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Fresh-water limestones of the Hlavina Bed in the Rišňov furrow and Bánovce Depression

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Abstract: Carbonate deposits (lacustrine carbonate, fresh-water limestone, travertine) crop out in the Rišňov Furrow and Bánovce Depression. They were studied at localities Malé Kršteňany, Kližské Hradište and Sádok. Based on the study of gastropods *Aegopinella orbicularis* (Klein), *Fortuna clairi* (Schlickum-Strauch), *Klikia* cf. *goniostoma* (Sandberger) and *Tropidomphalus* cf. *doderleini* (Brusina) showing their Late Panonian age they were assigned to the Hlavina Bed. The content of trace elements (Cu, Zn, Sr, Mn, K, Na, Ti , V a B) showed their fresