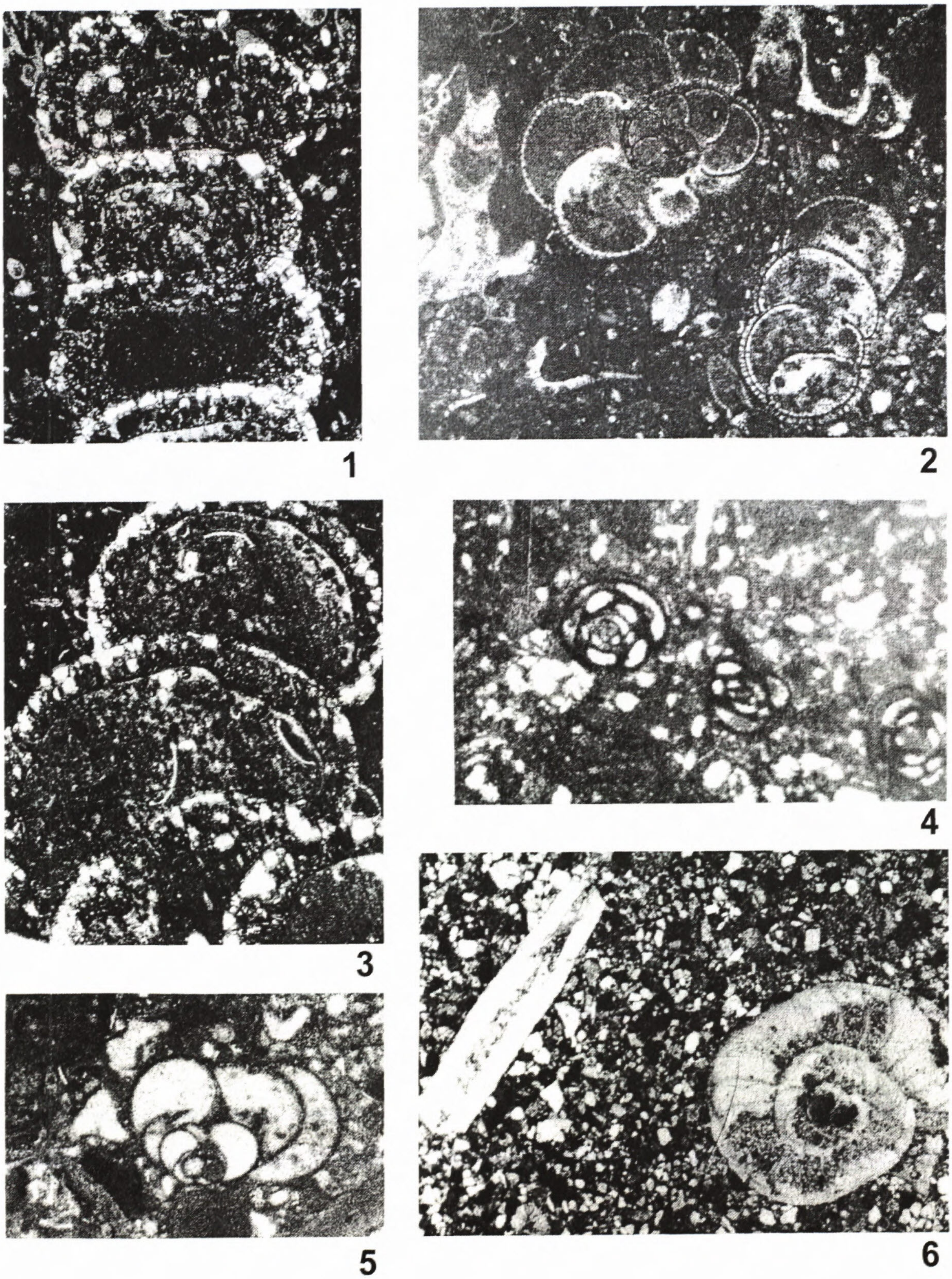

Plate 7

Fig. 1. *Acruliammina praeheissigi* (SAMUEL, KÖHLER et BORZA), axial section of chambers. Sample 9, thin section 38 VL/K, magn. 30x; Fig. 2. *Eoglobigerina pseudobulloides* (PLUMMER). Sample 17, thin section 1862/91, magn. 50x; Fig. 3. *Acruliammina praeheissigi* (SAMUEL, KÖHLER et BORZA). Sample 11, thin section 49 VL/K, magn. 30x; Fig. 4. *Miliolidae* sp. Sample 19, thin section 2034/92, magn. 50x; Fig. 5. *Spirobulimina* sp. Sample 12, thin section 57 VL/K, magn. 50x; Fig. 6. Sandstone with *Operculina azilensis* TAMBAREAU. Sample 21 (overlying beds of the reef complex), thin section 80 VL/K, magn. 20x. Photo by the authors.

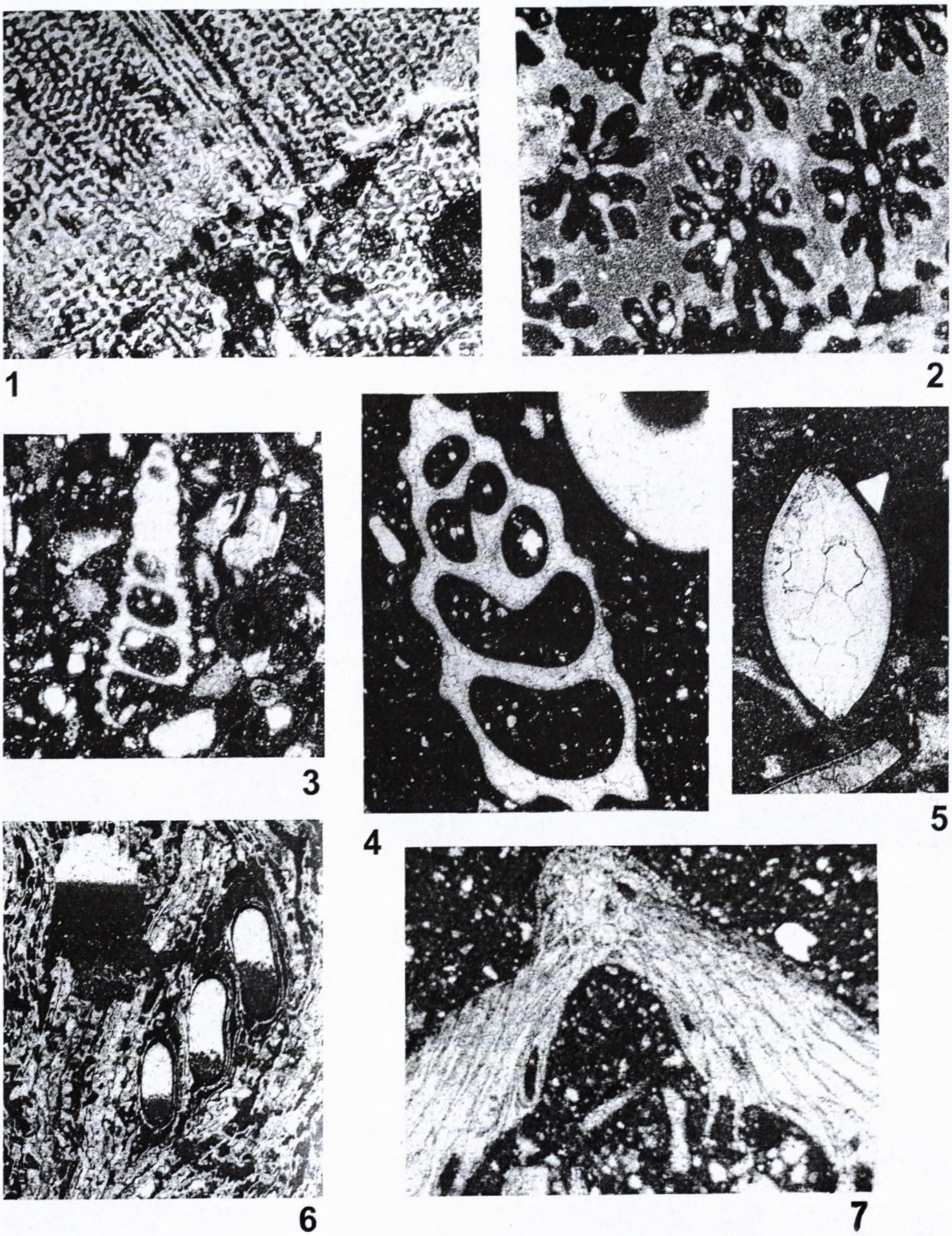

Plate 8
Fig. 1. *Actinacis* sp. Sample 12, thin section 55 VL/K, magn. 10x; Fig. 2. *Aastrocoenia* sp. Sample 12, thin section 55 VL/K, magn. 30x; Fig. 3. Gastropod shell in axial section. Sample 8, thin section 35 VL/K, magn. 30x; Fig. 4. Gastropod shell in axial section. Sample 15, thin section 73 VL/K, magn. 30x; Fig. 5. Ostracoda shell. Sample 13, thin section 59 VL/K, magn. 50x; Fig. 6. Serpulide shell in crusts of *Miniacina multiformis* Scheibner (in cavities geopetal structures). Sample 7, thin section 31 VL/K, magn. 10x; Fig. 7. *Cyclostomata* bryozoa. Sample 15, thin section 72 VL/K, magn. 50x. Photo by the authors.

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Middle Miocene assemblage of Rodents from Bonanza site near Devínska Nová Ves (Slovakia)

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Abstract. Eleven taxa of rodents (*Spermophilinus bredai*, Sciuridae gen. et spec. indet., *Eumyarion* sp., ?*Megacricetodon* sp., *Democricetodon vindobonensis*, ?Cricetidae gen. et spec. indet., *Neocometes brunonis*, *Bransatoglis astaracensis*, ?Gliridae gen. et spec. indet., ?Eomyidae gen. et spec. indet., and Rodentia gen. et spec. indet.) have been determined in the Middle Miocene micromammal assemblage from Devínska Nová Ves-Bonanza fossil site. Although this Late Badenian (MN 6) rodent assemblage is similar to that of Devínska Nová Ves-Fissures (Middle Badenian, early MN 6), it shows a decrease of the diversity, caused probably by environmental changes at the beginning of the Late Badenian in the Vienna Basin area. Found rodents inhabited forested insular region neighbouring with freshwater lagoon, marsh or delta.

Key words: Sciurids, Cricetids, Glirids, Eomyids, Late Badenian, MN 6, Devínska Nová Ves, Slovakia

1. Introduction

Records of fossil rodents are frequent in Miocene terrestrial deposits of Europe. However, only isolated teeth and bones are mostly found.

In Slovakia, only four of 13 sites with a record of Miocene mammals yielded also remains of rodents. The stratigraphically youngest record is known from the Late Miocene (MN 10) site of Pezinok, where Joniak (2005) recently found rodent assemblage with *Spermophilinus bredai*, ?*Albanensia* sp., *Trogontherium minutum*, *Microtocricetus mollasicus*, *Kowalskia* sp., *Progonomys* sp., Muridae gen. et spec. indet., *Anomalomys gaillardi*, *Graphiurops austriacus*, *Glirulus* (*Paraglirulus*) sp., and *Eomyops* sp.. He also mentions a fossil assemblage of micromammals from Borský Svätý Jur (MN 9) containing remains of *Spermophilinus bredai*, *Steneofiber* sp., *Trogontherium minutum*, *Eumyarion latior*, *Megacricetodon minutus*, *Democricetodon* sp., *Microtocricetus mollasicus*, *Glirulus* cf. *lissiensis*, *Muscardinus hispanicus*, Gliridae gen. et spec. indet., *Eomyops catalaunicus*, and *Keramidomys* sp.. Terrestrial deposits of Devínska Nová Ves-Fissures (also known as Neudorf-Spalte, MN 6) yielded thus far the richest insectivore assemblage, including *Spermophilinus bredai*, *Blackia miocaenica*, *Eumyarion latior*, *E. weinfurteri*, *Megacricetodon gregarius*, *M.* cf. *schaubi*, *Democricetodon vindobonensis*, *Lartetomys* cf. *zapfei*, *Neocometes brunonis*, *Anomalomys gaudryi*, *Bransatoglis astaracensis*, *Microdyromys* cf. *miocaenicus*, *Miodyromys hamadryas*, *Myoglis larteti*, *Muscardinus sansaniensis*, *Eomyops* sp., and *Keramidomys carpathicus* (Zapfe, 1949; Schaub & Zapfe, 1953; Fejfar, 1974; Sabol et al., 2004). However, only undetermined finds of rodent incisors are thus far known from the marine deposits of Devínska Nová Ves-Sandpit (also known as Neudorf-Sandberg; Thenius, 1952), dated to the late MN 6. Similarly, only *Eumyarion* sp. was known so far from nearby Bonanza site (Holec et al., 1987).

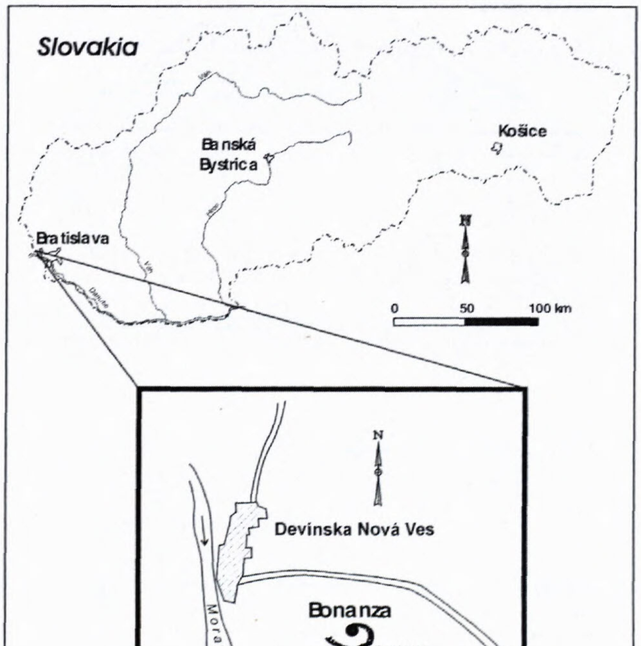


Fig. 1. Location of the Bonanza site on northern slopes of Devínska Kobyla Hill near Devínska Nová Ves (Neudorf) (according to Koretsky & Holec, 2002; partly modified).

The studied site is located at the eastern margin of the former Stockerau limestone quarry on the northern slope of the Devínska Kobyla hill near Devínska Nová Ves, a suburban part of Bratislava (a geographic co-ordinates of the site are 48° 12' N and 17° 01' E; Fig. 1). It is a broad fissure situated in the protective wall of Lower Jurassic limestone, oriented towards the railway line from Bratislava to Prague. Marine sands, sandstone, and large limestone boulders fill the fissure (Fig. 2). A detailed description of the site has been presented by Holec et al. (1987), who also mentioned rodent remains from marly to sandy deposits of layers Nr. 11 and 13 as well as from a vertical crevice of karsted debris on the left side of the exposed fissure (Fig. 2). The last research in 2001-2002 yielded fossils of eleven rodent taxa (*Spermophilinus bredai*, Sciuridae gen. et spec. indet., *Eumyarion* sp., ?*Megacricetodon* sp., *Democricetodon vindobonensis*, ?Cricetidae gen. et spec. indet., *Neocometes brunonis*, *Bransatoglis astaracensis*, ?Gliridae gen. et spec. indet., ?Eomyidae gen. et spec. indet., and Rodentia gen. et spec. indet.). Many of them represent the important finds from biostratigraphic viewpoint.

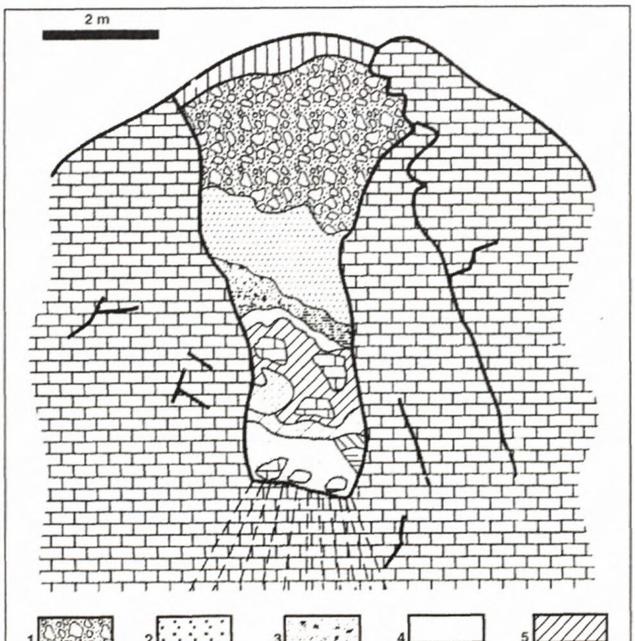


Fig. 2. Generalized section through the sediments of Bonanza (according to Ivanov, 1998).
1 – fine limestone debris; 2 – white lime sand; 3 – disaggregating sandstone with a higher content of muscovite; 4 – solid, light yellow marlstone with a great quantity of fossils; 5 – big boulders with white lime matter; 6 – greenish sand with interbeds of white lime matter; 7-11 – layers with coarse-grained, disaggregating sandstone without fossils to the fossiliferous marl, rich in fossils; 12 – white calciferous sandstone; 13 – yellowish-white sand with a large quantity of fauna; 14-17 – greenish to light sandstone, the biggest quantity of fossils are contained in the layer No. 17; a – Holocene humus-carbonate soil; b – Lias limestone; c – tectonic faults.

Apart from rodent remains, transgressive sandy sediments of the fissure also contain abundant marine and terrestrial vertebrates and invertebrates (Holec et al., 1987; Špinar et al., 1993; Ivanov, 1998; Koretsky & Holec, 2002; Sabol, *in press*). The fossil assemblage from the Bonanza site could be important in interregional correlations.

2. Material and methods

Former fossil remains of rodents were collected by amateur paleontologist Š. Meszároš in the 1980s. New material has been found by the screen washing of fossiliferous sediments in 2002. The studied material is a part of the fossil vertebrate collections of the Slovak National Museum - Natural History Museum (SNM-NHM; Meszároš ´s collections), and of the Department of Geology and Paleontology, Comenius University (DGP; new finds) in Bratislava.

Fossils were documented by magnifying using Carl Zeiss Jena binocular, drawing apparatus Meopta, and camera Nikon F-70, as well as scanned by SEM Philips XL30CP. They were measured partly according to methods of Anděra & Horáček (1982) and Daams & Freudenthal (in Freudenthal, 1988). All measured data are given in millimetres.

For terminology of tooth crowns, the papers of Bolliger (1992) for sciurids, Mein & Freudenthal (1971) for cricetids, Fejfar (1999) for platacanthomyines, and Daams (1981) for glirids are followed.

Abbreviations for the dimensions of the teeth and mandibles are: HM – height of the mandible, L – max. length of the tooth, LM – medial length, LOID – length of the lower tooth-row, Lm1-m3 – length of m1 – m3, W - maximum width of the tooth, WM – medial width.

3. Systematic paleontology

Family Sciuridae Fischer de Waldheim, 1817
Subfamily Sciurinae Fischer de Waldheim, 1817
Tribe Marmotini Pocock, 1923
Subtribe Spermophilina Moore, 1959
Genus *Spermophilinus* de Bruijn & Mein, 1968

***Spermophilinus bredai* (VON MAYER, 1848)**
Figs. 3 and 4

Material: m1 dext. (SNM-NHM, Z-14594, layer Nr. 13) and m2 sin. (SNM-NHM, Z-14593, layer Nr. 4).

Description: The unworn crown of right m1 is only slightly damaged. The metaconid is the largest cusp, with a distinct medio-anterior crest passing into the robust anterolophid. An antero-buccal syncline-like depression separates the damaged anteroconid from the conspicuous protoconid with the evident protolophid. Together with the anterolophid and a small crest between the protoconid and the anteroconid, it restricts a deep square-shaped depression. Between the protoconid and the distinct hypoconid, the small mesoconid with the tiny ectolophid is situated. The posterolophid consists of some small cusps, the largest of which is probably the entoconid(?). The mesostylid is not distinguishable. A deep dish-like basin

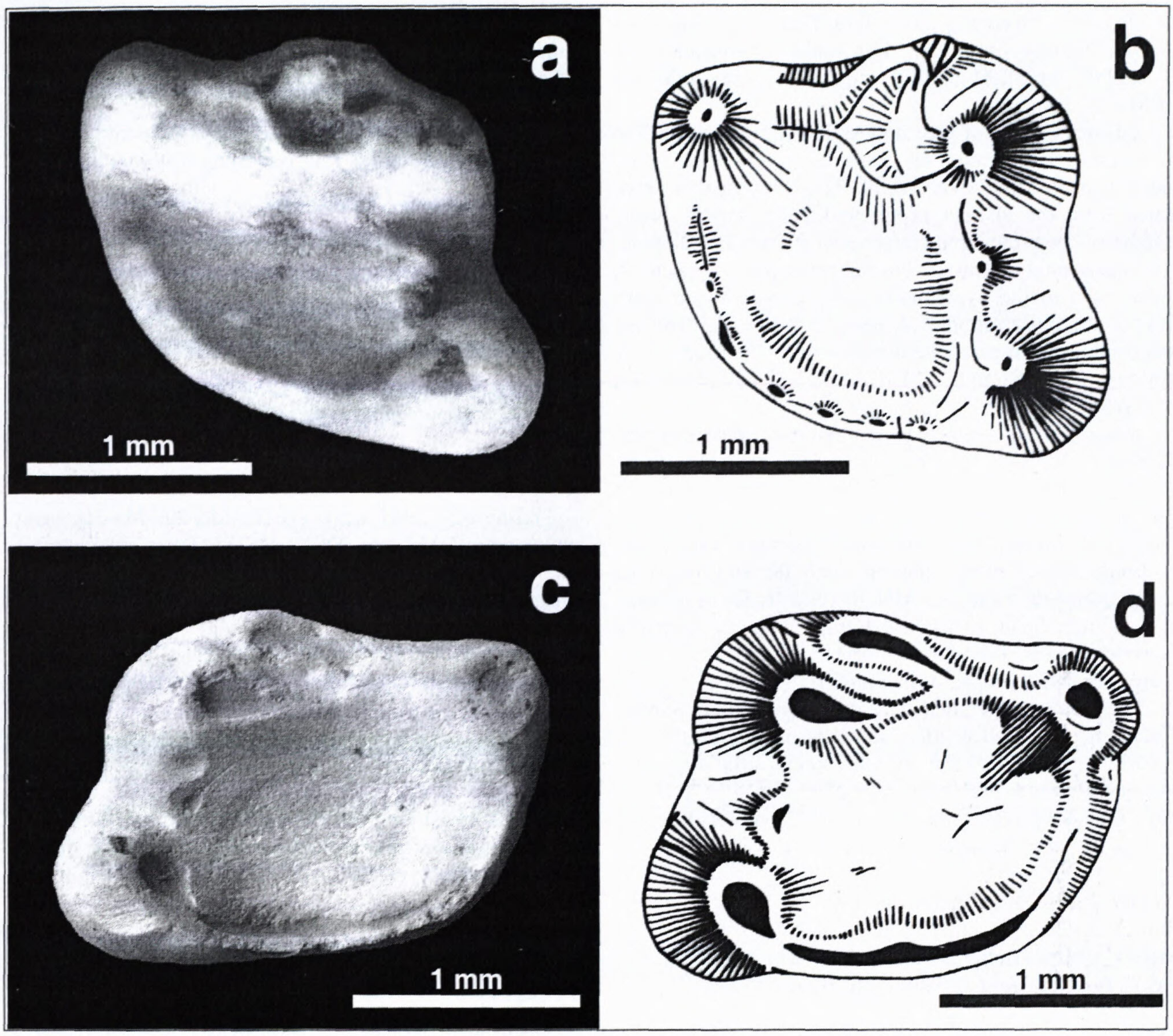
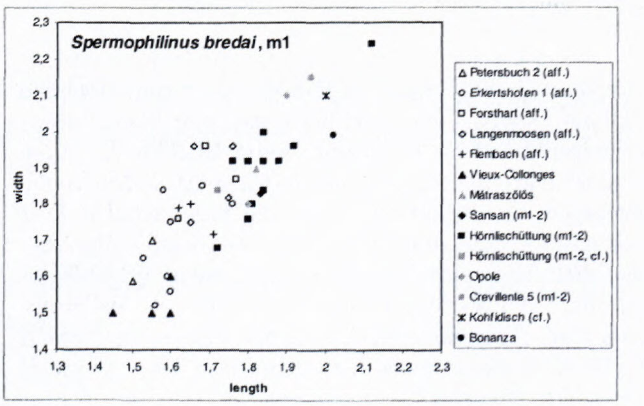


Fig. 3. *Spermophilinus bredai* (von Mayer, 1848), Late Badenian (MN 6), Bonanza. a-b) m1 dext. (Z-14594, occlusal view); c-d) m2 sin. (Z-14593, occlusal view).



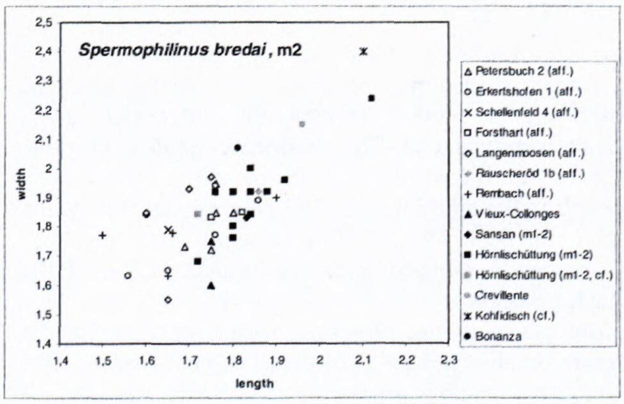


Fig. 4. Bivariate plot of molar (m1, m2) length/width of *Spermophilinus bredai* (used data: Bachmayer & Wilson, 1970; Baudelot, 1972; Bolliger, 1992; de Bruijn et al., 1975; Gál et al., 2000; Kowalski, 1967; Ziegler & Fahlbusch, 1986).

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is situated in the central crown part. From four roots, only one is entirely preserved. The molar dimensions are: L = 2.02 mm, LM = 1.76 mm, W = 1.99 mm, and WM = 1.73 mm.

All main cusps of the rootless left m2 are worn. The metaconid passes into the marginal anterolophid, connecting it with the anteroconid. This low cusp is separated from the distinct protoconid by a narrow basin. Medially, the protoconid connects to the tiny protolophid. The mesoconid is distinct, but the ectolophid is absent. A worn facet of the hypoconid nearly passes into a worn one of the posterolophid. A deep dish-like basin forms the central crown part. The dimensions of the tooth are as follows: L = 2.81 mm, LM = 1.58 mm, W = 2.07 mm, and WM = 2.03 mm.

Remarks: The genus *Spermophilinus*, described by Kretzoi (1951) as *Csakvaromys* and classified by de Bruijn (1999) to the tribe Tamiini, is one of the dominating ground squirrel genera in the European Neogene (MN 4 to MN 14; de Bruijn, 1999). From four species of this genus, *S. bredai* is the most common, with the stratigraphical range from MN 4 (aff.) to MN 10 (cf.). Its fossil records, known from Spain to Central Europe, show a relatively considerable variability in the morphology and size of teeth (Engesser, 1972; Ziegler & Fahlbusch, 1986).

The Bonanza specimens are rather larger than Sansan fossils, but they fall to the size-range of *Spermophilinus bredai*, showing also the morphological similarity with the fossil record of the Middle Miocene sites such as Anwil in Switzerland (Engesser, 1972) or localities in Hungary (Gál et al., 2000; Hír, 2001).

Family Cricetidae Rochebrune, 1883
Subfamily Cricetodontinae Schaub, 1925
Tribe Cricetini Fischer de Waldheim, 1817
Genus *Megacricetodon* Fahlbusch, 1964

?*Megacricetodon* sp.,
Fig. 5a, b, e, f

Material: Damaged left mandible with incisor (SNM-NHM, Z-14595, layer Nr. 17).

Description: The light-brown to brown hemimandible is slightly damaged in the posterior part. The hook-like coronoid process is tiny, whereas the condylar one is robust, with the broken posterior part and with a distinct blunt hump-shaped protuberance on the buccal side. The broken angular process probably formed a right angle with the condylar one. The masseteric fossa is shallow, extended up below the alveoli of m1 and distinctly bounded in the anterior part. The only mental foramen is close to the posterior part of the diastema. The mandibular foramen is situated over the ventral ramus of the condylar process.

The crown of the preserved lower incisor with the blackish dentine and the brownish enamel is worn, with an indistinct shallow groove on the labial side merging into an indistinct ridge. The bone between oval to round alveoli of the single molars is "serrated". Dimensions of the hemimandible are: HM (from the base to the coronoid process) = 6.35 mm and LOID = 3.60 mm.

Remarks: Exact determination of the hemimandible under study is more or less impossible because of the absence of molars. However, its appearance and the incisor texture distinctively indicate a cricetid, showing a close similarity with the *Democricetodon* record (see below). In spite of it, this find is slightly different: it is relatively more slender and longer, with the more blunt humpy protuberance on the buccal side of the condylar process and the more marked anterior part of the masseteric fossa; and the mental foramen is smaller and placed more nearly the diastema posterior margin. Thus, the including of the found molar-less hemimandible to the similar and relative genus of *Megacricetodon* is assumed.

Genus *Democricetodon* Fahlbusch, 1964
Democricetodon vindobonensis (Schaub & Zapfe, 1953)
Figs. 5c, d, g-r and 6

Material: 2 M1 dext. (DGP, MS-29, MS-30, layer unknown); 1 M2 sin. (DGP, MS-31, layer unknown); 1 m2 sin. (SNM-NHM, Z-14598, layer Nr. 13); and damaged left mandible with incisor and m1 – m3 (SNM-NHM, Z-14597, layer Nr. 17).

Description: The teeth, with generally light-brown low crowns, are unworn to worn and two of them (MS-30 and Z-14598) are damaged. Their roots are mostly broken off.

The anterocone of M1s (if preserved) is simple, undivided, and arched mesially. The anteromesoloph is slightly conspicuous. Other main cusps (protocone, paracone, hypocone, and metacone) are also clearly distinguishable. The protolophule I is not developed, while the protolophule II and the entoloph are evident. The long mesoloph extends to the tiny mesostyle and the metalophule is connecting to the metacone, which is posteriorly bordered by the marked posteroloph. The dimensions of molars are as follows: L = 1.62 mm (MS-29), W = 1.00 mm (MS-29), and 1.02 mm (MS-30).

The distinct anteromesoloph of the only M2 anteriorly borders the conspicuous paracone with the meander-like protolophule on the medial side. The mesoloph is long and narrow, extending almost to the buccal crown margin. The metalophule forms only a short spur on the postero-medial side of the metacone, merging into the marked posteroloph. L = 1.22 mm and W = 1.14 mm.

The broad anteroconid of m1 at the hemimandible is simple, undivided, merging into the short anterolophulid without clearly distinguishable spurs. The lingual cusps (metaconid and entoconid) are lower than buccal, more conical ones (protoconid and hypoconid). Whereas the metalophulid is short and wide, the mesolophid is long and narrow, extending to the blunt mesostylid. Opposite the short and wide hypolophulid, a small ridge (ecto-mesolophid?) is situated in the sinusid between the protoconid and the hypoconid. The partly worn posterolophid forms the postero-lingual margin of the crown. The molar dimensions are: L = 1.27 mm and W = 0.90 mm.

The anterolophid is distinct, situated on the mesial side of the both m2s. The metalophulid and the hypolophulid are almost symmetric, curved forward to anterior crown margin. The long and narrow mesolophid extends

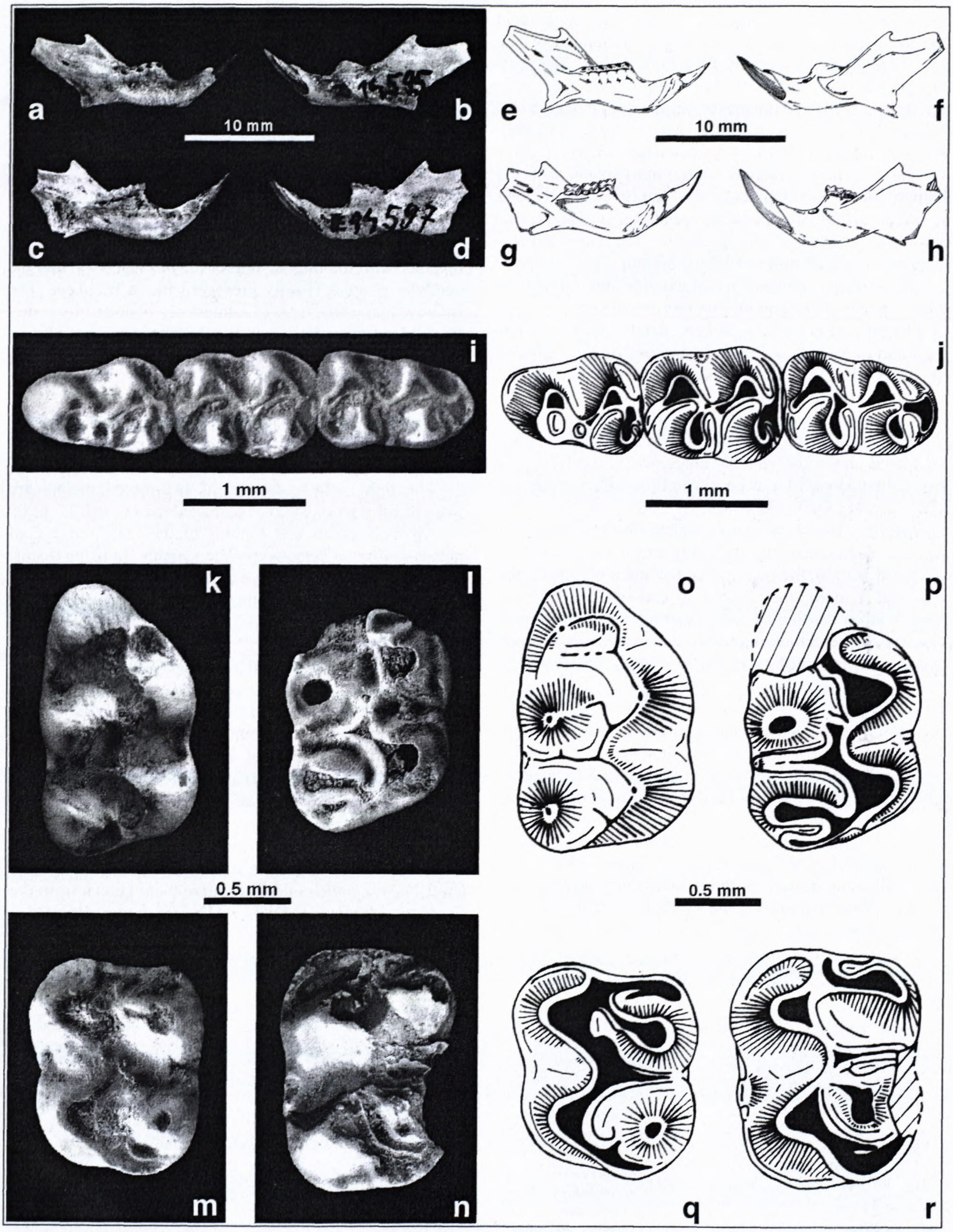

Fig. 5. ?Megacricetodon sp. and Democricetodon vindobonensis (Schaub & Zapfe, 1953), Late Badenian (MN 6), Bonanza. ?Megacricetodon sp.: a-b, e-f – left hemimandible (Z-14595, a, e – lingual view, b, f – buccal view).
Democricetodon vindobonensis (Schaub & Zapfe, 1953): c-d, g-h – left hemimandible (Z-14597, c, g – lingual view, d, h – buccal view); i-j – m1-m3 sin. (Z-14597, occlusal view); k, o – M1 dext. (MS-29, occlusal view); l, p – M1 dext. (MS-30, occlusal view); m, q – M2 sin. (MS-31, occlusal view); n, r – m2 sin. (Z-14598, occlusal view).

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up to the lingual crown margin. Between the protoconid and the hypoconid, the tiny ectostylid is situated on the buccal cingulid-like margin of the both molars. The posterolophid is conspicuous, forming the postero-lingual margin of the crown. The dimensions of the both molars are as follows: L = 1.18 mm (Z-14597) and 1.43 mm (Z-14598); W = 1.00 mm (Z-14597) and 1.12 mm (Z-14598).

The only m3 is relatively long and narrow, with the distinct short metalophulid, the faintly marked long mesolophid, and with the deep, rounded depression (posterosinusid) instead of the entoconid. The molar dimensions are: L = 1.22 mm and W = 0.86 mm.

An indistinct shallow groove extends along the labial side of the brown to grey-brown incisor enamel.

The light-brown damaged hemimandible has the short and blunt coronoid process, broken condylar and angular processes, and the shallow masseteric fossa, extending up below the anterior margin of m1, and with a blunt protuberance in the posterior part. The only mental foramen is situated below the diastema. The mandibular foramen is situated above the ventral ramus of the condylar process. Dimensions of the hemimandible are: Lm1-m3 = 3.72 mm and LOID ~ 3.80 mm.

Remarks: Based on morphological characteristics (the long mesoloph extending to the tiny mesostyle on the buccal crown margin; the presence of the anteromesoloph, the long and narrow mesolophid extending to the blunt mesostylid on the lingual crown margin; and the assumed presence of the ectomesolophid), the mentioned cricetids fossils are determined as *Democricetodon vindobonensis*, which mainly resemble *D. gaillardi* from the Sarmatian deposits (Fejfar, 1974). However, the type material, originally described by Schaub and Zapfe (1953) from Devínska Nová Ves-Fissures as *Cricetodon brevis vindobonensis*, is generally smaller than *D. gaillardi* (Schaub & Zapfe, 1953; Fejfar, 1974). Further, the Bonanza record is even smaller, when dimensions of found teeth fall into the range of *D. gracilis* (Fig. 6). Thus, it shows to the possibility of a wider metric variability of *D. vindobonensis*, indirectly validating a view on the assumed phylogenetic line *gracilis – vindobonensis – gaillardi* (Fejfar, 1974).

Subfamily Platacanthomyinae Alston, 1876
Tribe Platacanthomyini Stehlin & Schaub, 1951
Genus *Neocometes* Schaub & Zapfe, 1953

***Neocometes brunonis* Schaub & Zapfe, 1953**
Figs. 7 and 8

Material: Fragment of right mandible with m1 – m3 (SNM-NHM, Z-14596/1, layer unknown); 1 m2 dext. (SNM-NHM, Z-14596/2, layer Nr. 13?).

Description: The tawny hemimandible is very damaged – the coronoid and angular processes are broken off together with the lingual side of the *pars incisiva*, and the condylar process is only preserved like a fragment. The shallow masseteric fossa is anteriorly bounded by a distinct edge, extending below m1. The posterior of two mental foramens is larger. The distinct mandibular foramen is situated above the ventral ramus of the condylar process. LOID is approximately 5.10 mm.

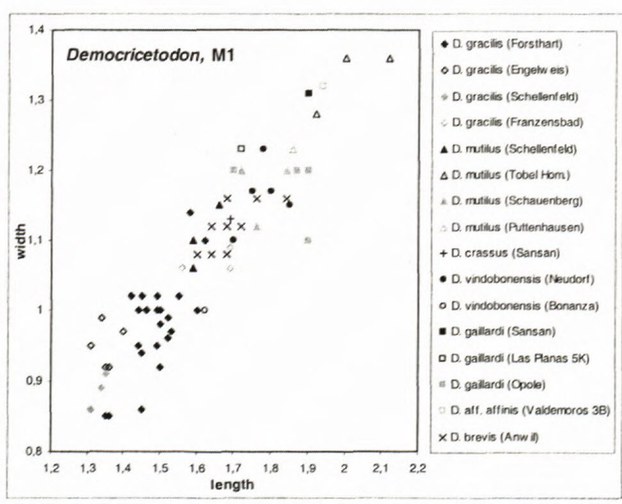
Only exposed posterior crown part of the lower incisor with blackish dentine and grey enamel is preserved. Its lingual side is nearly flat.

The light yellow crowns of two-rooted molars are worn to fully worn, such as damaged m1 (W = 1.23 mm).

All main cusps and lophids of the both undamaged m2s are worn to very worn. The syncline Ia is not distinguished. Other synclines are either deep or shallow; some of them (the syncline I in one case and the syncline IV of the both molars) are closed for the reason of deeper wear. Two roots of the loose m2 are posteriorly curved; the anterior root is longer and narrower than posterior one. The dimensions of the both m2s are as follows: L = 1.71 mm (Z-14596/1) and 1.81 mm (Z-14596/2), W = 1.24 mm (Z-14596/1) and 1.56 mm (Z-14596/2).

The triangular crown of m3 is damaged (a part of the posterior side is broken off) and very worn. Thus, all synclines (with the exception of the syncline III) are closed. The mesial margin is posteriorly arched. The dimensions of the molar: L = 1.36 mm and W = 1.16 mm.

Remarks: Two species of platacanthomyine rodents (*Neocometes similis* and *N. brunonis*) are known from the European Miocene (MN 3? – MN 7/8; Fejfar, 1999) to-



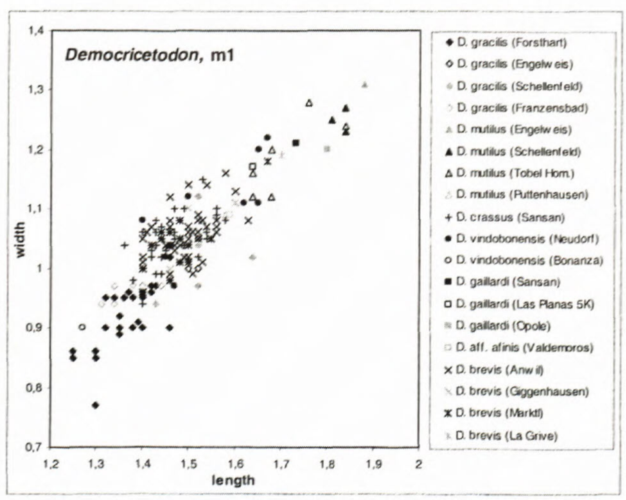


Fig. 6. Bivariate plot of molar (M1, m1) length/width of *Democricetodon*-species from the Miocene of Europe (used data: Baudelot, 1972; Bolliger, 1992; Engesser, 1972; Fejfar, 1974; Freudenthal & Daams, 1988; Kowalski, 1967; Schaub & Zapfe, 1953; Ziegler, 1995; Ziegler & Fahlbusch, 1986).

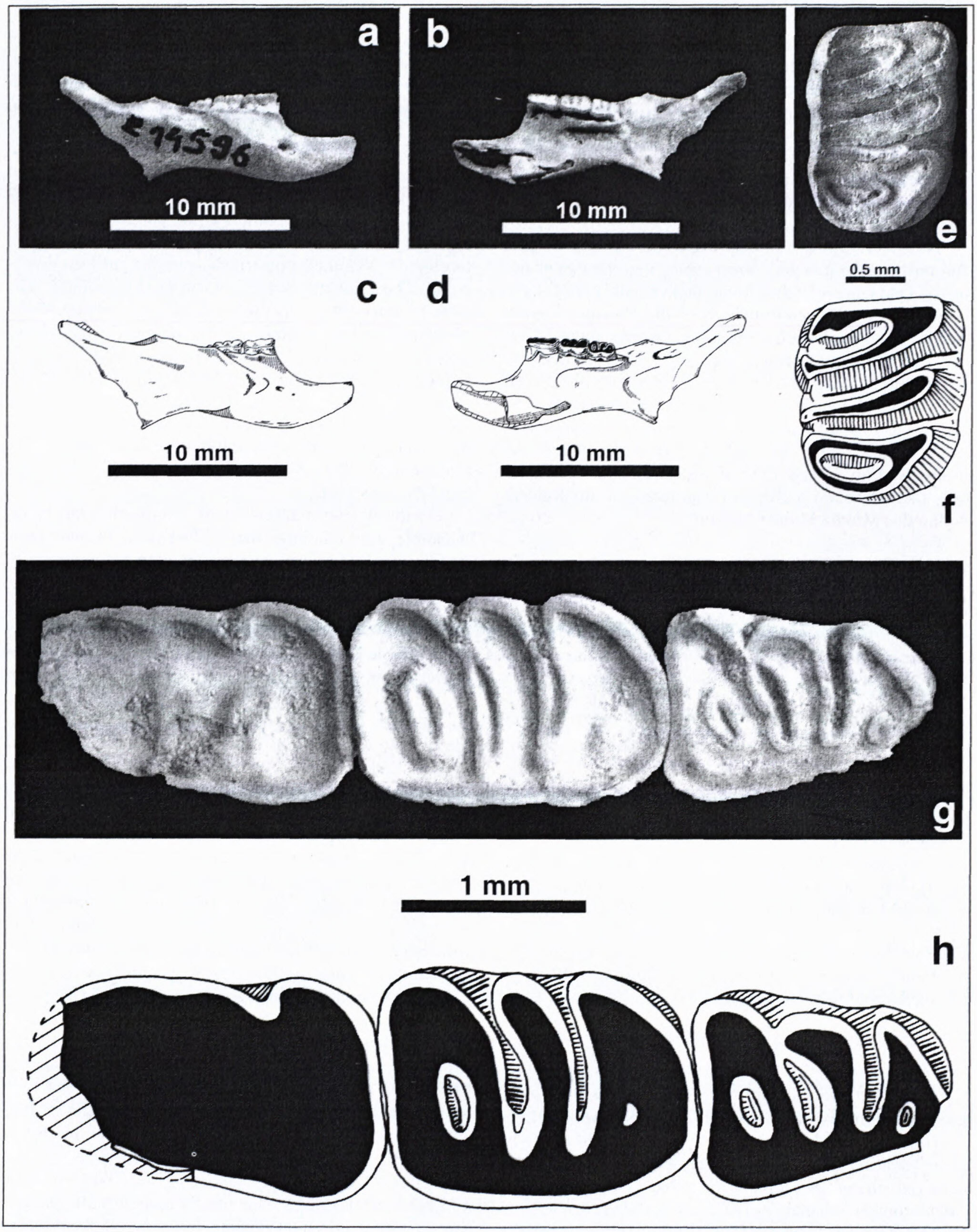


Fig. 7. *Neocometes brunonis* Schaub & Zapfe, 1953, Late Badenian (MN 6), Bonanza.
a-d: right hemimandible (Z-14596/1; a, c – buccal view, b, d – lingual view); e-f: m2 dext. (Z-14596/2; occlusal view); g-h: m1-m3 dext. (Z-14596/1; occlusal view).

gether with some close relative forms (e.g. *N.* cf. *similis* or *N.* aff. *brunonis*) from MN 5 sites of Czech Republic, Germany, or Switzerland (Ziegler, 1995; Fejfar, 1999). Although the sequence of these taxa does not display significant changes in the molar pattern, there is possible to detect some evolution trends in dental morphology, especially in the diagnostic anterior parts of the first both lower and upper molars (Fejfar, 1999), when two morphotypes (A and B) are distinguishable (Fejfar, 1974).

Found m1, however, is damaged in its anterior part and furthermore it is very worn. Thus, morphological and metric characters of other found teeth (mainly m2s) have been used for the determination of the Bonanza record. According to Fahlbusch (1966), none fundamental differences in the dental morphology are known between *N. similis* and *N. brunonis*. The both species only differ each other by the dimensions of their teeth, when molars of *N. similis* are smaller than these of *N. brunonis*. The dimensions of the found m2s fall to the size-range of *N. brunonis* (Fig. 8) and furthermore, they can reflect not only the metric variability but also a sexual dimorphism within this Middle Miocene species.

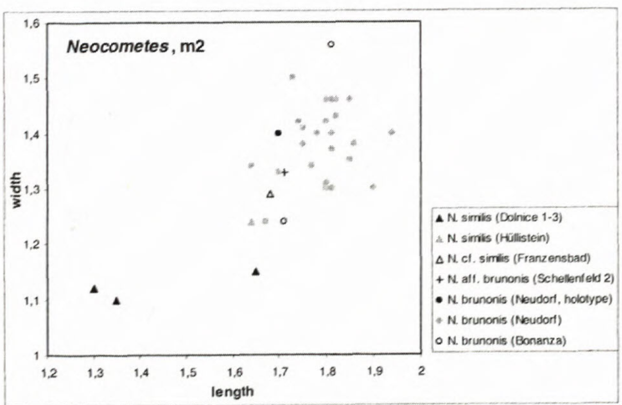


Fig. 8. Bivariate plot of m2 length/width of *Neocometes* - species from the Miocene of Europe (used data: Bolliger, 1992; Fejfar, 1974; Schaub & Zapfe, 1953; Ziegler, 1995).

Family Gliridae Thomas, 1897
Subfamily Bransatoglirinae Daams & De Bruijn, 1995
Genus *Bransatoglis* Hugueney, 1967

Bransatoglis astaracensis **(Baudelot, 1970)**
Figs. 9, 10 and 11

Material: Damaged left hemimandible with broken incisor, m1 and m3 (SNM-NHM, Z-14599, layer Nr. 13).

Description: The broken lower incisor with the light tawny dentine and the black enamel is exposed on the damaged lingual side of the mandible ramus. Its buccal side is convex, whereas its inner one is flattened.

The rounded crown of m1 with concave occlusal surface is faintly worn and damaged on the lingual side. The narrow anterolophid turns posteriorly in its buccal part. Other main dental ridges are straight (metalophid and mesolophid) or arched posteriorly (posterolophid), with expanded their buccal terminations (protoconid, mesoconid, and hypoconid). The centrolophid is isolated, whereas the both anterior and posterior extra ridges were probably connected with the ridge on the lingual crown side. Also, the metalophid was probably connected with the broken metaconid in the anterior crown part. The ridges are separated by the deep and narrow, buccally opened valleys. The dimensions of the molar are as follows: L = 1.74 mm, LM = 1.71 mm, and W = 1.84 mm.

The faintly worn and damaged rounded crown of m3 is tapering posteriorly. Whereas the anterolophid, metalophid, and mesolophid are narrow and straight, the posterolophid is arched posteriorly, passing into the hypoconid. The relatively short centrolophid is isolated. The anterior extra ridge was probably not connected with the metaconid and the posterior extra ridge is divided to two small isolated cusp-like parts. The entoconid is a small indistinct cusp on the postero-lingual border of the crown. The ridges are separated by relatively shallow valleys, opened on the buccal side (the valley between the metalophid and mesolophid is also opened on the lingual side). The molar dimensions are: L = 1.54 mm and W = 1.54 mm.

On the damaged fragment of the massive left hemimandible, only one large mental foramen, situated below the diastema, is preserved together with anterior part of the shallow masseteric fossa. Lm1-m3 is 5.07 mm.

Remarks: Individual species of *Bransatoglis* differ by dimensions of teeth and their morphology, especially of M1-2 (de Bruijn, 1998). The find under study corresponds most of all to the Miocene species *B. astaracensis*, known from Sansan, Anwil or La Grive, and also supposed in Devínska Nová Ves (Neudorf) by Engesser (1972). However, the Bonanza record differs from Anwil and Sansan specimens by both, the bigger measurements of m1 and lesser morphological differences, such as isolated centrolophid. On the other hand, the occlusal morphology of lower molars is very variable (Engesser, 1972) and various occlusal patterns of the main ridges and extra ones are noted depending on the stage of wear. For that reason, the find of dormice hemimandible with the dentition is determined as fossil remains of *B. astaracensis* in spite of the bigger molar dimensions, indicating probably a more robust specimen only.

Apart from aforementioned fossil record, 24 loose rodent incisors of various measurements and different morphological characters have been found too (Figs. 12 and 13). They were compared with found incisors situated in above-mentioned finds of mandible fragments and with specimens from the collection of Prof. O. Fejfar in Prague. Based on this comparison, some taxa can be distinguishable:

Sciuridae gen. et spec. indet. – four large incisors (3 upper and 1 lower) with mostly smooth dark enamel, smooth or striated light dentine and with elliptical cross-section (the cross-section of one upper incisor (deciduous?), is rhombic). They cannot be assigned to found sciurid species *Spermophilinus* (*Csakvaromys*) *bredai* because the anterior surface of its incisors is striated (Fejfar & Kretzoi, *in press*). Remains of this species were also found together with fossils of *Blackia miocaenica* in near

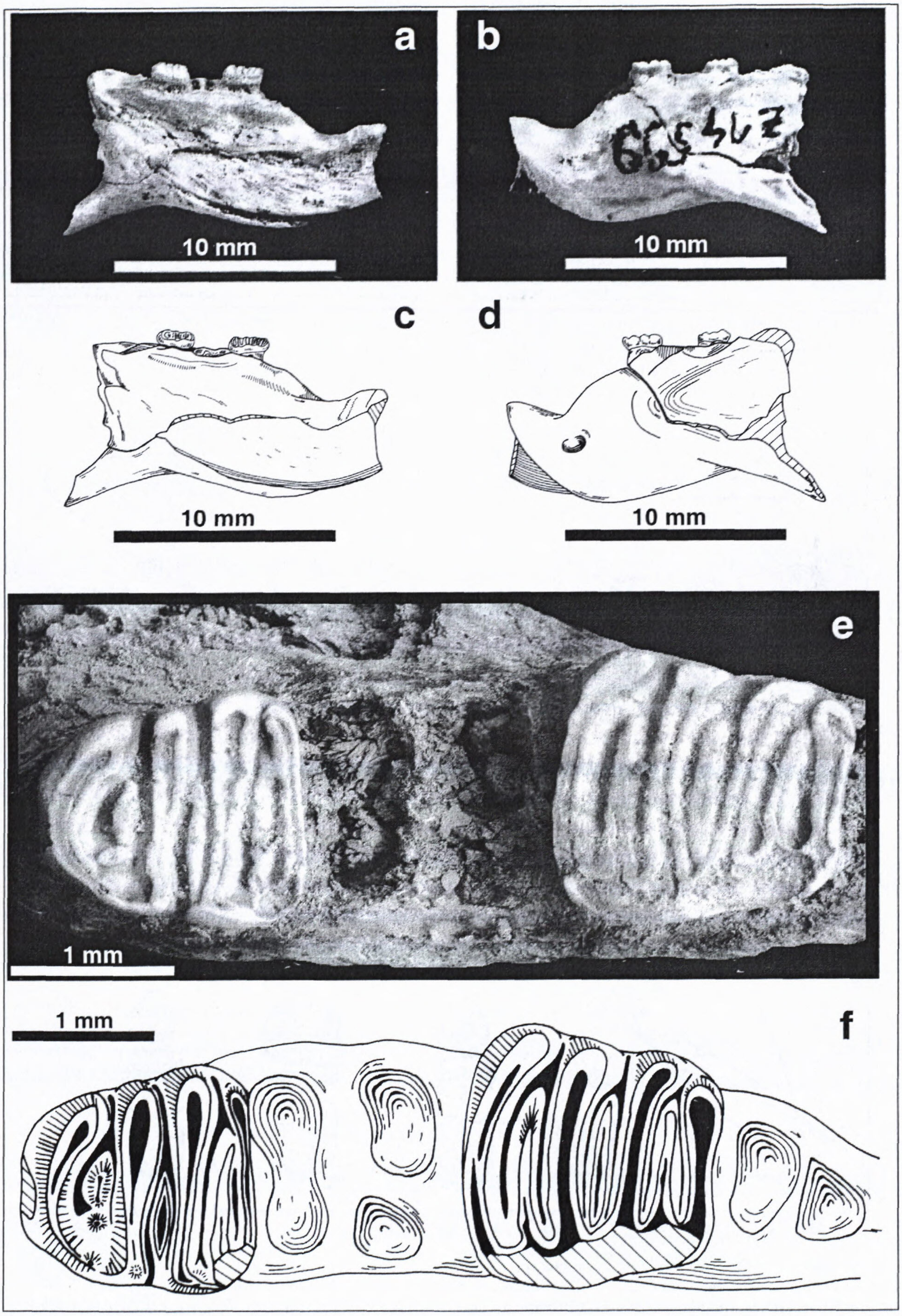


Fig. 9. *Bransatoglis astaracensis* (Baudelot, 1970), left hemimandible with broken incisor, m1 and m3 (Z-14599) from Late Badenian deposits of Bonanza. a, c: lingual view; b, d: buccal view; e-f: detail view to the occlusal surface of preserved molars.

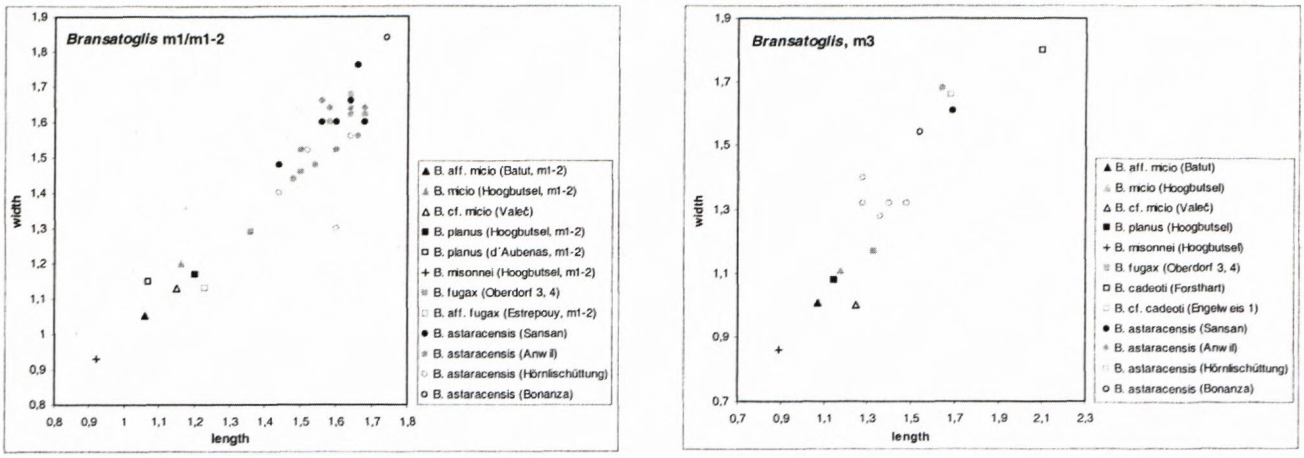


Fig. 10. Bivariate plot of molar (m1, m1-2, m3) length/width of *Bransatoglis*-species from the Tertiary of Europe (used data: Bolliger, 1992; de Bruijn, 1998; Bulot, 1980; Engesser, 1972; Fejfar et al., 1994; Vianey-Liaud, 1994; Ziegler, 1995; Ziegler & Fahlbusch, 1986).

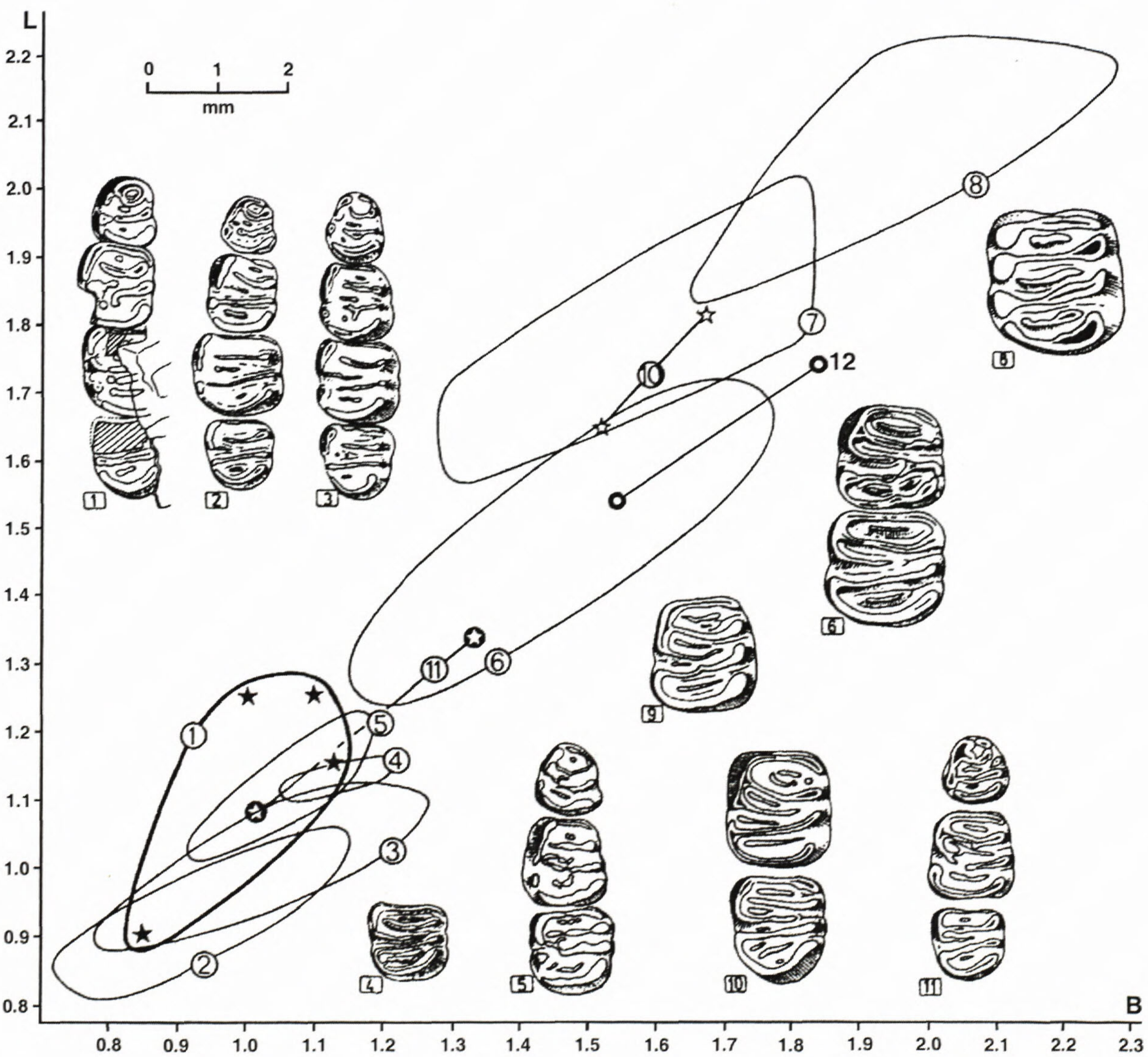


Fig. 11. Measurements of lower dentition of various species of *Bransatoglis* from the European Oligocene and Miocene (in mm; according to Fejfar et al., 1994; modified). 1 – *Bransatoglis* cf. *micio* from Valeč-Waltsch; 2 – *B. bahloi* from Isle of Wight; 3 – *B. micio* from Hoogbutsel; 4 – *B. planus* from Heimersheim; 5 – *B.*cf. *micio* from Charbon; 6 – *B. astaracensis* from Sansan and Anwil; 7 – *B. spectabilis* from Wintershof-West; 8 – *B. cadeoti* from Bézian and La Romieu; 9 – *B. concavidens* from Paulhiac; 10 – *B. concavidens* from Coderet-Bransat; 1 – *B. fugax* from Coderet-Bransat; 12 – *B. astaracensis* from Devínska Nová Ves-Bonanza.

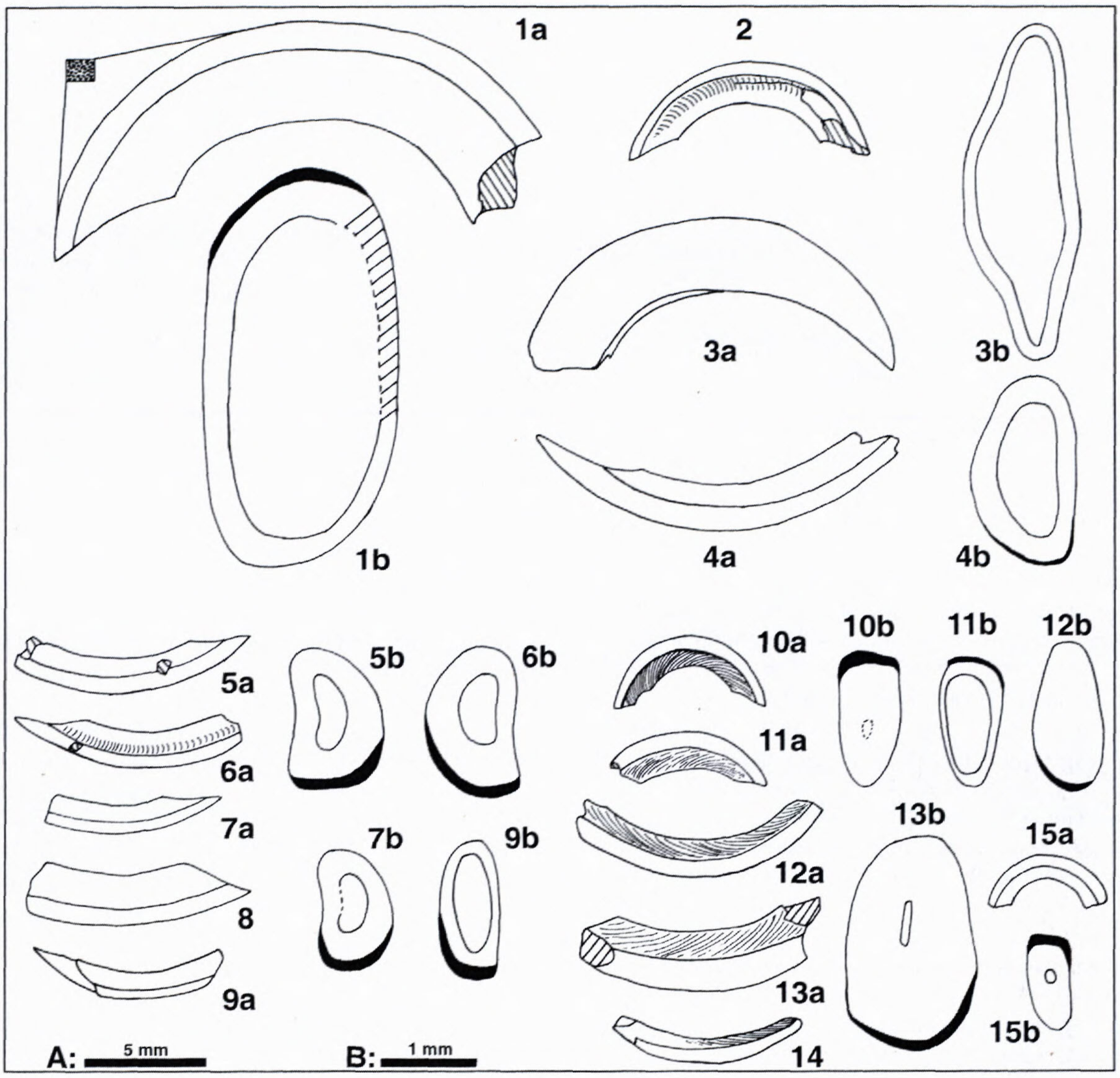


Fig. 12. Upper and lower incisors of rodents from the Late Badenian deposits of Bonanza.
1-4: Sciuridae gen. et spec. indet. (3 – incisor of a juvenile); 5-8: *Eumyarion* sp.; 9: Cricetidae gen. et spec. indet.; 10-14: Gliridae gen. et spec. indet.; 15: Eomyidae gen. et spec. indet.
a – lateral views, b – cross-sections; scales: A for incisors in lateral view, B for cross-sections of incisors.

Devínska Nová Ves-Fissures. However, no incisors of the latter sciurid have been seen, and so, finds of loose sciurid incisors from Bonanza are thus so far determined to the family level only. Furthermore, their metric differences probably indicate the occurrence of 2 to 3 taxa of squirrels on the site.

Eumyarion sp. – five lower incisors with characteristic two distinct longitudinal "grooves" on the anterior surface determine this large cricetid. Two species (*E. weinfurteri* and *E. latior*) of the genus are known from the nearby type-site Devínska Nová Ves-Fissures (Fejfar, 1974), but no molars have been found in Bonanza so far.

?Cricetidae gen. et spec. indet. – besides of five *Eumyarion* incisors, also one smaller damaged lower incisor with the only distinct longitudinal "groove" on the anterior surface followed by a marginal one was found in sample from Bonanza. It probably belongs to some of lesser cricetids (*Democricetodon*?, *Megacricetodon*?).

?Gliridae gen. et spec. indet. – the enamel of two upper and three lower incisors is smooth, whereas a texture of oblique lines is situated on the surface of their light dentine and its origin is probably connected with the growth of the incisor(-s). This texture is observed in incisors of glirids, but also in incisors of *Neocometes*. A difference among incisors of the both taxa could be seen in cross-sections of these teeth – the cross-sections of dormice incisors are more elliptical than those of platacanthomyine ones. However, findings of unbroken incisors in toothed jaws (or in their fragments) are necessary for more exact determination.

?Eomyidae gen. et spec. indet. – one upper incisor, the smallest of all, with smooth enamel and elliptical cross-section probably belongs to unknown eomyid.

The remaining 8 loose incisors are only determined as Rodentia gen. et spec. indet. because of their fragmentary.

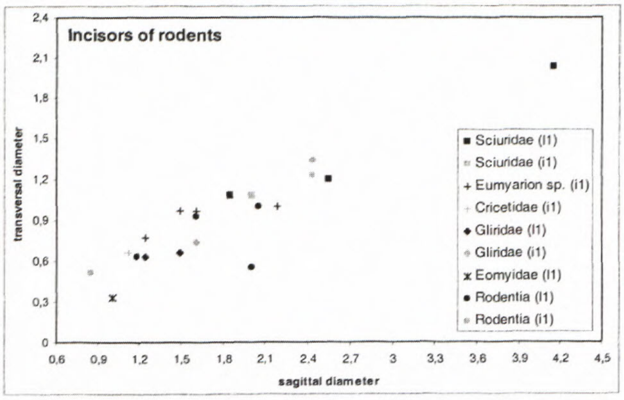


Fig. 13. Bivariate plot of incisor sagittal diamater/transversal diameter of rodents found in Devínska Nová Ves-Bonanza.

4. Biostratigraphic considerations

Rodents have a good stratigraphic value and they serve for biostratigraphic correlations over the world. The stratigraphic ranges of four species found in Bonanza are outlined in order according to de Bruijn (1999), Kälin (1999), Fejfar (1999) and Daams (1999).

The stratigraphic range of *Spermophilinus bredai* is mainly from MN 6 to MN 8, though slightly smaller *S.* aff. *bredai* is also known from MN 4 (e. g. Petersbuch 2 or Erkertshofen 1) and MN 5 sites (e.g. Forsthart, Langenmoosen, Rauscheröd 1b, Rembach or Schellenfeld 4; Ziegler & Fahlbusch, 1986). Also, slightly larger form is known from later periods (e.g. *S.* cf. *bredai* from MN 10 site of Kohfidisch; Bachmayer & Wilson, 1970). The lesser form probably represents an ancestor for *S. bredai*, whereas larger one can represent a descendant of the Middle Miocene populations. The Bonanza finds represent a typical form from the Middle Miocene.

Democricetodon vindobonensis is only known so far from the type-site Devínska Nová Ves-Fissures, dated to lower part of MN 6 zone.

The genus *Neocometes*, as an Ottnangian immigrant (Fejfar, 1974), is known in European Miocene from MN 3 to MN 7/8 in two species. Fossils of the stratigraphically younger of them, *N. brunonis*, come from deposits dated from MN 6 to MN 7/8, though close relative form (*N.* aff. *brunonis*) is known already from MN 5 sites (e.g. Schellenfeld 2; Ziegler, 1995), representing probably an ancestor of the Astaracian species.

The stratigraphic range of *Bransatoglis astaracensis* is from the Early Miocene (MN 4) to the Late Miocene (the last occurrence of this species is known from MN 9 in Spain; Daams & de Bruijn, 1995).

Based on the stratigraphic range of the determined rodent species from Bonanza, the age of this found assemblage can be correlated with MN 6 zone, what it also supported by record of insectivores from the same site (Sabol, *in press*). However, on the basis of lithological circumstances, the Bonanza represents a site from later period than a nearby locality Devínska Nová Ves-Fissures (Holec et al., 1987), whose faunal assemblage is dated to the lower part of MN 6 zone (upper part of the Middle Badenian; Fejfar, 1990, 1997).

5. Paleoenvironmental aspects

Besides their biostratigraphic value, rodents can also serve as relatively good indicator of paleoenvironmental conditions.

The squirrel *Spermophilinus* was probably a ground dweller (de Bruijn, 1999) of forested environments, preferring closed, relatively humid biotopes (van Dam & Weltje, 1999). However, Bolliger (1992) also do not exclude the arboreal mode of life for this Miocene genus. Extant close relatives of *Spermophilinus* are adapted to more cool environmental conditions.

The family Cricetidae represents relatively heterogeneous group, preferring both open and closer habitats (van Dam & Weltje, 1999). From found genera, *Eumyarion* is assumed to have preferred wet habitats and probably it was a dweller of proximal areas of alluvial fans (Kälin, 1999), whereas some *Megacricetodon* species probably preferred wet biotopes and others were indifferent (Daams et al., 1988). In the case of Bonanza, where aquatic vertebrates have been found together with terrestrial ones (see below), determined cricetids (*Democricetodon vindobonensis*, ?*Megacricetodon*, and *Eumyarion*) probably lived in the humid and warm habitat.

The genus *Neocometes* is the only Miocene representative of rodents with living close relatives (*Platacanthomys* and *Typhlomys*). The both extant genera are arboreal, living either in the rocky forests of Southern India (*Platacanthomys*) or in forested slopes of mountains with dwarfed, moss-laden deciduous trees and small bamboos in undergrowth in SE China (*Typhlomys*; Walker et al., 1968). The paleoecology of *N. brunonis* was probably similar – it was an arboreal rodent with frugivorous and granivorous diet, living probably in drier conditions (frequent records in karstic areas). However, the Spanish record of *N. similis* indicates also a humid habitat (Fejfar, 1999).

Representatives of the extinct subfamily Bransatoglirinae (*Bransatoglis astaracensis*) belong among arboreal/scansorial glirids, dwelling in sub-canopy to canopy of humid forests. Also, a preference for cool-warm seasonality is ascribed to this group of dormouses (van Dam & Weltje, 1999).

The eomyids are considered to have been gliding dwellers of humid forest biotope with high trees. However, the interpretation of all eomyids as gliders could be erroneous (Engesser, 1999). On the other hand, the simultaneous occurrence with *Spermophilinus* can confirm the hypothesis on their preference of close vegetation habitat (van Dam & Weltje, 1999).

The rodent assemblage under study generally indicates a forested environment. However, in detailed paleoenvironmental reconstruction, the whole fossil assemblage should be analysed. Besides rodents, representatives of Erinaceidae, Talpidae (including Desmaninae), Dimylidae, Soricidae, Viverridae, Phocidae, Mustelidae, Chiroptera, Cervidae, and Mammutidae are known from the site. Reptiles, frogs, fishes, sharks, and marine bivalves belong among relatively frequent fossil finds as well. Thus, the composition of the whole Bonanza assemblage refers to a mixed one living in an insular or peninsular area, covered by a subtropical forest with freshwater lagoons or marshes in near vicinity of a prograding sea. The record of terrestrial (reptiles and land mammals), freshwater (frogs) and semi-marine (seals) to marine (sharks and fishes) vertebrates could serve as a good evidence of this assumption.

Site	Number of rodent taxa								Reference
	Sciuridae	Petauristidae	Cricetidae	Anomalomyidae	Gliridae	Eomyidae	Castoridae	Index of similarity	
Faluns Pont Levoy	1	1	5	–	1	–	1	0.57	de Bruijn et al., 1992
Hambach 6C	4	3	8	–	10	3	3	0.39	Mörs et al., 2000
Sansan	3	2	6	–	5	1	2	0.44	de Bruijn et al., 1992
Neudorf-Spalte	1	1	8	1	5	2	–	0.55	Sabol et al., 2004
La Grive	2	4	9	1	6	2	–	0.31	de Bruijn et al., 1992
Anwil	2	4	9	1	11	3	1	0.43	Engesser, 1972
Bonanza	2	–	5	–	2	1	–	–	

Tab. 1. The number of rodent taxa from some Middle Miocene European sites and the comparison of similarity of individual assemblages with Bonanza sample on the basis of calculated Sorensen Index (2B/(F1+F2)).
B – number of common genera; F1 – number of genera from the first compared site; F2 – number of genera from the second compared site (Bonanza).

6. Composition of rodent assemblage

The European Miocene rodent assemblages display the larger diversity than extant rodent fauna, which is impoverished of some extinct and/or exotic taxa (e.g. eomyids, anomalomyids or flying squirrels) in comparison with the fossil record. However, the number of rodent taxa and the composition of individual fossil assemblages frequently vary both in space and time. Despite the incompleteness of fossil record, this compositional variability can be evoked by various factors, mainly by environmental and climatic changes.

From the viewpoint of the similarity of assemblages from some important European sites dated from MN 5 to MN 8 (Tab. 1) on the level of rodent genera, the Bonanza rodent assemblage displays the largest analogy especially with that of Devínska Nová Ves-Fissures (the high similarity of Bonanza rodent assemblage with the rodent assemblage of Faluns Pont Levoy – Thenay (MN 5) is probably caused by the lower diversity of the both sites). The difference is only observed in the larger number of both the cricetid and glirid taxa in the Devínska Nová Ves-Fissures locality and in the absence of anomalomids in deposits of Bonanza. This decrease of diversity in Bonanza rodent assemblage can probably be related to the paleoecological changes caused by the Late Badenian transgression in the territory of Devínska Kobyla hill.

The rodent assemblages of Sansan (MN 6) and Anwil (MN 8) display also relatively great index of similarity with the Bonanza sample. However, detailed comparisons are more or less limited, as the rodent fossil record from the site under study is very scarce.

7. Conclusions

The eleven taxa of rodents (*Spermophilinus bredai*, Sciuridae gen. et spec. indet., *Eumyarion* sp., ?*Megacricetodon* sp., *Democricetodon vindobonensis*, ?Cricetidae gen. et spec. indet., *Neocometes brunonis*, *Bransatoglis astaracensis*, ?Gliridae gen. et spec. indet., ?Eomyidae gen. et spec. indet., and Rodentia gen. et spec. indet.) were found in the Bonanza site. This rodent assemblage comprises several faunal elements known also from nearby Devínska Nová Ves-Fissures site, dated to the Middle Badenian (early MN 6 zone).

The composition of the Bonanza rodent assemblage, supported by the record of the whole mammalian assemblage, validated the assumed Late Badenian age of the site (MN 6).

Found rodents indicate a forested subtropical environment with neighbouring freshwater lagoon, marsh or delta, situated in insular or peninsular area on the eastern side of the Vienna Basin.

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Raw material aspects of the Neolithic pottery (Slovak Republic): Multi-analytical results

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Abstract. Paper presents results of multi-analytical study of the Neolithic/Aeneolithic pottery shards from several archaeological sites located mostly in the south-western part of the country. On the set of 18 earth ware fragments the thin sections study has been realized. Based on its result several fragments were chosen for X-ray diffraction analysis, stereoscopic electron microscopy, Mössbauer spectroscopy as well as archaeomagnetic measurements. Based on significantly preferrently oriented prolonged pieces of the used temper constituents, namely around both (convexe and concave) rims of shards, we assume that the most of ceramic earthwares have been made using turntables that permit rotary motion (being an ancestor of the potter's wheel?).

In the majority of pottery fragments studied – relative high amount of organic (grass, straw) up to 10 mm long pieces of temper were identified. After firing/annealing mostly (empty/hollow), "tunnel-like" or by amorphous $SiO_2.nH_2O$ gels filled up voids are preserved. Neolithic pottery was annealed in oxidizing and also in reducing conditions. The presence of charred matter (soot) of organic origin together with the presence of illite-smectite phyllosilicates identified by the X-ray diffraction analysis and low to very low grade of sintering of the pottery groundmass – allow us to suppose low temperature conditions (approx. 600-650° C) of the pottery firing/annealing.

Key words: Neolithic low-fired pottery, raw materials, multi-analytical results

Introduction

Archaeology concerns with a study of the material remains on the man's activities in the antiquity. These remains may be tools, weapons, utensils, decorative implements or even monuments. In the last decades the archaeometric research involves the physical as well as biological sciences applied to the problem of archaeology. Concerning the paleoceramics several comprehensive monographies (Shepard, 1956; Peacock, 1970; Olin and Franklin, 1982; Rice, 1987 and others) were published.

Ceramic/pottery represents one of the earliest and the most significant innovation of the prehistoric man activities. As a result of the potter's activities in preparing pastes, after already shaped vessels by their firing the more-or-less metamorphic rock like material originates. So application of geosciences laboratory methods led to establishing of specialized "ceramic petrography".

Interdisciplinary/transsectorial approaches, in this multi-analytical study, applied in study of ancient ceramic shards, were used. Such complex study is realized mostly at present (e. g. Maritan, 2004). It is generally accepted that combination of complementary results of various methods can provide much more reliable explications than the use of a single technique. Such a complex study leads in general to a better understanding of the cultures growth, their spread, and regress including development of various technologies. Methods for the examination of artefacts have been deve_loped from simple visual studies and their relation to the written record, to the sophisticated modern techniques of archaeometry.

Human tribes activities, and namely reached level of mental and physical abilities are studied also via physical implements found also on the territory of nowadays Slovakia. They were made from two principal abiotic raw material categories: from hard (e. i. eruptive and metamorphic) rocks and minerals on one side and from clays on the other one. Comparison of the style and technology concerning elaboration of above raw material types enables us to rank any studied implement to sophisticated generally used time-table.

Meanwhile stone raw materials used namely in the Neolithic were studied in the last decade (Hovorka and Illášová, 2000; Hovorka et al., 2002; Spišiak and Hovorka, in print; and the others) systematically, pottery shards were studied sporadically only. Exceptions are presented in pioneering works by Bareš and Lička (1976), Sitek et al. (1980), Lipka et al. (1990), Pawlikowski (1999) and Hovorka et al. (2002), respectively.

We present results obtained using the following laboratory devices and methods of study: stereomicroscopic observations of the artefacts fresh surface fracture topography, thin sections studies under polarizing microscope, results of which are documented by thin sections micrographs, X-ray diffraction studies presented by X-ray patterns, scanning electron microscope patterns of pottery shards, Mössbauer spectroscopy and archaeomagnetic measurements. Results of the last mentioned methods are presented in the form of appropriate diagrams and patterns.

Archaeological background of the pottery shards studied

Many of the identification techniques in archaeometry are now relatively well developed. Among them belong also geosciences identification laboratory methods. Their results are presented below. Pottery fragments were studied from the following archaeological sites from western Slovakia (Fig. 1).

Fig. 1. Location of sites wherefrom pottery shards were studied 1 – Žlkovce, 2 – Podolie, 3 – Kuzmice, 4 – Výčapy-Opatovce, 5 – Santovka, 6 – Svodín, 7 – Bíňa, 8 – Štúrovo

Žlkovce

The rescue field survey of the site has been realized after its discovery during the highway construction in the early 1980s. The settlement belonging to the Lengyel culture has been uncovered. The other cultures, older as well as younger ones, are smaller by their areal extent and meaning. The site is located on loess table between the Malé Karpaty Mts. and the river Váh, approximately 15 km to the NE of the Piešťany town. The main time period of settlement inhabitation belongs to the Lengyel II stage, which is characterized by white painted ceramics. Discussed archaeological site by its extent, number of objects, inventory of its stone implements and ceramic fragments is unique for this stage of the Lengyel culture (Pavúk, 1998). Later on a part of the Lengyell II culture site was covered by younger cultures (Baden culture, the Bronze Age settlement of the Nitra group, up to German culture, as well (Němejcová-Pavúková, 1986).

Studied fragments:

I - 8-10 mm walled uneven thick grey fragment, on the convex side with light brown rim, Lengyel culture, stage Lengyel II

N - 6-8 mm walled fragment of grey colour with transition to the brown one in direction to the fragment rim, Lengyel culture, stage Lengyel II.

Podolie

This site of the Bošáca group for the first time has been reported in 1964 based on systematic field survey realized by Němejcová-Pavúková in 1963. No consequent studies were realized, so the information on the site are still poor.

D - 9 mm walled dark-grey fragment, on the convex side with 1.5 mm brownish rim, seldom also dark relics after fired grass (straw) are observable; Bošáca group.

Kuzmice

The eastern Slovakia site Kuzmice belongs to the Lengyel culture and the Bronze Age. The studied ceramic fragments document the Lengyel III stage, phase Moravany.

K – 16-18 mm thick-walled fragment. In central part of grey, on rims of light-brown colour, which just on the rim gradually pass to dark-brown tint. High amount of clastic light micas being constituent of temper.

Výčapy-Opatovce

This polycultural site is located to the north of the Nitra city on the bank of the river of the same name. Field survey was carried out by Točík and Porubský in years 1951-1954. They discovered 8 tombs of the Ludanice as well as more than 300 tombs of the Nitra group. But settlement of mentioned ranking partly destroyed older settlement belonging to linear ceramic with ceramic relics belonging to the Želiezovce, Bükk and Tisza cultures. Later on this site several successive cultures have been stationed and documented by the presence of physical artefacts. Site from the point of view of excavated artefacts and variability of human activities remnants belongs to the richest Lengyel culture settlements in the country.

Fragment **L**: 8 mm thick dark-grey sherd with brown rims, Lengyel culture, stage Lengyel IV.

Santovka

This site was discovered during the field survey for gas pipeline construction in 1971. In the wider vicinity of Santovka the other Older Lengyel culture settlements are known to occur: Bíňa, Bardoňov, Svodín, Nitriansky Hrádok and Koláry. Site is areally extented – until known objects are distributed in the area of 25 000 m². During the rescue survey in 1976-1986 the ceramic fragments of two types have been documented:

a) pottery fragments made from the fine-grained pastes with smooth or painted surface, as well as

b) pottery made from the coarse grained pastes with higher amount of temper and with rough surface.

The site represents the easternmost appearance of the Lengyel culture (Pavúk, 1977). On the Santovka site there are documented also younger (Maďarovce and Baden) cultures. Artefacts from the Santovka site represent transition between the Lengyel I and II stages (Pavúk, 1981).

J - 9 mm walled fragment of dirty-brown colour with on the convex side more brownish tint, Lengyel culture, phase Santovka.

Svodín

This polycultural, from the archaeological point of view intensively studied site belonging to the Lengyel as well as Baden ceramic cultures is located in the river

Hron wide valley to the NW of Štúrovo town. Archaeological site described under the local name Busahegy is located on brook high terrace.

The first information about the site was published by Neustupný (1932), later by Točík and Lichardus (1966), Lichardus and Šiška (1970) and namely Němejcová-Pavúková (1970). The Lengyel culture population is represented by its oldest stage, with the Slovak-Moravian red, yellow and white painted and curved ceramics. The areally huge settlement was protected by the strong fortification with two ditches and adjacent palisades system. They have irregular ring ground plan with 4 entrances located against each other. This fortification by its size is unique among the Lengyel culture settlements in the whole central Europe (Němejcová-Pavúková, 1995). The occupation of the mentioned site by the Baden culture population belongs to several successive stages (Novotný, 1986). Within the fortification the ceramics belonging to the older linear ceramic culture was also described (Pavúk, 1980).

The following shards were studied:

A - 4 mm walled dark-grey fragment, on convex side 1 mm thick light-brown rim, Lengyel culture, stage Lengyel I

B - 8 mm walled ash-grey fragment with darker up to 1 mm rim on the convex side, Lengyel culture, stage Lengyel I

C - 21-22 mm thick walled storage vessel, coarse-grained, pinkish coloured fragment with 2-2.5 mm brownish rim on one side, Baden culture

E - 5 mm thick ash-grey fragment, on the convex side yellow-brown rim with gradual transition to the darker portion, on the concave side 1-1.5 mm thick identical rim is observable, Lengyel culture, stage Lengyel IA

F - 5 mm walled fragment, very dark-grey with thin (less than 1 mm) rims on the both sides, Baden culture

Bíňa

The total extent of the Neolithic settlements in the vicinity of present village Bíňa is not yet known - part of it was erroded by the river Hron.

During the rescue field surveys the settlements belonging to the Baden culture, but also to the Linear culture, Želiezovce group Proto-Lengyel as well as Bajč-Retz cultures (Cheben, 1984) were identified. Various types of ceramic vessels have been described from this site (l. c.). Underground objects have been found in the thick (5-6 metres) loess bed. Field rescue survey (Pavúk, 1980) discovered several Baden culture objects which respect each other. During the consequent field survey another settlement belonging to the Older Linear ceramic culture was discovered. Last settlement is located on 4-8 metres high river Hron terrace and is located of approx. 15 km distance from the Danube river.

Shards:

G/a - Thin walled (6 mm) fragment of dark-grey colour with black spots. Temper (approx. 7 per cents) is formed by quartz, micas, and carbonates. Characteristic is the presence of burned grass/strew represented by planparalelly oriented relics.

G/b - Thick-walled (12 mm) fragment of grey colour with darker core and symmetric lighter rims. In comparison to sample G/a this sample has higher (approx. 25 per cents) amount of the middle-grained temper: quartz, micas, feldspars, carbonates, but also grass/strew.

Štúrovo

The site of archaeological interest is located just on the left river Danube bank. The field survey in 1965-1967 was carried out by Pavúk (1994). The area of more than 1500 m² was excavated. Except of numerous tombs also 31 big pile constructions, representing three types of houses, have been disclosed. The length of all three mentioned type houses was 12-37 metres. Among artefacts the pottery fragments prevail over those made of stones as well as tools made from bones. On discussed site the organic relics (grass, straw), cereals (husks), and namely animal bones were preserved.

The settlement was inhabited during the middle stage of the younger Linear ceramic culture and during the Želiezovce culture except of its latest stage. Just this settlement belongs among the hugest Neolithic sites not only in Slovakia but also in the whole Carpathian Basin territory (Novotný et al., 1986).

Two shards were studied:

H - It represents 5 mm walled dark-grey fine-grained shard, with slightly lighter rims on its both sides. It is ranked to the linear ceramic culture.

M – Greyish light-brown pottery shard of 14 mm thickness. Rims of the fragment are of lighter tint. Low amount of silt-like temper has homogeneous distribution in the sherd.

Experimental

After the naked eyes observation the next step of pottery fragments study was the thin sections study under polarizing microscope realized on thin sections oriented perpendicularly to the pottery fragments walls. In such manner it was to disposal crosscuts of all pottery shards (Figs. 2 and 3). From thin sections the photo documentation of individual fragments has been performed.

From the surface of the cleaned, "glazed" pottery-splinters the coating as a vitreous-like material was firstly scraped down, which was then thoroughly rubbed off to very fine powder. From five such prepared, averaged samples the diffractometric records were performed – (without a previous sedimentation procedure – owing to the low amounts of powders, approx. 200 mg) – in the X-ray laboratory of Faculty of Natural Sciences, Comenius' University by X-ray diffraction device DRON-3 in the range/extent of 2° 2θ to 74° 2θ.

Petrographic analyses

At the early beginning of the problematic it ought to be mentioned, that the set of ceramic fragments studied consits of: a) Thin-walled (5-8 mm) fragments as well as those of b) thick-walled (15-22 mm) ones, the most probably of a vessels character. Last mentioned pottery type had the most probably function of pottery contai-

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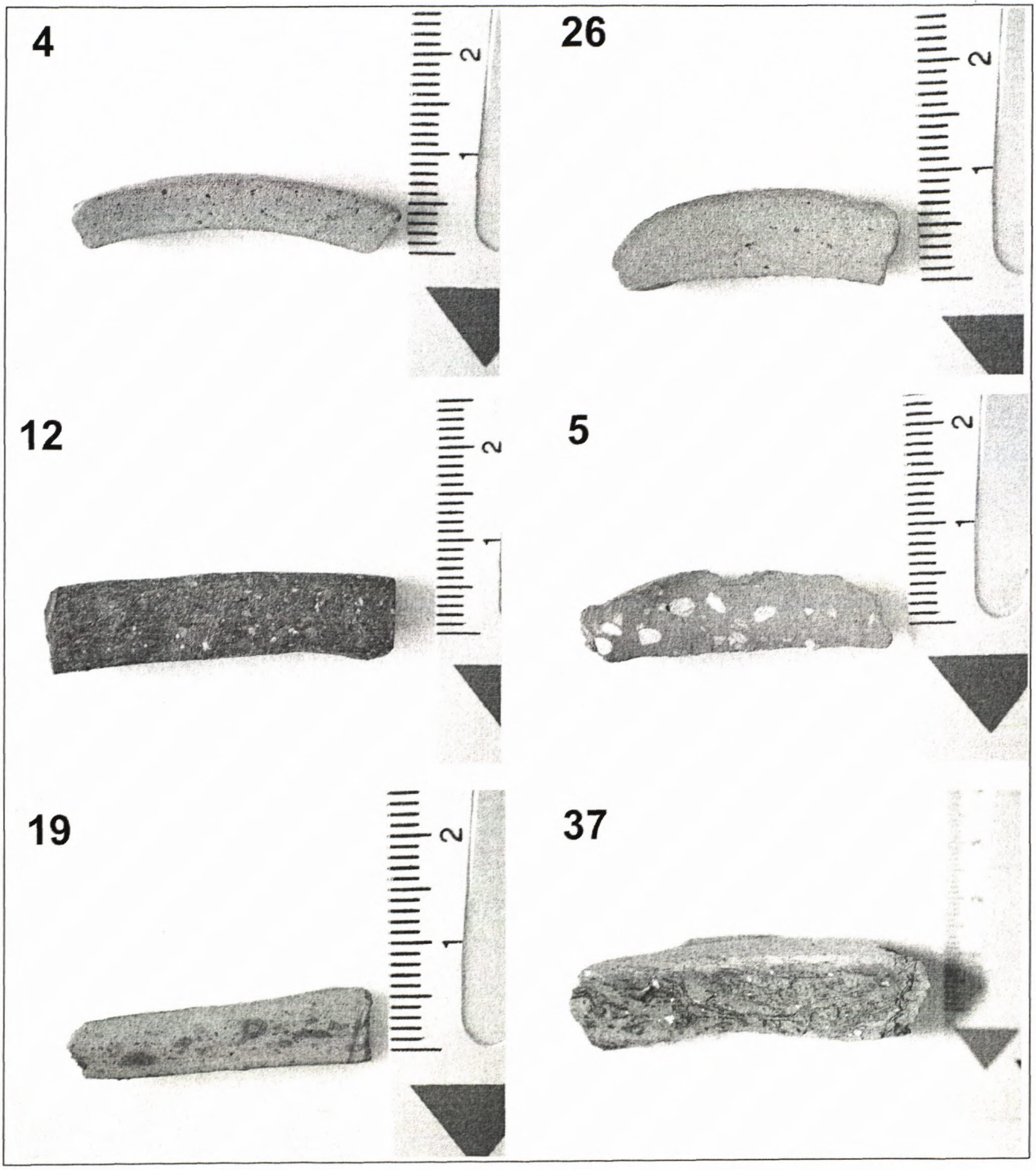

Fig. 2. View of pottery shards cutted planes.
2/4, 2/26 = pottery pastes with low amount of temper; 2/12 and namely 2/5 = pottery pastes with high amount of coarse-grained temper; 2/19 and 2/37 = pottery pastes with high amount of organic temper (black spots)

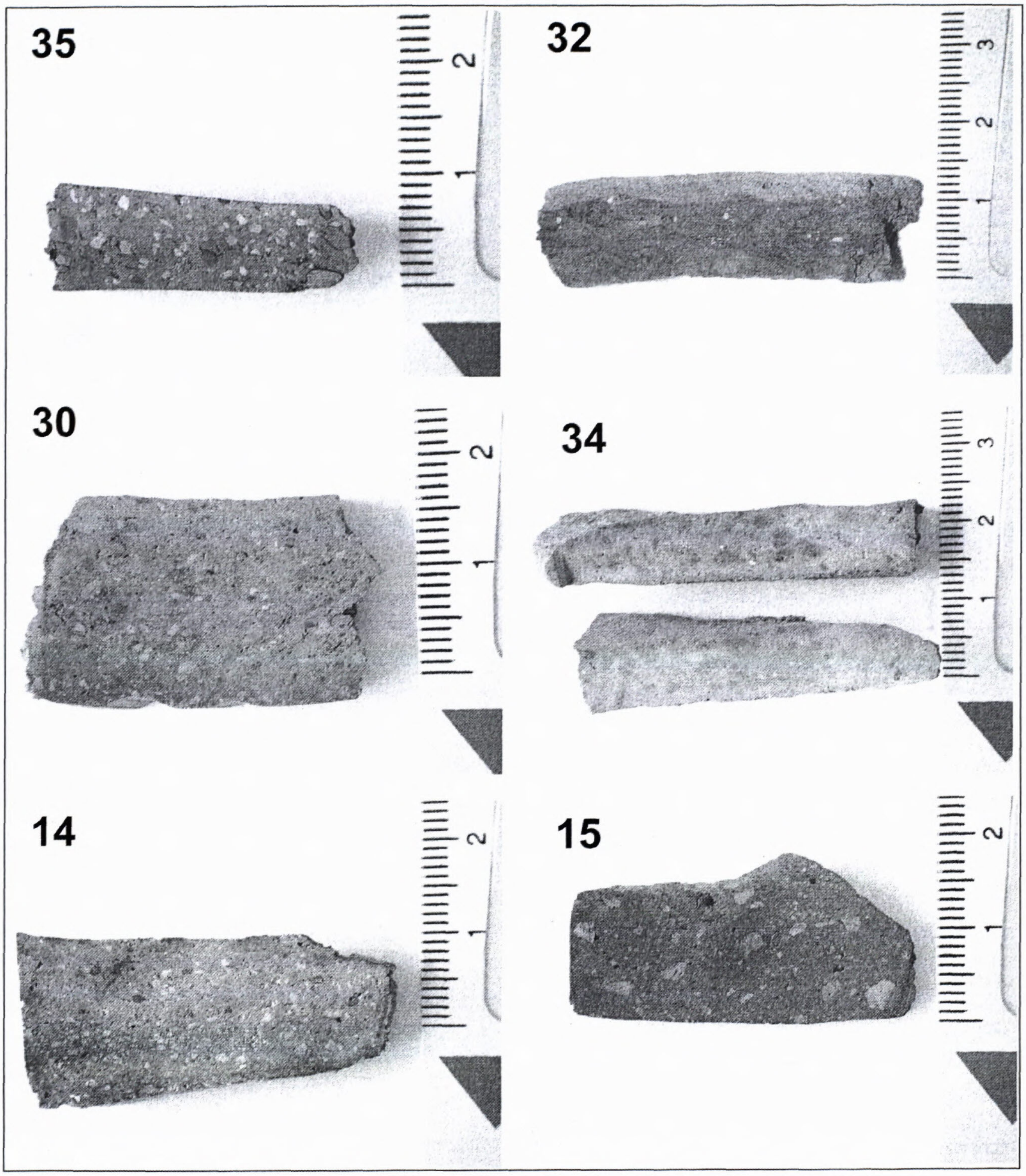

Fig. 3. View of thick-walled pottery shards cutted planes.
3/35, 3/32, 3/30 = pottery shards with various amount of inorganic temper; 3/34 = dark irregular spots represent original organic temper location; 3/14, 3/15 = various amount of temper of different quality and quantity

ners, being used for storage, processing and transport. Typical thin sections patterns are presented in Figs. 4 and 5.

Ceramic paste in all studied cases was prepared from "coloured clay", e. g. montmorillonite-illite type. White clays (= kaolinite) were not used. Based on this fact we assume very local provenience of the raw material used for paste elaboration.

Temper (terms "temper" and "grog" are used in accordance of Rice, 1987) is represented by both, e. g. inorganic as well as organic types.

Inorganic temper is represented by its extreme end members which are:

a) detritus of granitic rocks (quartz, feldspars, micas, accessories of zircon, apatite, tourmaline and others),

b) detritus of volcanic rocks (volcaniclasts) of basaltic as well as rhyolitic composition mostly with glassy matrix and tiny plagioclase crystals setting in it, partly recrystallized volcanic glass, individual minerals: amphibole, pyroxene, zonal plagioclases,

c) detritus of prevailing limestones and dolostones of various facies (Figs. 4/a and 4/b)

d) grog of older ceramic fragments of very different grain-size, colour (mostly darker as the host-pottery fragments) – in the case of sample "C" (Svodín) 2 generations of pottery were identified (Fig. 5/a).

In the most cases temper is represented by typical mixture of above mentioned associations. But individual temper associations are well identifiable. So used temper simultaneously help us to identify the temper source areas (granitic as well as Late Tertiary volcanic complexes, or even Mesozoic carbonate complexes being the main suppliers of detritus as a natural component of ceramic raw material/pastes; Fig. 4/a).

Ca and Ca-Mg carbonates present in the form of silt-sized constituents of temper represent sensitive/critical constituents of a ceramic paste (Fig. 4/b). Their various varieties during firing behave differently (Fig. 4/b). Pure limestone (the upper part of the picture) is thermally recrystallized on the rim meanwhile broader core is thermally untached (light oval pebble in the lower part of the Fig. 4/b. Over temperature of 650 °C limestones start to decompose producing $CaO + CO_2$. This process is accompanied by the volume expansion causing cracking and spalling ("lime poping": Rice, 1987).

Organic type temper was identified (namely, but not only), in sample G (two thin sections from site Svodín). Fragment is ranked among the Baden culture pottery. Generally the amount of carbonaceous material (humus, rottlets, fibres) in pre-fired pastes was highly variable. Significant quantities of organic matter in a fired clay pieces are normally signalized by a dark core in a freshly broken cross sections through the pottery walls (Rice 1987). They have character of no completely fired up to 5 mm long pieces of grass or straw. After burning in the space of their pieces black carbonaceous substance (carbon?, soot?, or generally graphite like matter) is preserved in their central portions Fig. 4/d), in some cases also as extremely thin black "skin" on the inner walls of empty (tunnel like) spaces in pottery bodies. The presence of blackened rims of the pottery fragments should be a result of the carbon particles moving during the firing/annealing toward the surfaces from the interior. The carbon, being the constituent of pottery paste, is not effectively eliminated until temperatures above 600 °C, but usually above 750 °C, or higher. It means the atmosphere must contain free oxygen (Rice, 1987).

Still more preserved organic remnants of a fish-bone and vegetable tissues in an amphora was described in detail by Pawlikowski (1999) from Ostrovany (eastern Slovakia). Author (l. c.) concluded that firing of the amphora underwent under reducing conditions under temperature of 800 °C.

Among the most interesting observed phenomena belong the presence of few euhedral platy crystals of acid plagioclases, some of them of well developed zoned structure (Fig. 4/c). They are present in a distinct field in thin section, so suitable composition of paste for the new plagioclase crystals blastesis ought to be considered. Very seldom also very fine-flaky light brown dark micas have been observed. They are concentrated in prolonged irregular zones of 0.X mm thickness.

Colour is one of discriminant aspects of ceramic firing. Among studied shards there are pinkish-brown, as well as grey coloured fragments. So we should expect oxidizing and simultaneously also reducing conditions during annealing/firing. As we are not able to connect individual pottery shards to discovered kilns on several sites, the position in kiln (lower or higher situated position of individual pottery pieces during firing) ought to result in various oxidizing/reducing conditions.

In mentioned two colored contrast ceramic fragments types in both of them the rims of the other colour are developed. In the dark coloured (of the ash-grey to dark-grey colours) shards rims have lighter coloured appearance. The incomplete oxidation of present carbon in firing leads to the creation of dark central part often seen among pottery fragments.

In light coloured fragments the rims are a little bit darker. It is typical, than mentioned rims, which represent parts of pottery bodies being in direct contact to fire, are thicker on the convex in comparison to concave sides.

Despite, several pottery fragments are characterized by the development and persistence of black to dark-coloured cores of pottery. This phenomena in the ancient pottery has been many times discussed in the literature (e. g. Brownell 1976).

Effects of weathering

Deposition of ceramic vessels and the other types of pottery craft production in the soil, in the majority of places in soils developed on loess is characterised for its high Ca contents. So seasonal migration of Ca dissolved in water penetrating from the surface (rains, snow) is responsible for precipitation of $CaCO_3$ in the form of thin crust on ceramic fragments (Fig. 5/b). The product of such precipitation is represented by the matrix of original silty sediment + cryptocrystalline carbonate aggregates. Originated "sandy limestone" has various proportion between neighbouring loess and precipitated calcium carbonate. In the majority of observed cases

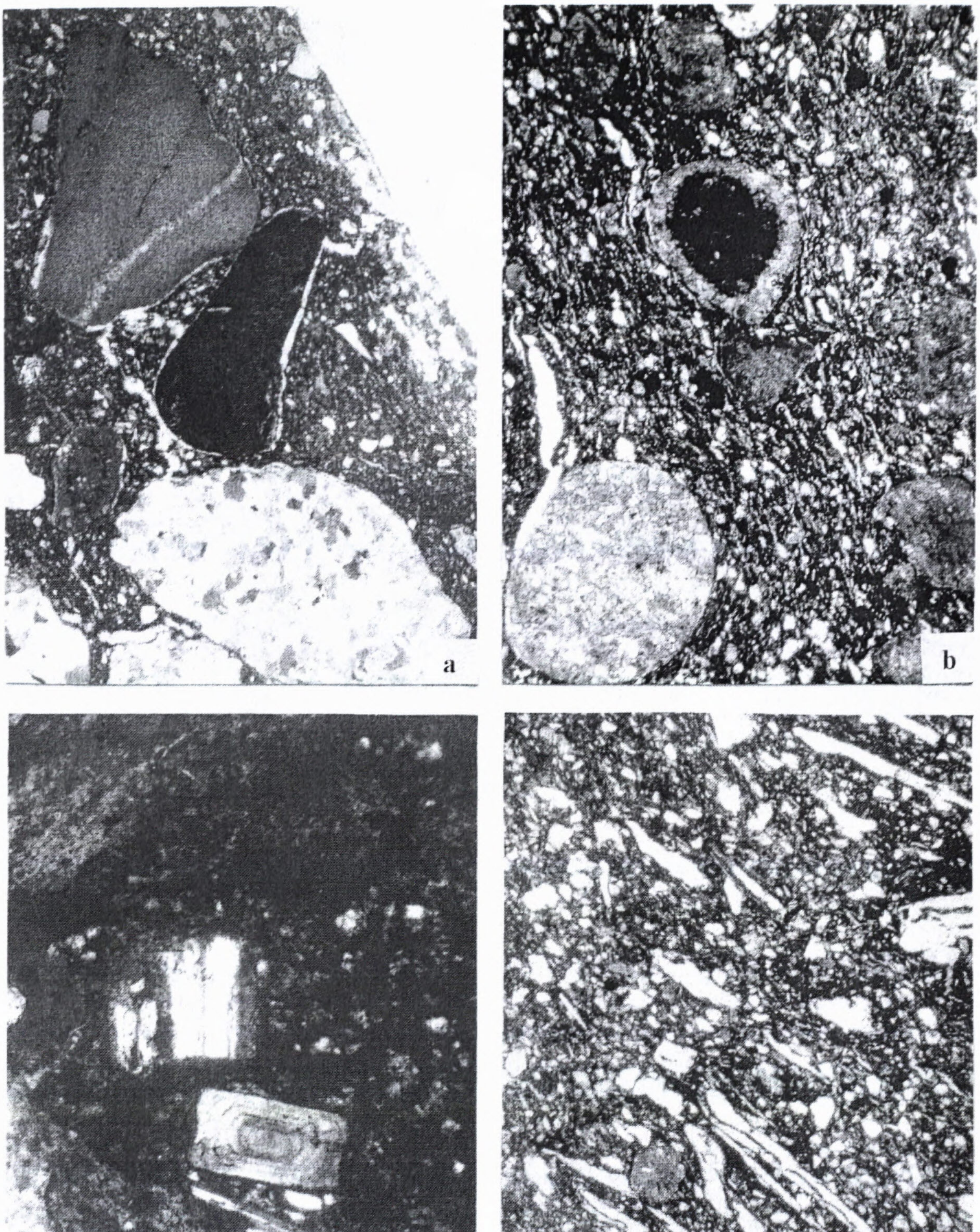

Fig. 4a-d. Pottery thin-sections patterns.
4/a = coarse-grained (2-3 mm) temper of different quality; 4/b = rounded grains of carbonate temper: crystalline dolomite without reaction (left lower corner) and grain of limestone (dark, rounded) with recrystallized rim; 4/c = in pottery paste euhedral small crystals of albites are present (clasts or newly formed phase?); 4/d = high amount of grass/straw in pottery paste; after burning dark organic matter in individual temper pieces spaces is still preserved

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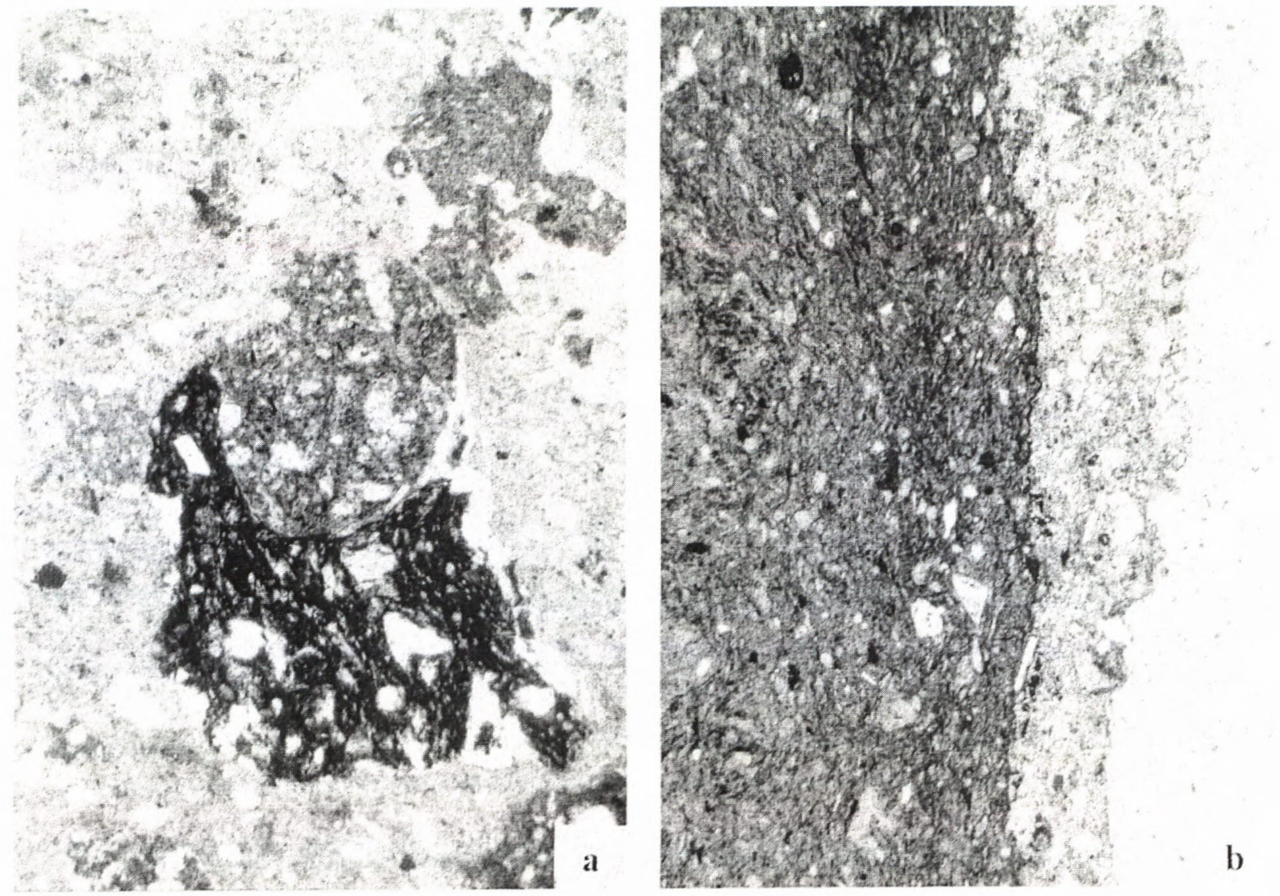

Fig. 5a-b. Pottery thin sections patterns.
5/a = irregular fragment of pottery of the older generation used as the constituent of temper; 5/b = on the convex surface of the pottery sherd the newly formed precipitate of "sandy limestone", being the product of weathering processes, is developed.

mentioned crust is not preserved as continuous layer on the whole pottery fragment surface. Typical example is representedby the fragment B from the Svodín site.

Another effect of the long acting weathering processes is represented by the dark thin "lines" (mostly oxides and hydroxides of Fe) copying the outlines of the pottery fragments. They are developed in some shards only – in those deposited in permeable soils which allow many times repeated penetration of soils humidity into the outermost parts of individual shards. Mentioned "frontal line" of humidity penetration into the pottery fragments is located in some 0.1-0.2 mm distance from the ceramic fragment surface.

Among the effects of the weathering processes ought to be counted also split of ceramic artefacts due to the water freezing in cracks and fissures. Such frozen water acts as mechanically penetrating wedges following individual cracks. So in situ deposited potters' products split into smaller and smaller partial pieces.

X-ray diffraction data interpretation

At lower angles 2θ range there are no doubt numerous, distinctive diffractions, such as on the records of sample B (Svodín: Fig. 6a) but with considerably low intensity and therefore not exactly identified. These diffractions may not be printed and they may be determined only approximately – as it is seen on the not-smoothed records. The distinguishing is better particularly on the "second-rate components", i.e. on the smoothened records performed with a lower sensitivity/response, i. e. on the records of sample N (Žlkovce: Fig. 6b). The presence of a weak diffraction around 1.0 nm belonging to mica or micaceous/illitic clay minerals indicates the relative low annealing temperature. It is known by their high thermal stability. Obviously this is the question of silt-sized particles distribution.

Commentary to the shape of records

Contrary to all expectation – it was gained only little information, because all shapes of five records are entirely uniform – with quite sporadic reasonable/logical contribution to knowledge. Nevertheless, in spite of this fact – some indications about the interaction reactions may be drawn. For example, round shapes of sample B (Fig. 6a) especially of the "first-rate", i.e. in not-smoothened records some differences are clearly evident.

Commentary to the background

Concerning to the not-smoothened records, not only in the lower angles 2θ range, but in the remaining range of 10° 2θ to 74° 2θ also, the following can be stated: We must emphasize that the studied samples may be

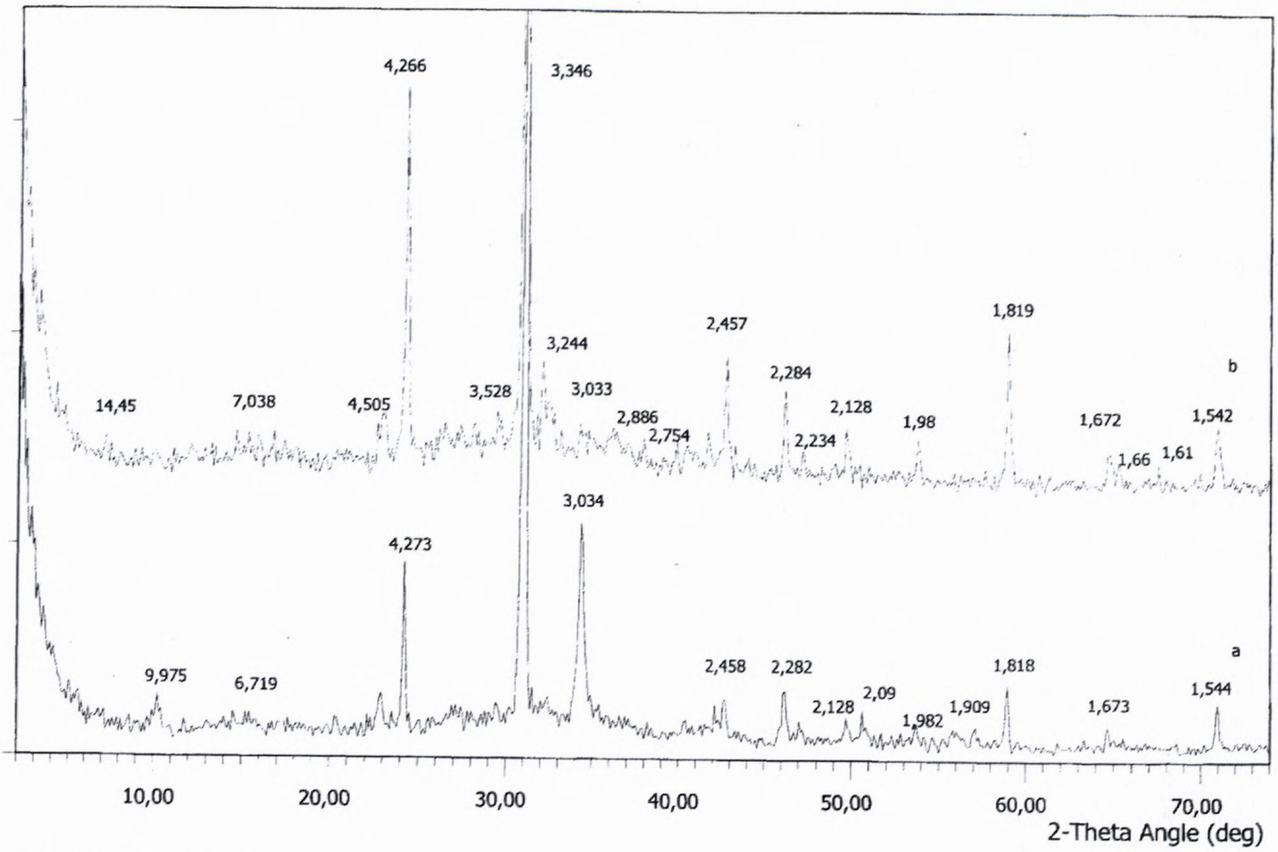

Fig. 6a-b. X-ray diffraction patterns.

divided into two groups, namely with higher background, i.e. sample N (Fig. 6b) and with lower background, i.e. sample B (Fig. 5/a).

Especially on the "second-rate components" records, on all sample records may be seen the same or almost the same character, but nevertheless, by a certain speculative approaching a little better possibility to distinguish the phase composition at sample B (Fig. 6a) is given. These samples have namely more "glassy" phase, the most probably owing to the absence of limestone.

Commentary to the ferric/ferrous phases

The studied samples were not ochred or even rusty at all. Based on that it may be assumed that they contain little or even very little ferric/ferrous compounds/phases (more about this by Mössbauer spectroscopy results). Nevertheless, some indications show on the presence of magnetite phases ("magnetite phases" therefore – because not only the stoichiometric ratio Fe^{3+}/Fe^{2+}, i.e. $Fe_2O_3 \cdot FeO$, but various oxidative/reductive valences of iron in these iron oxides may be present). Possibly only the main diffraction of 0.253 nm is seen on several records. It was searched for some magnetite phases – and even if the interplanar spacing was not precisely the same as in ASTM card – may be assumed that the diffraction 0.294 nm might be belonging to this, but not pure iron compound, i.e. owing to the presence of some solid solutions. Unfortunately, also the hematite as a single phase, i.e. α-Fe_2O_3 is not present! Even the sharpest/strongest diffraction record of hematite 0.269 nm of (α-Fe_2O_3) hematite is not seen on the X-ray diffractometric records. Maghemite γ-Fe_2O_3 might be present, but its the most pronounced diffraction record of 0.252 nm coincides with magnetite 0.296 μm one. More information on the DTA curve offers exotherm at round 700 °C. From this fact may be drawn that the annealing of the ceramic pastes were performed at reductive conditions – and that the surface of potteries were not or scarcely oxidized.

Commentary to the carbonate phases

Calcite was identified in several samples. Dolomite, by its strongest diffraction record 0.289 nm was identified clearly only in one sample, while in the others less clearly and scarcely identified by a shifted diffraction by possibly 0.287 nm.

With regard to a relatively plain region on the diffractometric records in the lower angles 2 θ range – it was necessary or even indispensable to obtain more identifiable, rather unambiguous phases, especially with possibility to attribute the diagnostic diffraction patterns to individual phases in the investigated samples on the diffractometric records.

Therefore the experimental parameters were changed concerning the voltage and current intensity. The step was enlarged (broadened) and the intensity or sensitivity elevated also. Thus, by the increasing sharpness of diffraction patterns the identification was enhanced on possibility to interpret the records more exactly. The obtained superstructure – like spacing with 2θ position,

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their intensity and especially with interplanar distances, were also printed.

Depending on the site of finding – the performing or manufacturing conditions, as well as the low temperatures of annealing (not firing) –clay minerals of micaceous features, i.e. mainly muscovite-like and illite-smectite like minerals remain almost untouched – and their shape was not anhedral or only on the edges was observable some rounding – what is seen by their observation under a binocular microscope. So – the main feature – in general – is the same at all investigated samples – and the strongest diffraction patterns belong to quartz, calcite, feldspars and muscovite or similar micaceous – and illitic minerals.

Besides these facts and by strong reductive conditions of annealing, some of them contain a considerable amount of phases which belong with their great interplanar spacing round 2.30–2.50 nm to rectorite-type superstructure clay minerals, also with one or two diffraction patterns with smaller intensity around 1.2 nm. The other – also a real possibility is the incomplete or only partially annealed hydromuscovite, hydrous mica, hydrobiotite or some other difficult identifiable micaceous phases.

In summary – from X-ray diffractometric records of investigated Neolithic annealed pottery splinters may be concluded on similarity of the phase composition. The crystalline phases belong to mainly quartz and to adjacent feldspar phases. In some samples the diffractions of calcite are markedly seen. The low content of phyllosilicates indicates on the presence rather muscovite and illite, as well as of rectorite (some time ago named "allevardite") and mixed-layered minerals of interstratified smectite-illite type. The iron oxide phases are present only in traces. Chlorite and kaolinite may be present also. The higher background in some samples indicates/suggests a little portion of glassy-like X-ray amorphous phases.

Summary of diffraction studies

In all investigated powdered samples from Neolithic potteries – the dominant phase is clearly quartz. In some of the samples less amounts of feldspars and some calcite (dolomite) are present. To minor phases belong the micaceous or illitic clay minerals from probably original mixtures, not changed by annealing – and very little iron oxides containing phases. In trace amounts there are also other – not or more-or-less not-identified phases, as products of annealing or from the original pastes.

Mössbauer spectroscopy

The introduction of Mössbauer spectroscopy in the study of archaeological artefacts is one of the most additions to physical analytical techniques that have been used in elucidation of archaeological problem. Mössbauer spectra of ancient pottery were first realized by Cousins and Dharmawardena (1969). Mőssbauer spectra have been used for studying the iron-containing phases in clays and their transformations upon firing (Simopoulos et al., 1975). It is generally accepted that the most common occurrence of iron in clay (ferric Fe^{3+} and ferrous Fe^{2+}) is:

a) Substitution of Al or Si sites in clay minerals, or
b) in the form of magnetic iron oxides or hydroxides usually dispersed as small particles.

The importance of this method is based on the pressumed elimination of subjectivity in criteria used by archaeologists to classify and extract information from ancient objects. The methods is convenient for determining the provenance and manufacturing of pottery. Transformation, induced by firing the clay and characterized by Mössbauer spectroscopy, gives valuable information regarding the manufacture as, for instance, the final temperature of firing in it and age dating, etc. The relative abundance of Fe^{2+} and Fe^{3+} determines the atmosphere used to fire a pottery. The pottery fired in an oxidizing atmosphere contains mostly ferric (Fe^{3+}) iron and pottery fired in reducing atmosphere contains a lot of ferrous (Fe^{2+}) iron. The presence of magnetically split hematite (Fe_2O_3) indicates the oxidizing atmosphere. On the other hand the presence of magnetite (Fe_3O_4) indicates the reducing atmosphere. Sometimes some amount of Fe^{3+} is present in hematite in superparamagnetic state (small particles with the mean diameter around 15 μm or less). In such case a superparamagnetic spectrum is observed at room temperature, consisting of quadrupole doublet, whose parameters are very similar to those for the ferric ions in a clay minerals. This is due to the fact that the magnetization direction changes at a rate comparable to or greater than the Larmor precession frequency of the nucleus. During cooling of the sample this rate is decreased and the magnetic spectrum is recovered. Normally there will be a range of particle sizes, and a blocking temperature is defined as a temperatures at which the spectrum is divided equally between magnetic and superparamagnetic components. Thus by measuring the spectrum at least at two different temperatures the oxide component may be separated (Fig. 7). The temperature dependence of the ratio of paramagnetic and magnetically split components can be used to determine the particle size of the magnetic oxides. The main differences between the red and grey earthenwares is in relative amount of ferric and ferrous ions. The grey ware contains a greater ferrous component. The firing of similar clay showed that the colour could be reproduced by using either an oxidizing (red ware) or reducing (grey ware) atmosphere. The reddish colour is associated with magnetic iron oxides while the greyish colour is associated with the predominantly ferrous components produced by firing in a reducing atmosphere. The appearance of different colour layers in shards document the changing reducing/oxidizing atmosphere during studied pottery firing/annealing.

It ought to be mentioned that in the past there were attemps to solve some partial problems of ancient pottery from the sites on the Slovak Republic territory (Sitek et al., 1980; Lipka et al., 1990). But results were not compared with results of complex laboratory studies.

The results

Mőssbauer spectroscopy is a technique which allows measurements of the electric and magnetic interaction between an atomic nucleus and its surroundings. Specifi-

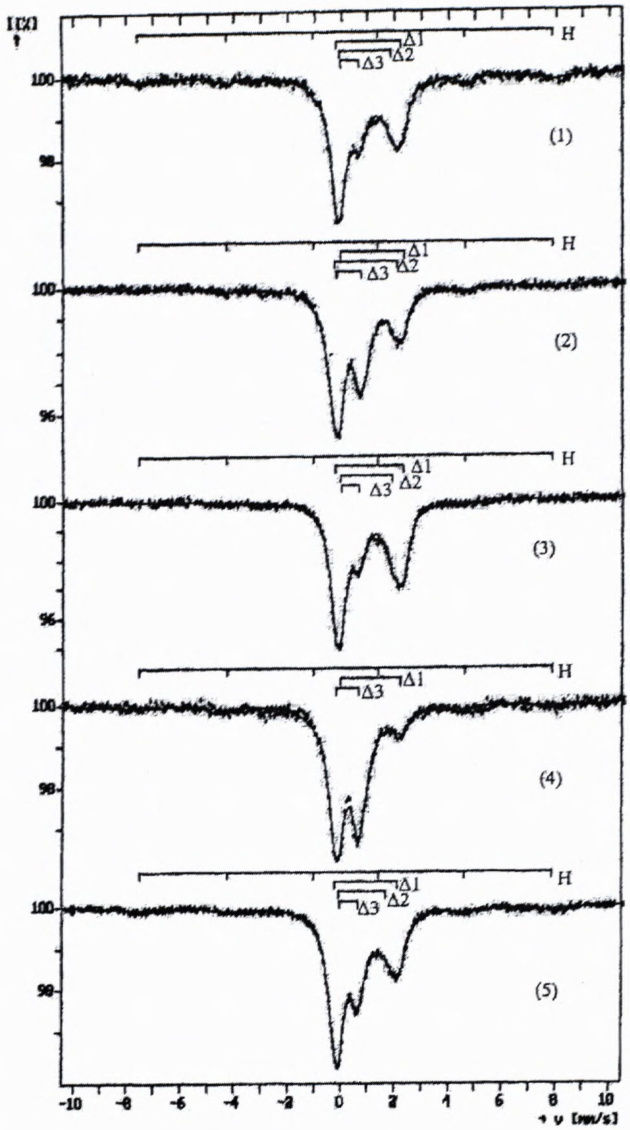

Fig. 7. Mössbauer spectroscopy patterns.
1 = A (Svodín); 2 = N (Žlkovce); 3 = L (Výčapy-Opatovce); 4 = J (Santovka); 5 = M (Štúrovo)

cally, it gives an information about the electron density at the nucleus (via isomer shift), the electric field gradient at the nucleus (via the nucleus quadrupole splitting), and the magnetic field at the nucleus (via the nucleus Zeeman splitting). Therefore, the technique gives information on important parameters such as the valence state of atoms, the coordination numbers, the distribution of charge around the nucleus, and the magnetic properties of the material which is investigated.

Each compound or phase has typical parameters of its Mőssbauer spectrum that means the method is suitable for quantitative as well as qualitative analyses. Mőssbauer spectroscopy is non destructive and requires relatively small quantities of samples (approx. 100 mg). It may be applied to polycrystalline and amorphous or superparamagnetic compounds (Morup et al., 1976; Long,1984; Morup and Knudsen, 1986).

We have investigated five Neolithic pottery shards denoted with numbers from 1 to 5.

The necessary amount of powder was prepared by scrapping of the potshard neglecting the different coloured layers.

Mőssbauer spectra were measured at room temperature using conventional Mőssbauer spectrometer with source ^{57}Co in Rb matrix. Spectra were fitted using NORMOS program.

Corresponding Mőssbauer spectra are shown in Fig. 7. Mőssbauer parameters: quadrupole splitting Δ, hyperfine fields Hef, and isomer shifts IS and relative areas are given in Table I. Relative errors for QS and IS are ± 0.02 mm/s, for Hef ±- 1.0 and for relative areas is ± 0.5 %.

Table I

Fraction	Sample:		1	2	3	4	5
Magnetic	H	(T)	47.9	47.9	47.9	47.9	47.7
	IS	(mm/s)	0.15	0.15	0.15	0.15	0.19
	A_{rel}	(%)	12.5	5.4	5.6	10.4	9.9
Δ1 Fe^{2+}	QS	(mm/s)	2.43	2.37	2.52	2.25	2.35
	IS	(mm/s)	1.03	1.15	1.03	1.06	0.95
	A_{rel}	(%)	22.9	4.0	5.6	13.4	31.3
Δ2 Fe^{2+}	QS	(mm/s)	1.98	2.34	2.00	-	1.77
	IS	(mm/s)	0.89	0.89	0.92	-	0.77
	A_{rel}	(%)	28.8	30.2	38.9	-	18.5
Δ3 Fe^{3+}	QS	(mm/s)	0.79	0.93	0.74	0.88	0.74
	IS	(mm/s)	0.30	0.28	0.32	0.24	0.30
	A_{rel}	(%)	35.8	60.4	27.8	76.2	40.3
Fe^{2+}/Fe^{3+}			1.4	0.6	1.6	0.2	1.2

In the Mőssbauer spectra of all samples we have identified two (sample 4) or three (samples 1, 2, 3, 5) paramagnetic doublets which correspond to Fe^{2+} iron (doublets Δ_1, Δ_2) and Fe^{3+} (doublets Δ_3) valence state. From the relative area the values of the Fe^{2+}/Fe^{3+} ratios were estimated.

In all spectra magnetically split component (H) with very low intensity was identified. This component corresponds to nonstoichiometric magnetite Fe_3-xMxO_4, where M is a nonmagnetic substituent. Relative amount of iron in magnetite varies from 5.4 to 12.5 %. The presence of magnetite indicates partly reducing atmosphere of firing. From the relative abundance of Fe^{2+} and Fe^{3+} the atmosphere used firing a pottery was determined (Lipka et al., 1990).

Very high amount of Fe^{2+} in samples 1, 3 and 5 indicates the reducing atmosphere. On the other hand the high amount of Fe^{3+} in sample 2 and 4 indicates the oxidizing atmosphere.

Scanning electron microscope (SEM)

Scanning electron microscopy of fired clays/pottery was introduced into paleoceramic studies several decades ago (Tite and Maniatis, 1975; Noll, 1976; a.o.). Mentioned and the other authors formulated theoretical background of the above method and presented various stages of different composition clays during their firing/sintering. So we apply existing published data in the following presentation.

The thermal process to which the shards were subjected is possible to document only by partially melted

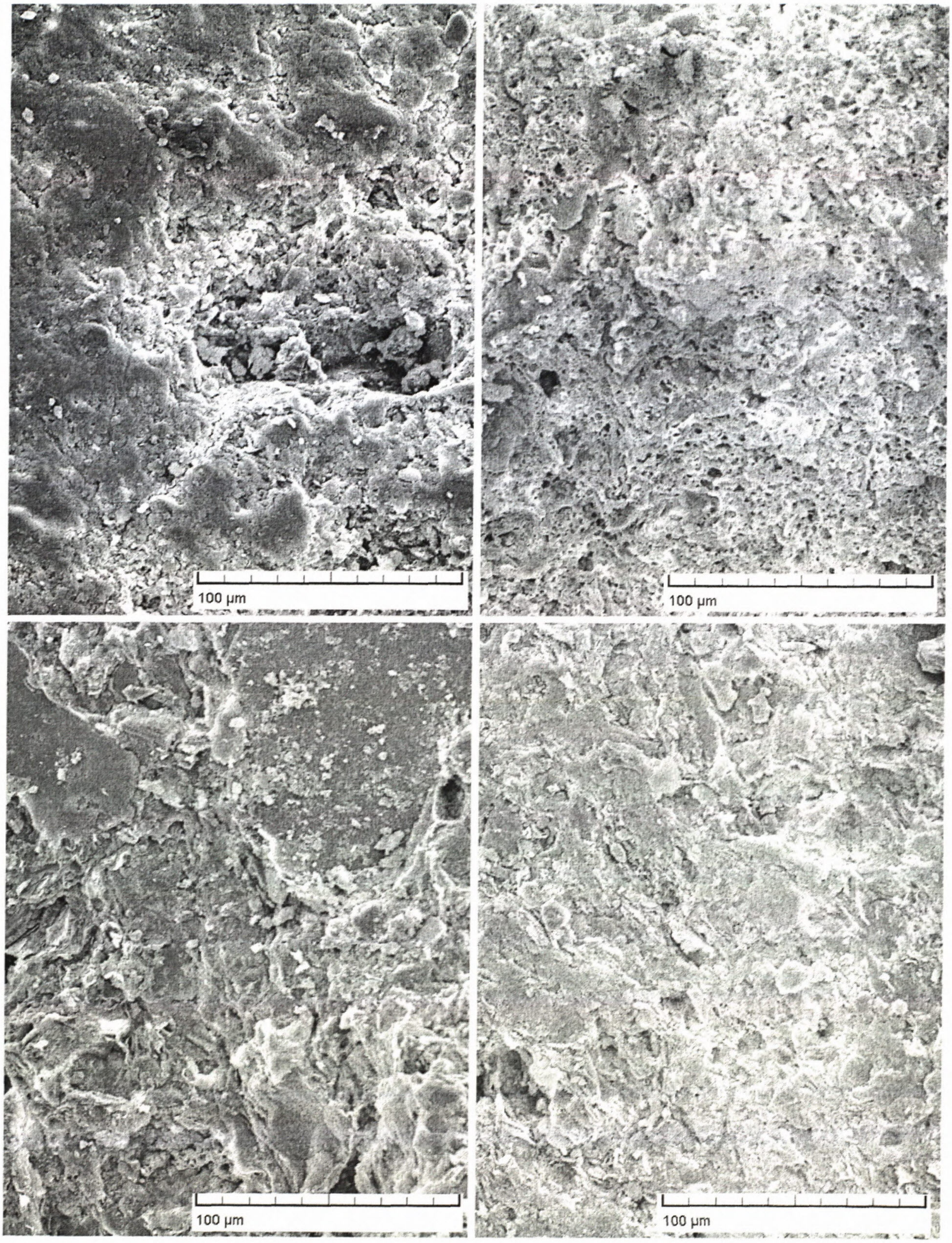

Fig. 8. SEM patterns of natural splitting planes.

rims with a little vitrified coating of micaceous–like anhedral, rounded, flamed irregular particles. It is indicated also by aggregates and/or clusters of very fine-grained homogeneous splinters used already before as a temper (Lamiová, 1982). The most expressive figure in this series (Figs. 8 and 9) is certainly the micrograph belonging to the surface fracture topography of the sample A.

There are clearly visible the compacted, not sharp-grained particles, or flakes, but rather a little rounded micaceous and illitic minerals. Numerous shallow depressions, pits as well as big cavities (that is before the fracturing perhaps round voids) indicate a gasification of some organic matter (maybe rice-, corn-husks, or straw/grass), or an insufficient scarce pugging with air-bubbles. Production of more open structure (the presence of vesicles) was documented when original pastes contain higher quantity of $CaCO_3$, which composition simultaneously reduce the temperatures of vitrification (Tite and Maniatis, 1975). On several areas on the investigated sample – clusters of mineral fragments are seen. In these compressed, layered plates, or thin slices, or a slice-like flakes – an entirely layered microstructure with evidently characteristic preferred orientation may be seen (Schneider, 1989).

Contrary to the previous sample – in this one (A, C) is the surface fracture expressive porous and extremely wrinkled and penetrated all through with porous material – so that it may be stated, or at least assumed that it deals round a secondary material. It is a product of an interaction. The ceramic matter passed obviously through a thermal process at which an organic material, probably an active dry grass/straw, husks – was used, because the portion of non-reacted matter is very low (Hanykýř et al., 1997).

The surface of the fractured ceramic splinter (sample E) is extremely porous and typically spongy as a cellular, regularly foamed matrix with countless very small pores. These represent certainly the product of burning/annealing. Some thin flakes and slices of fumed, scraped, layered material there is also visible. Entirely is the surface relatively homogeneous, uniform – indicating a higher quality of a pottery's treatment, or burning. It appears that the microstructure of ceramic fragments on the picture - performed by the scanning electron microscope - is remarkable, impressive and especially very informative (Makovicky and Thuesen, 1981).

The fracture surface topography of the sample F from Svodín (Hovorka et al., 2001) is very rugged, considerably wrinkled and there are seen flamboyant, compact areas without fissures – with mostly turned–up flakes of micaceous minerals as well as ubiquitous scarcely melted aluminosiliceous matter. It seems the shard would be homogeneous and slightly altered.

Archaeomagnetic measurements

The archaeomagnetic investigation was performed on identical pottery pot shards from several localities listed above. All measurements were carried out in Palaeomagnetic laboratory of the Geophysical Institute of the Slovak Academy of Sciences in Modra. Classical Thellier's method, or method of double heating, was used (Thellier and Thellier, 1959). The heatings were realized on demagnetization equipment MAVACS. Magnetization was measured on rock generator JR5 and magnetic bulk susceptibility on the so-called kappabridge KLY2. All instruments are of AGICOI Brno comp. provenience. As cylindrical samples only can be measured, the pot shards were overpoured by gypsum and drilled to the cylindrical forms. Differed amount of specimens (from different sites) was caused by extension of archaeological artefacts. After each thermal steps of Thellier's method the magnetization as well as magnetic susceptibility were measured. This parameter is important indicator of phase transition of magnetic minerals during heating. If the phase changing occurred, we can see rapid jump on curve of thermal dependence of magnetic susceptibility. Application of archaeomagnetic method after such jump is without sense as we would measure the magnetic characteristics on new magnetic material, occurred during the phase transition.

The samples had been heated up to temperature 600-700 °C but because their desintegration in the middle temperatures, measurements were performed only up to 450 °C.

The results are presented in Fig. 10, and Tab. 2. The classical demagnetization and magnetization diagrams (so called Thellier´s curves) and J_P-J_L diagrams, where J_P means geomagnetic intensity in the time of burning of ceramics and J_L means laboratory magnetic, or present geomagnetic field of selected specimens, are shown in Fig. 8. We can see at the majority of samples the monotonous behaviour of curves up to 200–300 °C, eventually up to 300–350 °C (e. g. speciments 5-a, 6-a). The graphs (Fig. 10) represent thermal dependence of magnetic bulk susceptibility. The phase transition in temperatures 300- 400 °C can be observed at specimens 1-b and 4-a.

The fact that samples desintegrated in temperature about 400 °C gives an idea that pottery artefacts studied by our samples were not originally heated much over 400 °C.

Calculation of ratio J_P/J_L, where J_P means intensity of geomagnetic field in the time of pottery burning and JL means laboratory magnetic, or present geomagnetic field, is in Tab. 2. This value is in interval of 0.37-0.68. Comparison of obtained data with archaeomagnetic scale (Bucha, 1975; Fig. 11) shows, that age of measured pottery remnants is from 3750 to 4900 years BC. In the central European chronology of the Neolithic and Aeneolithic presented by Neustupný (1968) the above time span corresponds to beginning of the Early till the Middle of the Late Neolithic. Mentioned time-span covers the Linear pottery, Želiezovce, as well as all Lengyel culture stages (Neustupný, 1968).

General discussion and interpretation

Results obtained by application of several laboratory methods listed above, allow to sum up:

- Taking into account geological background of the areas wherefrom the pottery shards were studied, dominant Quaternary cover is represented by mostly

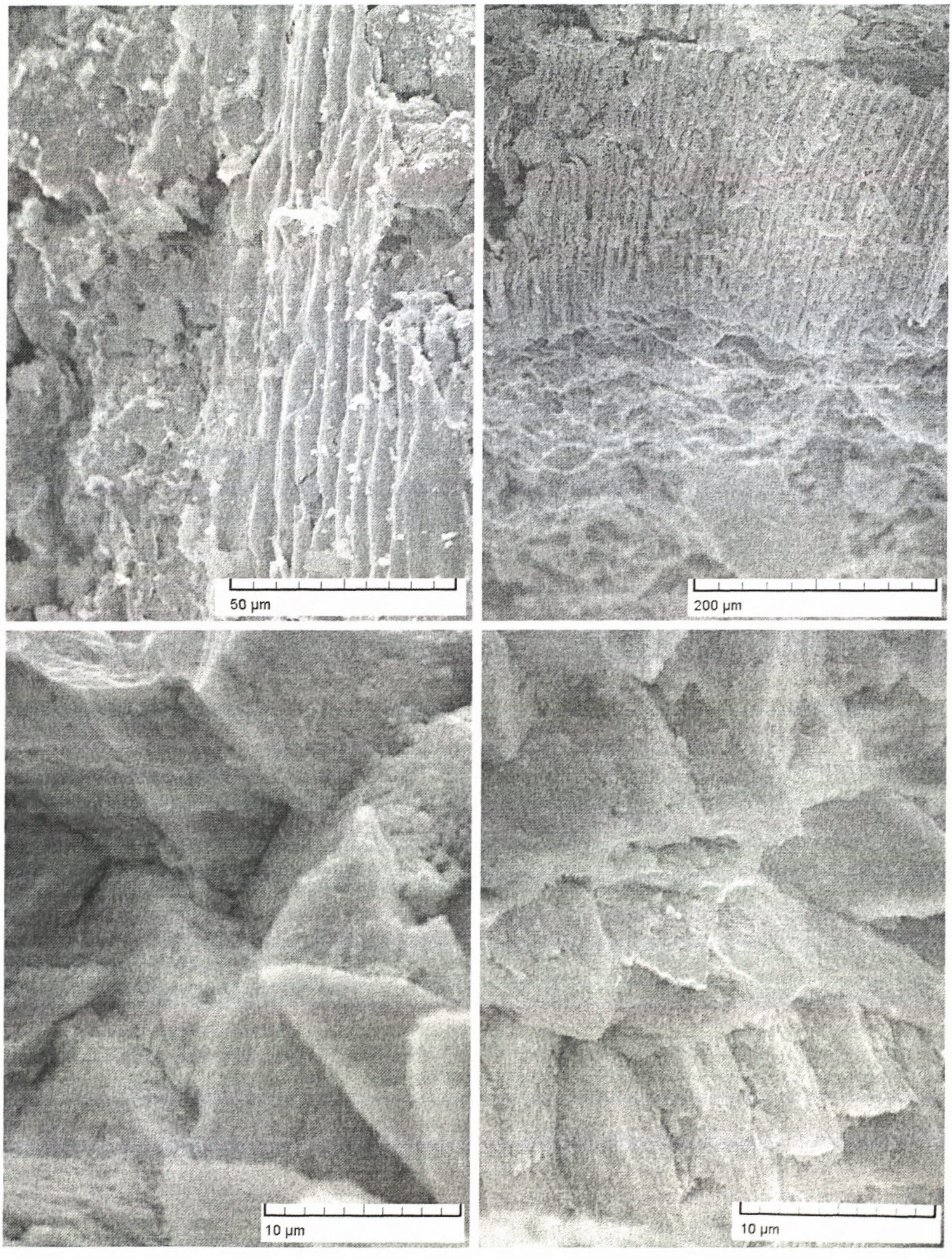

Fig. 9. SEM patterns of natural splitting planes. In Figs. 9/a and 9/b footprints of plants are well visible.

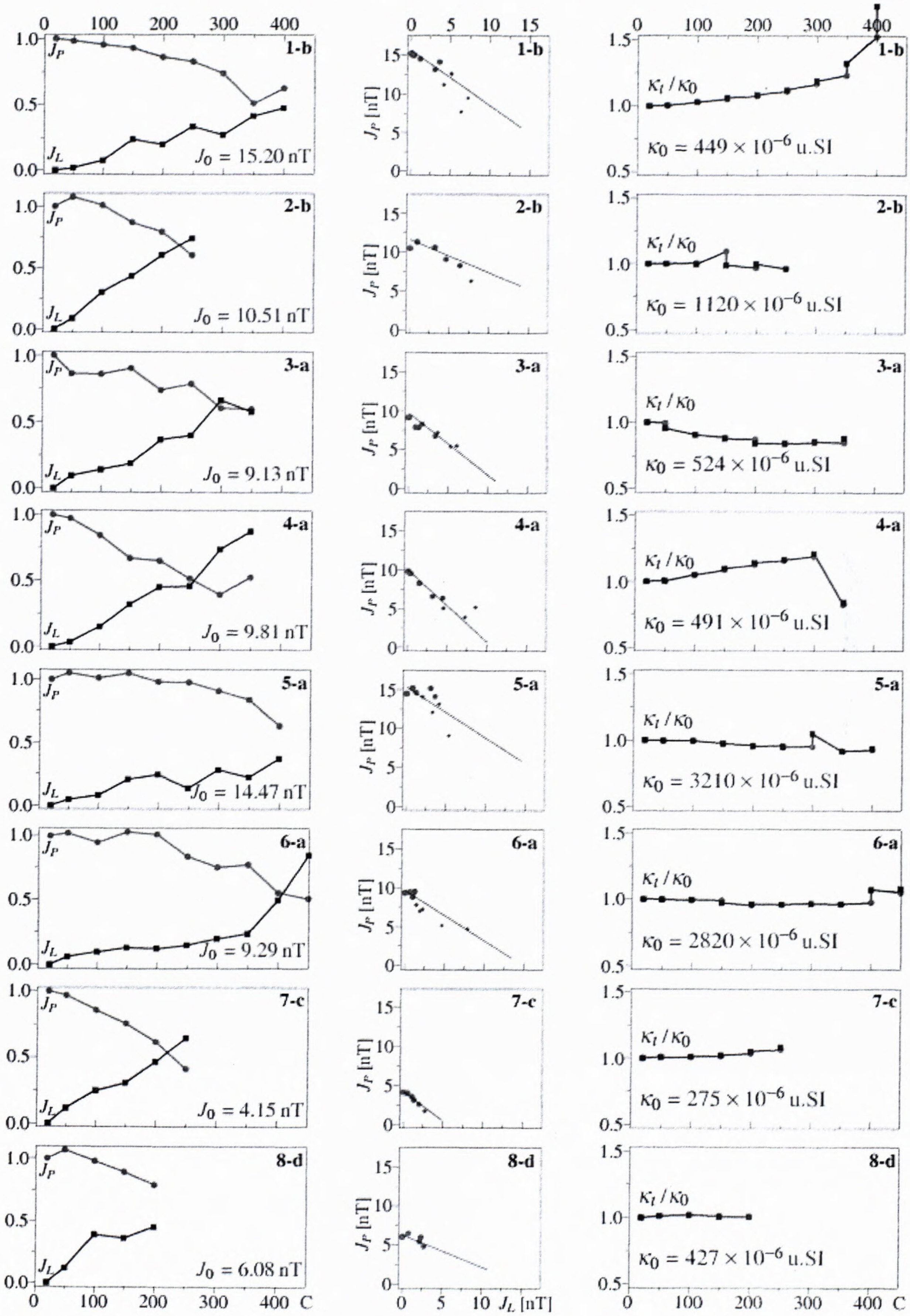

Fig. 10. Demagnetization (J_P) and magnetization (J_L). Thellier's curves of selected samples normalized by value of initial magnetization ($J_0 : J_P/J_L$) diagrams and thermal dependence of magnetic bulk susceptibility, normalized by initial value of susceptibility (K_o) measured after each step of Thellier's method application

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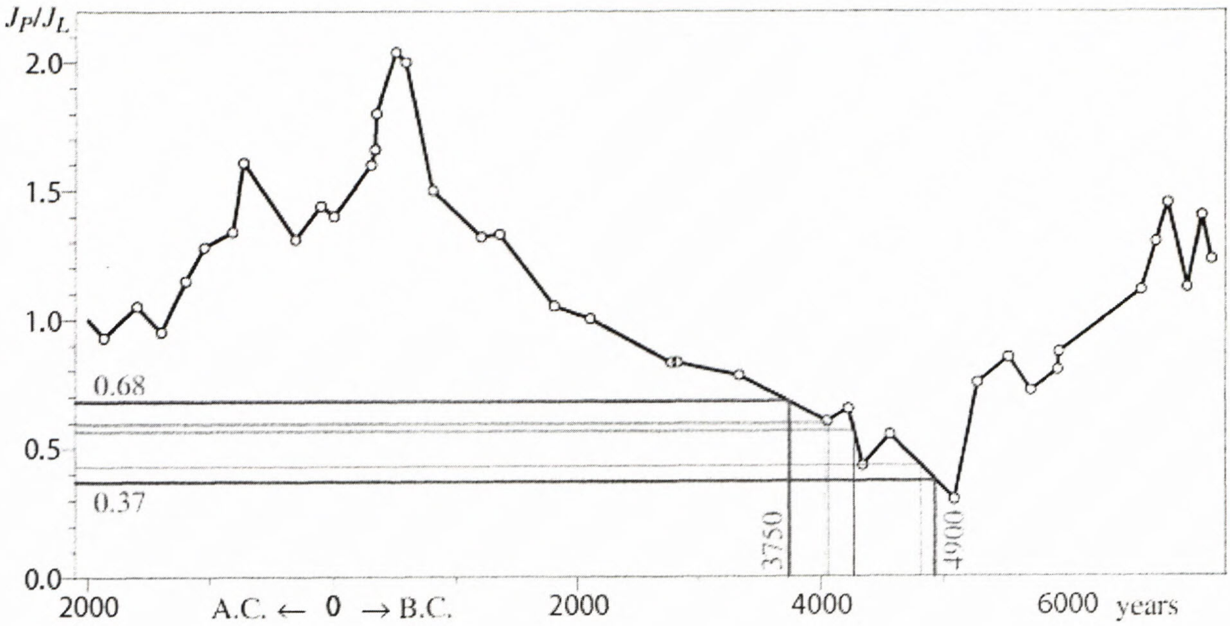

Fig. 11. Changes of intensity of geomagnetic field obtained by the archaeomagnetic investigations in Czechoslovakia (Bucha, 1975) with the interval obtained Jp/J_L results from studied pottery fragments.

Table 2. Results of archaeomagnetic measurements on pottery pot shards from 8 sites. J_o – initial magnetization of specimens; K_o – initial magnetic bulk susceptibility of specimens; steps – temperatures at which ratio J_P/J_L was calculated; J_P/J_L – ratio of magnetic field in time of burning of pottery and laboratory, or present geomagnetic field (mean values ± standard deviation).

No. loc.	Locality	Numb. spec.	No. spec.	J_0[nT]	K_0 x 10^{-6} u.SI	Steps x 10 °C	J_P/J_L
1	Bíňa	3	1-a	2.25	768	5, 10, 15, 20	0.60 ± 0.21
			1-b	15.20	449	5, 10, 15, 20, 25, 30, 35	
			1-c	16.48	470	5, 10, 15, 20, 25, 30, 35	
2	Štúrovo	3	2-a	13.99	1268	5, 10, 15	0.37 ± 0.10
			2-b	10.51	1120	10, 15, 20, 25	
			2-c	11.44	1567	5, 10, 35	
3	Santovka	2	3-a	9.13	524	5, 10, 15, 20, 25, 30, 35	0.56 ± 0.13
			3-b	10.43	534	5, 10, 15, 20, 25, 30, 35	
4	Svodín KD	8	4-a	9.81	491	5, 10, 15, 20, 25, 30	0.68 ± 0.14
			4-b	8.99	431	5, 10, 15, 20, 25, 30	
			4-c	6.28	317	5, 10, 15, 20, 25, 30 40	
			4-d	15.34	463	5, 10, 15, 20, 25	
			4-e	11.65	487	5, 10, 15, 20, 25, 30	
			4-f	14.76	694	5, 10	
			4-g	4.10	237	5, 10, 15, 30	
			4-h	2.82	149	5, 10	
5	Žukovce	3	5-a	14.47	3210	10, 15, 20, 25, 30, 35	0.56 ± 0.22
			5-b	2.58	5580	10, 15, 20, 25, 30, 35	
			5-c	11.32	3042	10, 20, 30, 35	
6	Kuzmice	4	6-a	9.29	2820	10, 15, 20, 25, 30, 35, 40, 45	0.57 ± 0.27
			6-b	16.16	5390	10, 15, 20, 25, 30, 35	
			6-c	2.16	5815		
			6-d	12.37	5185	10, 15, 20, 25, 30, 35, 40	
7	Svodín	4	7-a	15.94	148	5, 10, 15	0.59 ± 0. 22
			7-b	3.07	2748	5, 10, 15	
			7-c	4.15	275	5, 10, 15, 20, 25	
			7-d	11.94	94	5, 10, 15, 20	
	Výčapy Opatovce	4	8-a	4.33	272	10	0.43 ± 0,16
			8-b	4.93	359	15, 20	
			8-c	1.92	93	10, 15	
			8-d	6.02	427	10, 15, 20	

thick loess deposits. Based on generally accepted opinion, that this type of sediment is characteristic for its high calcium contents, we suppose that this main paste substance is of mentioned character. Adding documented presence of clasts of both, limestone and dolomite among temper constituents, the raw material of pottery studied was calcareous fine clastic-clayey sediments of the very local provenience (= loess). In several cases to the loess as the main paste constituents, the temper of inorganic (fine-grained sand, temper represented by older generation pottery shards) as well as organic temper of grass/straw character, have been added.

- Among studied pottery shards there are fragments of the light colour on one side, and the fragments of dark-gray to nearly black on the other. Studied set of pottery shards has been fired in oxidizing as well as in reducing conditions. In the majority of cases it should be concluded that big vessels (or fragments of thick-walled ones) have been burned probably under oxidizing conditions and those of thin-walled character mostly in reducing ones.
- Taking into account supposed low temperature of annealing/firing and the documented presence of both, e.g. products of annealing/firing in oxidizing as well as reductive conditions just on one pottery sherd, the annealing/firing under open air conditions seems to be the most probable.
- Mineral composition of temper (granite, Late Tertiary volcanics or Mesozoic limestone areas supplying detritus) being both of natural constituents as well as added constituents to the ceramic pastes help us to reconstruct source areas of the raw material for the given ceramic product.
- It is rather difficult if not impossible to adjust/attribute all diffractions on the records, especially at lower angles 2 θ range, i.e. of 2° 2 θ to 10° 2 θ to some certain, almost precise phases or even to stoichiometric compounds whether to phases in the original, not annealed pastes of the future potteries or to the products of the thermal annealing treatment. It was tried to scrape only from the glazed surface.

Much better it is by the distinguishing of the phase composition at interpretation of records in the remaining range, i.e. of 10° 2θ to 74° 2θ. In those it was simpler to adjust the diffractions to several dominant, as well as to minor phases present in the studied samples. It may be concluded that the coating ("glaze") on the Neolithic potteries and the investigated "glazed" splinters of them – were annealed (not fired!) – at reductive conditions.

An extremely valuable informatiom has been given in the article (series) of UCH TEPE by authors Makovicky and Thussen (1981) in which – besides the comprehensive text – also excellent micrographs were performed and especially an opposite commentary, or interpretation of the micrographs concerning the morphology of particles was presented.

For the evaluation of annealing/firing temperatures we used the following results of realized studies:

a) in numerous pottery shards (namely from the site Svodín, but in less amount also from the other ones) the black carbonaceous organic substances are documented. They are present generally in two morphological appearances: 1) as prolonged homogeneous non transparent central parts of "tunnel-like" textural forms, and 2) disseminated organic substance forming irregularly limited black spots concentrated namely in the central parts of individual pot shards.

As organic matter the annealing was up approximately to temperatures around 600–700 °C. These temperatures are the highest temperature limits for studied pottery shards annealing conditions. Low temperature annealing (below 550 °C!) of ceramic from Padova and Altino (Italy) was reported recently by Maritan (2004). Just the same (= 550 °C) temperature has been reported for prehistoric Japanese Jomon pottery (Eto, 1963).

b) Among the temper clasts those of limestones of different types as well as dolomites are documented. But only low part of limestone clasts is partly thermally recrystallized on their rims. Recrystallization effect is represented by the presence of coarse-grained rims which have mostly lighter colour than the non recrystallized central part of individual clasts. Dolomites are thermally intact. Decomposition (dissociation) of carbonate clasts was not observed as well.

c) The presence of limestone up to 3 mm clasts in the majority of studied shards is another temperature limit. In this case the dissociation of $CaCO_3$ into $CaO + CO_2$ is shifted to higher (920-950 °C: Kostov, 1968; Eliáš et al., 1957) temperatures. The presence of a sand category of limestones fragments changes the temperature of dissociation to the lower values.

d) As the presence/absence of discriminant minerals is, together with the composition (mineral as well as chemical) of pre-firing pastes, essential, realized powder X-ray diffraction patterns in any case proved the presence of, during firing originated, high-tempered diopside, sillimanite, mullite or the other, under the high-temperature originated phases.

e) Abundant clastic quartz grains did not show any signs of sintering even on their outer limits.

f) Vesicles in the groundmass of pot shards, which are the characteristic textural feature documenting escaping water "bubbles" after decomposed clay minerals, chlorite and dissociation of carbonates, were not observed in thin sections.

g) SEM images of natural fresh surfaces of broken pot shards show only very beginning stage of the sintering processes.

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Contribution to the recognition of the algal genus *Elianella*

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Abstract: The nodules of algae *Elianella elegans* PFENDER et BASSE, 1947 and *Parachaetetes asvapatii* PIA, 1936 are described from Paleocene and Early Eocene deposits of the Western Carpathians. The authors analysed contradictory opinions on the taxonomic position of genera *Elianella* and *Parachaetetes*. On the basis of own observations they prefer conservation of both genera – *Elianella* with irregular arrangement of arched cross partitions in filaments and *Parachaetetes* with straight cross partitions and regular inner structure. After their view these differences in algal inner structure are not connected with the local environmental influences but they are taxonomically significant on the genus level. Many contradictionary evaluations result from the study of nonoriented (oblique) sections of nodules. In the Western Carpathians this genus *Elianella* is known from Late Cretaceous to Early Eocene and genus *Parachaetetes* only from Paleocene. Both genera prefer protected lagoonal, back-reef and reef environments.

Key words: Algae, *Solenoporaceae*, *Elianella*, *Parachaetetes*, taxonomy, stratigraphy, Paleocene, Western Carpathians, Slovakia.

Introduction

Studying Paleocene limestones from the Slovak Western Carpathians there hardly can be neglected up to 2 cm large nodules of conspicuous algae, occurring in all regions where shallow-water limestones deposited. It is not difficult to distinguish these algae, however, their taxonomy poses certain difficulties. The authors studied over 700 thin-sections with cross sections of these nodules (Pls. I-IV). In the presented paper the authors deal with their taxonomic classification, position in ecosystems and stratigraphic range.

Historical background

In the literature there are many contradictory opinions on the systematic position of these algae. Two genera can be considered for the classification, both belonging to the algal family Solenoporaceae: *Parachaetetes* and *Elianella*. It will be useful to recall the history of Paleocene representatives of these genera.

The genus *Parachaetetes* was defined by Deninger (1906). As a type-species of this genus he designated *P. tonquisti* from Middle Jurassic of Sardinia. Pia (in Rao & Pia, 1936) described a new species *Parachaetetes asvapatii* from Niniyur Beds in the Indian district of Trichinopoly. Rao in the above work classified the Niniyur Beds as the ?Maastrichtian - Danian, in presented conception they belong to Paleocene. According Pia *P. asvapatii* nodules reach a diameter of 7 cm and in cross section they are characterized by wide lobes separated by thin fissures. The shape of nodules is very irregular. Cells are arranged in filaments with a width of 0.04 to 0.06 mm. Cross-partitions are usually dissolved and destroyed, the distance between them (= cell length) varies between 0.04 to 0.12 mm. The author emphasized the regular arrangement of transversal cell membranes in neighbouring filaments. He pointed out that the division of nodule tissue into hypothallus and perithallus is in cross-sections usually not very distinctive, transversal membranes are present in perithallus.

Already after the death of Mme Pfender in 1944 a short paper of Pfender & Basse was published in 1947, containing the description of the new genus *Elianella* with type-species *E. elegans*. This species was found in the Paleocene deposits of the south-western part of the island Madagascar. According to the original description the nodules (up to 5-6 cm) are rounded or lobed, formed by densely packed cell filaments arranged in the fan-like structures. The cells, barrel-like in form, are arranged above each other, separated by arched cross-partitions. They are disordered and not arranged linearly. The cells are in longitudinal cross-sections 0.045 mm wide and 0.050 to 0.060 mm long. In transversal cross-sections they are rounded to polygonal shape.

The authors of the genus *Elianella* had not registered the Pia's description of *Parachaetetes asvapatii* and thus they did not compare their new species with it. In this way they started a misunderstanding lasting until present. Pfender and Basse mentioned that the genus *Elianella* occurred widely in the Mediterranean area, from Venezuela to the Pyrenees, Alps and to Anatolia. Although they considered the genus to be of Paleocene age, they pointed out that in the Western Carpathians it appears already in the Late Cretaceous.

The explanation of the occurrence of *Elianella* in the Late Cretaceous was brought in Andrusov's monograph (1950) about plants and foraminifers of the Carpathian Mesozoic. In Slovak text (pp. 30-32) he explicitly wrote that description of species *Elianella elegans* from Carpathian Santonian limestones commemorated him late Mme Pfender. She in the diagnosis had stated (Andrusov, l. c., p. 30) that filaments have chain-like arrangement and cells have barrel-like shape. Transversal membranes are very arched (as hour-glasses) and they are in the system of filaments situated prevailingly very irregularly. Very interesting is her notice, that in the side-branches or digitations of the thallus the barrel-like cells show tendency to elongation and to arrangement into more regular rows. From this is evident, that Pfender on the basis of the study of Carpathian material admitted also possibility of more regular arrangement of cells in tissue of *Elianella*.

Segonzac (1962) described (but did not depicted) in Thanetian sections of southern France besides coralline algae also the species *Parachaetetes asvapatii* PIA and she included into its synonymy also *Elianella elegans* PFENDER et BASSE. She pointed out that the cells are arranged in rows, but cross partitions are usually destroyed.

Elliott (1964) also did not accept the genus *Elianella* and connected it with *Parachaetetes asvapatii* PIA. According to this author this species forms nodules or lobed "cauliflower heads" up to several cm in diameter. The cells arranged in rows have a diameter of 0.04 to 0.06 mm, their length is very variable. According to Elliott the distinguishing of hypothallus and perithallus is never quite clear. He pointed out that even after study of several hundred thin-sections from the Middle East he could not find in nodules any signs of reproductive organs. Scarce cavities are the result of the activities of boring organisms. Nodules on his Pl. 104 show regular *Parachaetetes* arrangement.

At the same time Schaleková (1963, 1964) mentioned, but did not describe the occurrence of the species *Elianella elegans* together with rich coralline algae in Carpathian Cretaceous and Paleocene limestones. In the paper from 1963 she considered this species as characteristic component of Senonian algal communities.

The genus *Elianella* appreciated also Hagn & Ott (1975) and described it from Paleocene pebble found in Oligocene-Miocene molasse north of Salzburg. Paleocene age of pebble was confirmed by the presence of the species *Miscellanea miscella* (ARCHIAC et HAIME). Nodules of *Elianella* reach up to 2 cm in diameter. It is conspicuous that within one row of cells their height as well as width varies and transversal bottoms are always arched downwards. The height of cells is usually 0.015 to 0.030 mm but rarely there are the cells overreaching 0.15 mm height.

Similarly as Beckmann & Beckmann (1966) the above cited authors pointed out that these nodules cannot be the representatives of the genus *Parachaetetes*, because the transversal bottoms in neighbouring rows of tissue are not in the same height. The authors noted that in literature presented depictions of *Parachaetetes asvapatii* PIA show strongly recrystallized nodules, where horizontal bottoms are not visible and therefore this species is questionable. Hagn & Ott (1975) mentioned, that the possible predecessor of the Paleocene *Elianella* is Cretaceous species *Cordilites cretosus* (REUSS).

Moussavian (1984) presented the occurrence of *Elianella elegans* PFENDER et BASSE in a limestone pebble with alveolinas and miliolids. Thanetian age of this pebble is indicated by larger foraminifers *Alveolina* (*Glomalveolina*) *primaeva* REICHEL and *Falotella alavensis* MANGIN. This author pointed out that *Elianella elegans* is an important component of Thanetian reef limestones and in the stratigraphic table (p. 56) he limited stratigraphic span of this species to Thanetian.

Moussavian (1989) in his paper about the system position of Solenoporaceae (Rhodophyceae) directed his attention also to problem of the conservation of genera *Parachaetetes* and *Elianella*. On the other hand he expressed an opinion that *Elianella elegans* is a younger synonym of *Parachaetetes asvapatii* but he accentuated that question of the genus *Eliannella* is still open. According Moussavian the solution of this problem depends on the revision of *Parachaetetes tornquisti*, a type species of the genus *Parachaetetes*, whether its inner structure is regular or irregular. He explained the abandonment of the species *Elianella elegans* by the fact that in the same thallus he observed both types of structure – irregular *Elianella*-type and regular *Parachaetetes*-type, but his Fig. 2 on the Plate 5 shows between these two types the sharp boundary (overgrowing of two individuals?).

Poignant (1989) presented an overview of the situation in the classification of Solenoporaceae. In the evaluation of diagnostic signs he did not avoid the horizontal partitions and he attributed them the diagnostic significance. He mentioned also the classification of Mamet & Roux (1977) in which forms with horizontal partitions are classed into the genus *Parachaetetes*. Poignant did not even mention the genus *Elianella*.

The first report of *Elianella elegans* in the Early Cretaceous gave Schlaginweit (1991) and he destroyed the conception that genus *Elianella* lived only in the Paleocene. He described and depicted the species *Elianella elegans* PFENDER et BASSE (determined him by Moussavian) from Calcareous Alps, from Lower Albian pebbles in Urgonian facies. Specimens from the Albian have filaments with a diameter of 0.02-0.03 mm. Schlaginweit described from Urgonian facies also the species *Parachaetetes* cf. *hadramauensis* ELLIOTT with nodules reaching 5 mm in diameter, having filaments with diameter of 0.025-0.045 mm and diameter of transversal bottoms of up to 0.029 mm.

Stockar (2000) stated that ring-shaped structures (cross partitions) in cell filaments are not coinciding with the true transverse cell partitions. After him they are the membranes discoid structures closing the central pores. Stockar also emphasized that the *Elianella* and *Parachaetetes* arrangement of cells may coexist inside the same single thallus and demonstrated his opinion of coexisting structures of both types in Fig. 3 (p. 430). His picture indeed shows nodule of *Parachaetetes asvapatii* PIA but different appearance of cells results from different planes of section and from the state of preservation (degree of recrystallization) of nodule. It is interesting that Stockar (l. c.) recorded considerable different measurements for *Elianella* and *Parachaetetes* in his Fig. 2 (p. 429) – low values for *Elianella* in comparison with *Parachaetetes* ones. Stockar by all means consider *Elianella elegans* as a younger synonym of *Parachaetetes asvapatii*.

Aguirre & Barattolo (2001) after detailed analysis of Late Cretaceous-Eocene material of *Parachaetetes asva-*

patii from Turkey revealed nemathecia-like structure in one specimen. The presence of nemathiecien led these authors to tentatively refer *Parachaetetes asvapatii* and related species (*Elianella elegans*) to the Gigartinales.

Bucur, Hoffmann & Kolodziej (2005) mentioned the presence of *Parachaetetes* cf. *asvapatii* in the Upper Jurassic limestones from the Holy Cross Mts. in Poland.

Comparison of the genera *Elianella* and *Parachaetetes*

On the basis of availiable literature data the following characteristics of the genera *Parachaetetes* and *Elianella* can be determined:

	Parachaetetes	*Elianella*
outer form	irregular, with lobes	irregular, with lobes
outer size	up to 7 cm	up to 6 cm
inner structure	parallel cell filaments	parallel cell filaments
diameter of filaments	0.04-0.06 mm	0.02-0.06 mm
cross partitions	present	present
shape of cells	elongated cells cylindrical	barrel-like
form of cross partitions	straight	markedly arched
arrangement of cross partitions	regular	irregular
cell height	0.04-0.12 mm	0.015-0.15 mm

From the above facts it follows that the genus *Elianella* differs from the genus *Parachaetetes* mainly by irregularly arranged cells with markedly arched cross-partitions. In view of regionally frequent occurrence of nodules of the genus *Elianella* in the Tethys region the irregularities in cell structure cannot be connected with local environmental influences. Stockar (2000) doubted the signification of cell arrangement in classification and stated that these features actually have a poor taxonomic value and can be used in separating taxa neither at generic nor at specific level, but presenting authors have a different opinion.

Already Mme Pfender (in Andrusov, 1950) conceded the possibility that locally in nodules of *Elianella elegans* are seen traces of more regular arrangements of filaments and cells. This fact is confirmed also by the presenting authors but these more regular arrangements are always only suggestions. Presenting authors did not find in nodules of *Elianella* the real typical *Parachaetetes* arrangement, only its indications. It is possible that between these two closely related species occurred also cross-breed specimens.

After the detailed study of more than 700 thin sections with presence of algae nodules the presenting authors prefer conservation of both mentioned species. In the Western Carpathian Paleogene genus *Parachaetetes* is present in lesser quantities but the genus *Elianella* in some environments is very common. In the following text the representatives of both genera will be briefly described.

Systematic description

Division Rhodophyta WETTSTEIN, **1901**
Class Rhodophyceae RABENHORST, **1863**
Subclass Florideophycidae SCHMITZ **in** ENGLER, **1892**
Order Cryptonemiales SCHMITZ **in** ENGLER, **1892**
Family Solenoporaceae PIA, **1927**
Genus *Elianella* PFENDER **et** BASSE, **1947**

Elianella elegans PFENDER **et** BASSE, **1947**
Pl. I, Fig. 2; Pl. III. Figs. 1-4; Pl. IV, Figs. 1-4

1947 *Elianella elegans* n. gen., n. sp. – Pfender & Basse, pp. 275-276, Pl. 12, Figs. 1-3.

The Carpathian specimens form compact nodules but commonly they have also lobed outer growth forms - "cauliflower heads" (Pl. I, Fig. 2; Pl. III, Figs. 3-4). Well preserved individuals reach up to 2 cm in diameter.

The tissue consists of parallel and curved (frequently fan-like arranged) filaments of cells in the form of tubes (Pl. III, Figs. 1-2; Pl. IV, Figs. 1-4). Characteristic is moniliform arrangement of barrel-like cells (Pl. IV, Fig. 1), which is not always clearly visible (Pl. III, Fig. 2). The diameter of filaments reaches 0.03-0.06 mm, the cell height varies between 0.02 and 0.12 mm. The cross partitions (membranes) are strongly arched. In contrast to the genus *Parachaetetes* the cross partitions of the adjoining filaments are not arranged in the same height (compare Pl. IV, Fig. 1 with Pl. II, Fig. 1). In some nodules the zoning in concentric belts can be observed (Pl. I, Fig. 2).

Polygonal as well as circular outlines of filaments can be seen in tangential sections (Pl. III, Fig. 1). In some oblique sections locally the traces of cross partitions are destroyed (recrystallized) (Pl. IV, Fig. 3, lower part of picture).

Occurrence: In the territory of Slovak Western Carpathians five regions with occurrences of genus *Elianella* are known (Fig. 1).

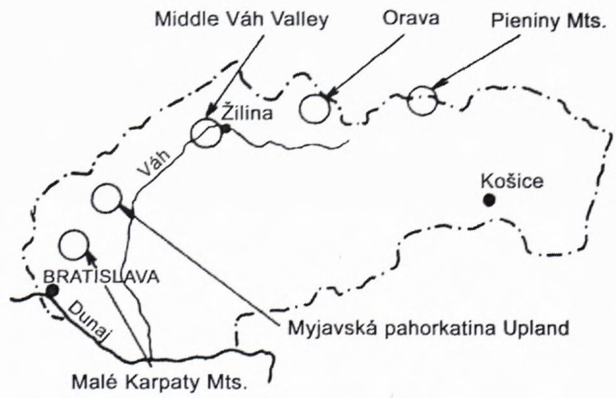

Fig. 1. Main areas of *Elianella elegans* PFENDER et BASSE and *Parachaetets asvapatii* PIA occurrences in Paleogene of Western Carpathians, Slovakia.

In the Malé Karpaty Mts. genus *Elianella* occurs in micrite limestones of the Paleocene and Early Eocene age. These limestones are either in situ (Plavecké Podhradie) or have been redeposited in the form of pebbles and blocks into Miocene conglomerates (Rozbehy – Vápenková Skala, Buková – Osečník).

Paleocene limestones do not contain larger foraminifers and their main organic components are coralline algae, *Elianella elegans* PFENDER et BASSE, *Polystrata alba* (PFENDER) DENIZOT, Dasycladales, bryozoans, molluscs, among small foraminifers the miliolid and sessile benthic forms dominate (locality Rozbehy – Vápenková Skala).

The Early Eocene limestones with *Elianella elegans* PFENDER et BASSE are very rare. Their age is indicated by the larger foraminifers *Nummulites partschi* DE LA HARPE, *Discocyclina archiaci* (SCHLUMBERGER), etc. The coralline algae and corals are frequent, but bryozoans, molluscs and benthic foraminifers are rare (Plavecké Podhradie, Buková – Osečník).

In many places of the Myjavská pahorkatina Upland the pebbles and blocks of Paleocene (Thanetian) limestones occur in Early Eocene conglomerates and flysch beds. The blocks with *Elianella elegans* PFENDER et BASSE are especially frequent in the surrounding of the villages Matejovec, Lubiná, the settlements Jeruzalem, U Kravárikov, Dlhý vŕšok, Tížikovia, Jandova dolina, Batíkovia, Hodulov vrch and near the town Stará Turá. They are predominantly micrite limestones. The Paleocene age of limestones has been confirmed by larger foraminifers *Alveolina* (*Glomalveolina*) *primaeva* REICHEL, *Miscellanea juliette* LEPPIG and *Discocyclina ramaraoi* SAMANTA. Main organic components of limestones are coralline algae, corals and small foraminifers. Very interesting is the presence of dasycladalean algae: Bystrický (1976) – *Broeckella belgica* MORELLET et MORELLET, *Dactylopora* aff. *cylindracea* LAMARCK, *Digitella radoičićae* BYSTRICKÝ; Buček (1998) – *Broeckella belgica* MORELLET et MORELLET, *Zittelina bystrickyi* (DIENI, MASSARI et RADOIČIĆ), *Z. radoičičae* (BYSTRICKÝ), *Cymopolia elongata* (DEFRANCE) MUNIER-CHALMAS, *Neomeris* (*N.*) *herouvalensis* STEINMANN, *N.* (*L.*) *koradae* DIENI, MASSARI et RADOIČIĆ, *N.* (*L.*) *oroseiana* DIENI, MASSARI et RADOIČIĆ, *N.* (*L.*) *grandis* DIENI, MASSARI et RADOIČIĆ, *Jodotella sloveniaensis* DELOFFRE et RADOIČIĆ, *Sarosiella feremolis* SEGONZAC, *Sandalia multipora* DIENI, MASSARI et RADOIČIĆ, *Frederica coniconvexa* DIENI, MASSARI et RADOIČIĆ, *F. arbutiformis* DIENI, MASSARI et RADOIČIĆ, *Terquemella macrocarpus* MORELLET et MORELLET, *Orioporella villatae* SEGONZAC, *Uteria sarda* DIENI, MASSARI et RADOIČIĆ, *U.* cf. *brocchii* MORELLET et MORELLET, *Acicularia* sp., *Rusoella radoicicae* BARATTOLO and *Halimeda* sp. The bryozoans, molluscs, ostracods, echinoids, sessile agglutinated and rotalid foraminifers are also present.

In the Middle Váh Valley region the Thanetian beds are known from the surroundings of the villages Rybárikovo (probably in situ), Hričovské Podhradie, Hlboké nad Váhom, Ovčiarsko and in the vicinity of the towns Žilina and Považská Bystrica (prevailingly in form of blocks in Early Eocene flyschoid deposits). The Thanetian age is confirmed by larger foraminifers *Alveolina* (*Glomalveolina*) *primaeva* REICHEL, *Miscellanea juliette* LEPPIG, *Discocyclina seunesi* DOUVILLÉ, *D. ramaraoi* SAMANTA, *Idalina sinjarica* GRIMSDALE, etc. Conspicuous is the correspondence with the assemblage from the Calcareous Alps mentioned by Moussavian (1984). Abundant are coralline algae, *Distichoplax biserialis* (DIETRICH) PIA, *Polystrata alba* (PFENDER) DENIZOT, bryozoans, molluscs, corals (*Dendrophylia* cf. *candelabrum* HENNIG), *Actinacis* sp.), tubes of worms, fragments of echinoids and crinoids, common are sessile and miliolid benthic foraminifers. In the vicinity of the village Hričovské Podhradie (Buček, 1998; Buček et al. in Mello et al., 2007) less frequently the dasycladalean algae occur: *Cymopolia zitteli* L. et J. MORELLET, *C. elongata* (DEFRANCE) MUNIER-CHALMAS, *Cymopolia* sp., *Neomeris* (*L.*) *koradae* DIENI, MASSARI et RADOIČIĆ, *N.* (*L.*) cf. *grandis* DIENI, MASSARI et RADOIČIĆ, *Uteria* cf. *brocchii* L. et J. MORELLET, *Uteria* sp. (?nov. sp.), *Orioporella villattae* SEGONZAC, *Rostroporella oviformis* SEGONZAC, ?*Sarfatiella* sp., *Frederica arbutiformis* DIENI, MASSARI et RADOIČIĆ, *Sandalia multipora* DIENI, MASSARI et RADOIČIĆ, *Sarosiella* sp. - *Trinocladus* sp., *Terquemella* sp. - *Acicularia* sp., *Rusoella radoičićiae* BARATTOLO, *Dactylopora bystrickyi* DIENI, MASSARI et RADOIČIĆ, *Dasycladacea* (?nov. gen.) (cf. Samuel, Borza & Köhler, 1972) and *Dactylopora deloffri* BYSTRICKÝ, *D.* aff. *cylindracea* LAMARCK (Bystrický, 1976).

In the Orava area the blocks with Paleocene limestones occur redeposited into the Late Eocene beds (Skorušina, Brezovica, Zábiedovo). Their Thanetian age is determined by *Miscellanea juliette* LEPPIG, very frequent are coralline algae, corals, miliolid foraminifers and more rare are dascladalean algae: (Bystrický, 1976) – *Broeckella belgica* MORELLET et MORELLET, *Dactylopora gusici* BYSTRICKÝ and *Neomeris* (*L.*) *koradae* DIENI, MASSARI et RADOIČIĆ, *Acicularia* sp. (Buček, unpublished); further there occur bryozoans, molluscs, ostracods, echinoids and segments of crinoids. Almost all thin sections contain sessile and agglutinated as well as rotalid foraminifers.

The last region is the Spišská Magura region (the Pieniny Mts.), where blocks of micrite limestones of Paleocene age were found near the villages Haligovce (Scheibner, 1968) and Veľký Lipník (Köhler & Buček, 2005). The Early Thanetian age is confirmed by the presence of *Alveolina* (*Glomalveolina*) *primaeva* REICHEL, *Discocyclina seunesi* DOUVILLÉ and *Miscellanea* cf. *primitiva* RAHAGHI. Nodules of *Elianella elegans* PFENDER et BASSE are very common together with coralline algae and corals, rare are dasycladalean algae, *Distichoplax biserialis* (DIETRICH) PIA, fragments of bryozoans, molluscs, echinoids, crinoids, small foraminifers are represented by miliolids, agglutinated foraminifers and rotalids.

Ecology: Elianella elegans PFENDER et BASSE prefer protected lagoonal, back-reef environments. Accumulations of nodules were recorded in back sides of reef frameworks.

Age: Paleocene to Early Eocene (in the Western Carpathians also Late Cretaceous).

Genus *Parachaetetes* DENINGER, 1906
***Parachaetetes asvapatii* PIA, 1936**
Pl. I, Fig. 1; Pl. II, Figs. 1-3

1936 *Parachaetetes asvapatii* sp. nov. – Pia in Rao & Pia, pp. 32-34, textfigs. 35-38, Pl. 3, Figs. 1-5.

The growth form is almost identical to that of *Elianella elegans* PFENDER et BASSE. Nodules have up to 2.6 cm in diameter (Pl. I, Fig. 1; Pl. II, Fig. 3). The tissue is characteristic uniform in appearance and consists of tubes (filaments) divided in cells with straight cross partitions (Pl. II, Fig. 1). The arrangement of cells of adjoining filaments into concentric rows can be seen clearly.

Cell diameter measured between centres of limiting partitions is about 0.02 to 0.05 mm. Straight horizontal partitions in adjoining filaments are arranged in the same height. This arrangement gives it the appearance of more or less regular latticework formed by transversal and longitudinal calcareous walls (Pl. II, Fig. 1). The length of cells varies considerably, even in one and the same filament between 0.03 and 0.15 mm.

In tangential sections the indications of the arrangement into rows occur (Pl. II, Fig. 2).

Occurrence: True nodules of *Parachaetetes asvapatii* PIA were found only in three regions of the Western Carpathians (Fig. 1).

In the Malé Karpaty Mts. this species was found in blocks of Paleocene limestones in Miocene conglomerates at the locality Rozbehy – Vápenková Skala together with *Elianella elegans* PFENDER et BASSE.

In the Myjavská pahorkatina Upland this species is known from localities Matejovec and Dlhý vŕšok. The Thanetian age is confirmed by larger foraminifers *Discocyclina seunesi* DOUVILLÉ and *Miscellanea juliette* LEPPIG. The thin sections demonstrated the common occurrence of fragments of corals, coralline algae, *Polystrata alba* (PFENDER) DENIZOT, fragments of molluscs, echinoids and small foraminifers (sessile forms and miliolids).

In Eastern Slovakia the blocks of Paleocene reef limestones were found near the village Radvanovce (northwest of the town Hanušovce nad Topľou) being redeposited into Early Eocene beds. These blocks are Thanetian in age after the presence of *Discocyclina seunesi* DOUVILLÉ. Besides thalli of coralline algae, *Polystrata alba* (PFENDER) DENIZOT, bodies of *Pieninia oblonga* BORZA et MIŠÍK, fragments of corals, bryozoans, molluscs and benthic small foraminifers are present.

Ecology: Parachaetetes asvapatii PIA lived in protected lagoonal and back-reef environments.

Age: Paleocene.

Conclusions

Authors of this paper prefer conservation of both genera *Elianella* and *Parachaetetes* although they admit also presence of *Elianella* nodules with indices of *Parachaetetes* structure. They did not record the typical transitional forms between these two genera but they did not exclude possibility of finding of these forms in the future.

From the above data it follows that the genus *Elianella* prefers (and together with it also the genus *Parachaetetes*) protected lagoonal and back-reef environments, the accumulations of *Elianella* nodules are known also from back sides of reef frameworks. These genera do not occur in environments connected with open sea, in front of reefs, neither on sea slopes (they are present only as redeposited fragments). Most frequently they are associated with coralline algae, corals and miliolid and sessile foraminifers.

The presenting authors cannot agree with the opinion that the genus *Elianella* is limited to the Thanetian. It evidently appears already in the Early Cretaceous (Albian), in Western Carpathians it is known from the Late Cretaceous (Senonian) to Early Eocene.

The answer to the question in the title of this paper is following: Nodules of the genus *Parachaetetes* did grow in the Paleocene in inferior quantities, but in the same time this was a period of maximal growth of nodules of the genus *Elianella*.

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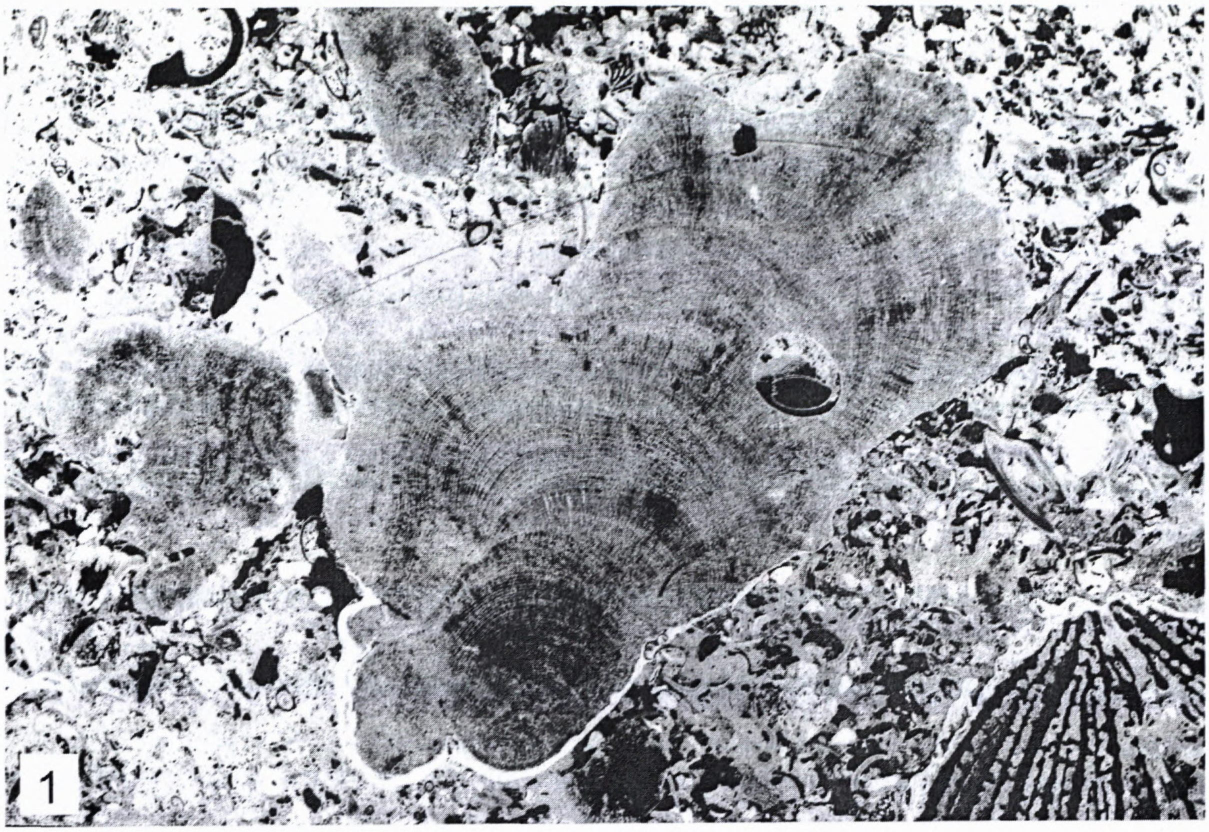

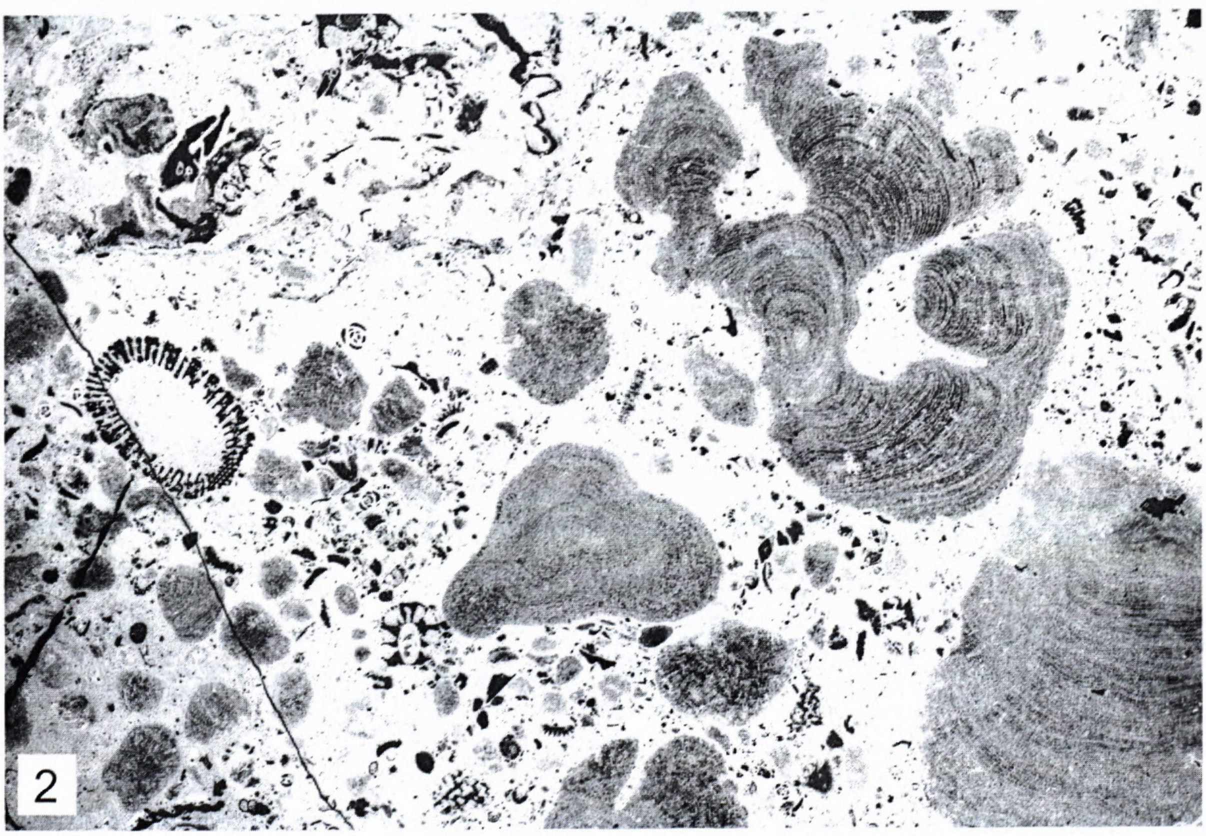

Plate I

Fig. 1 - Organodetrical limestone with section of nodule of *Parachaetetes asvapatii* PIA. Typical dense radial-concentric structure in longitudinal section. The right side of the nodule contains the boring trace infilled by calcite. Community of corals, encrusting algae and foraminifers. Back-reef environment. Myjavská pahorkatina Upland, locality Matejovec-2, thin section 1242 Bu, magn. 5x. Thanetian. Negative print; Fig. 2 - Algal foraminiferal boundstone with nodules of *Elianella elegans* PFENDER et BASSE (right side of picture). Lagoonal deposit with dasycladalean algae – *Zittelina bystrickyi* (DIENI, MASSARI et RADOIČIĆ) - middle left and *Broeckella belgica* MORELLET et MORELLET - lower left. Myjavská pahorkatina Upland, locality Matejovec-3, thin section 1546 Bu, magn. 5x. Thanetian. Negative print. Photo by authors.

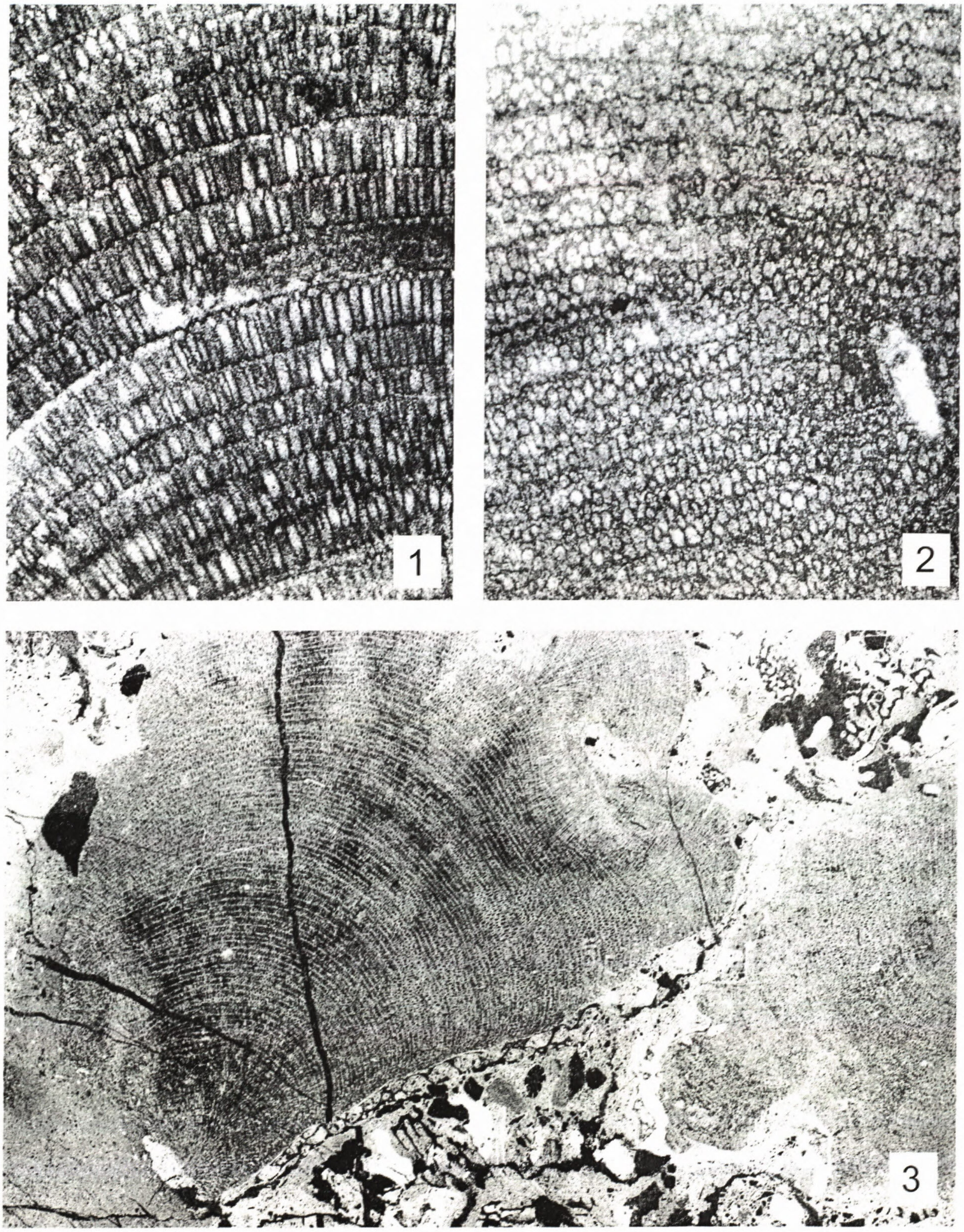

Plate II

Parachaetetes asvapatii PIA

Fig. 1 - Longitudinal section of nodule. The cells are arranged in continuous rows, cross partitions are straight. Back-reef environment. Myjavská pahorkatina Upland, locality Matejovec-2, thin section 1242 Bu, magn. 50x. Thanetian; Fig. 2 - Oblique tangential section of nodule with indications of the arrangement in the rows. Back-reef environment. Malé Karpaty Mts., locality Rozbehy – Vápenková Skala, thin section II/5 K, magn. 50x. Thanetian; Fig. 3 - Organodetrital limestone with nodules of *P. asvapatii* PIA. Typical *Parachaetetes* – regular arrangement of filaments and cells. Back-reef environment. Myjavská pahorkatina Upland, locality Dlhý vŕšok, thin section 6/3 K, magn. 5x. Thanetian. Negative print. Photo by authors.

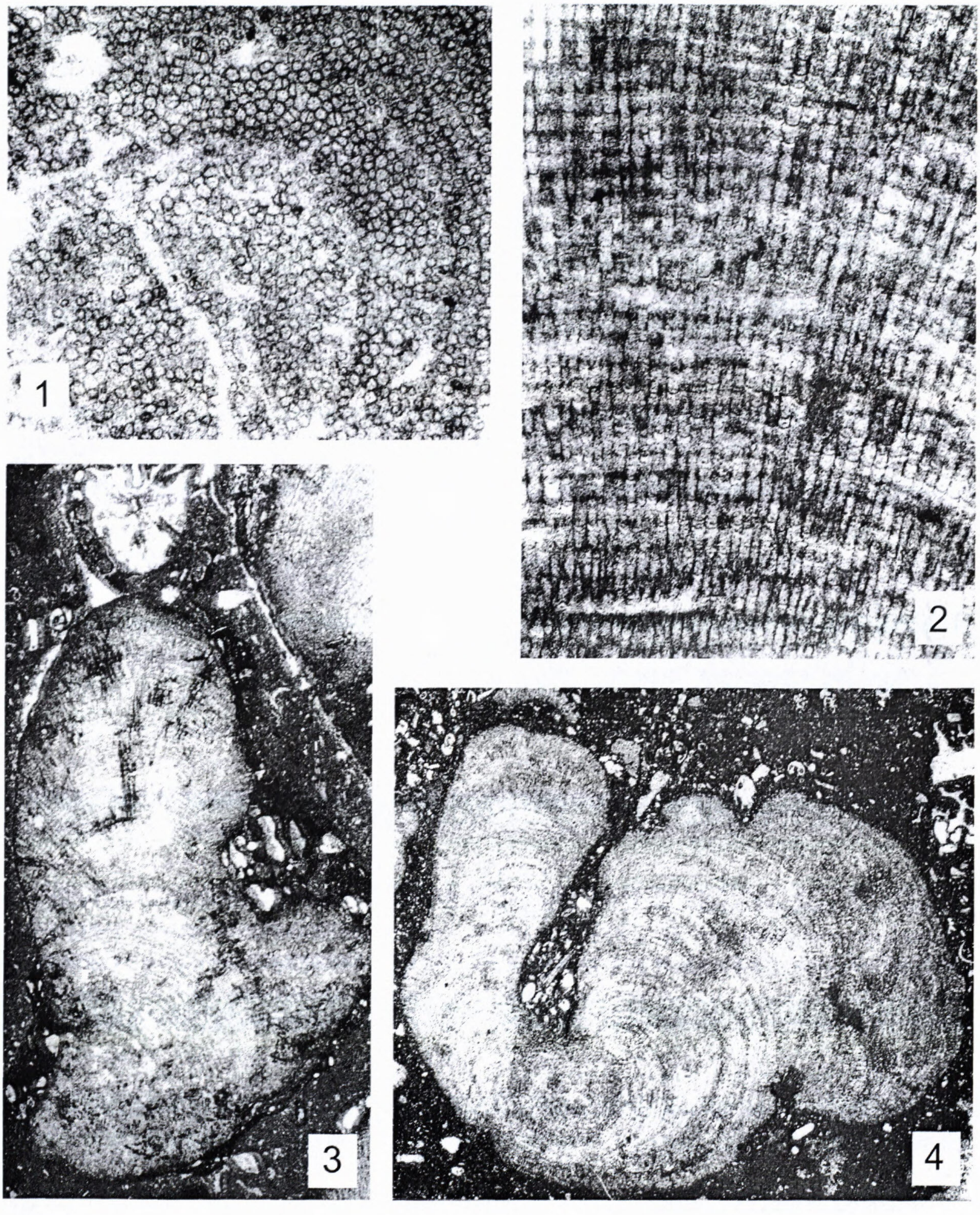

Plate III

Elianella elegans PFENDER et BASSE

Fig. 1 - Tangential section of filaments with rounded and polygonal outlines. Back-reef environment. Myjavská pahorkatina Upland, locality Hodulov vrch, thin section 7/2 K, magn. 50x. Thanetian; Fig. 2 - Nearly longitudinal section of filaments and cells. Back-reef environment. Myjavská pahorkatina Upland, locality Matejovec -1a, thin section 1335 Bu, magn. 50x. Thanetian; Fig. 3 - Section of nodule. Back-reef environment. Myjavská pahorkatina Upland, locality Jeruzalem, thin section 1/1 K, magn. 10x. Thanetian; Fig. 4. Section of irregular nodule. Back-reef environment. Orava valley, locality Zábiedovo, thin section 19/1 K, magn. 10x. Thanetian. Photo by authors.

Slovak Geol. Mag., 11, 4 (2005), 301 – 310

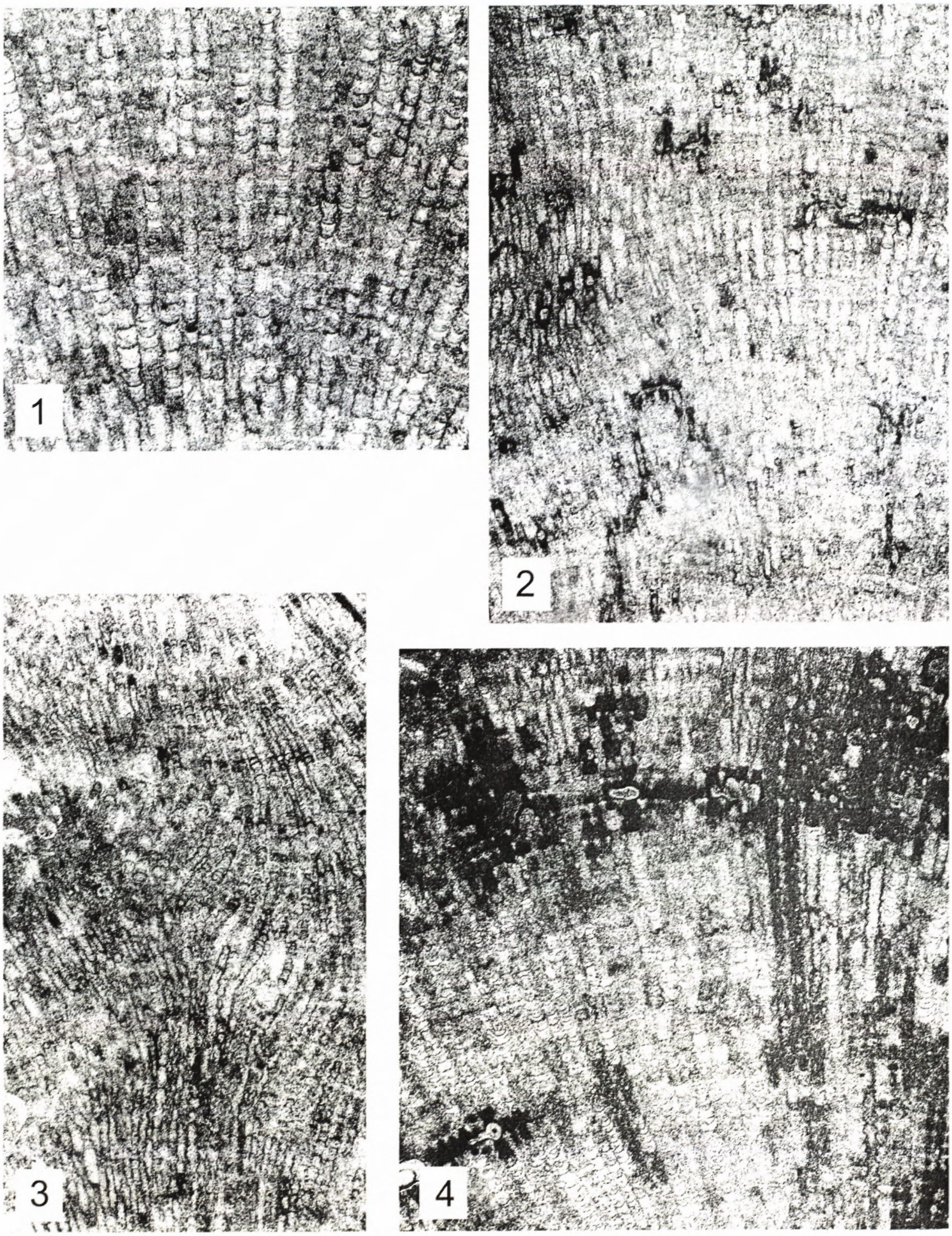

Plate IV

Elianella elegans PFENDER et BASSE

Fig. 1. Typical longitudinal section of nodule. Cross partitions of cells are irregularly arranged and strongly arched. Myjavská pahorkatina Upland, locality Jandova dolina, thin section 1/6 K, magn. 50x. Thanetian; Fig. 2. Slightly oblique longitudinal section of nodule. Spišská Magura region (the Pieniny Mts.), locality Haligovce – Paluby-6, thin section 1854 Bu, magn. 50x. Thanetian; Fig. 3. Oblique section of filaments and cells. Myjavská pahorkatina Upland, locality Priepasné, thin section 279 Bu, magn. 50x. Thanetian; Fig. 4. Longitudinal section of barrel-like cells in filaments. Orava valley, locality Skorušina, thin section 4/1 K, magn. 50x. Thanetian. Photo by authors.

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Beránek, B., Leško, B. & Mayerová, M., 1979: Interpretation of seismic measurements along the trans-Carpathian profile K III. In: Babuška, V. & Planèár, J. (Eds.): *Geodynamic investigations in Czecho-Slovakia*. Bratislava: VEDA, p. 201-205.

Lucido, O., 1993: A new theory of the Earth's continental crust: The colloidal origin. *Geol. Carpathica*, vol. 44, no. 2, p. 67-74.

Pitoòák, P. & Spišiak, J., 1989: Mineralogy, petrology and geochemistry of the main rock types of the crystalline complex of the Nízke Tatry Mts. MS – Archív GS SR, Bratislava, 232 p. (in Slovak).

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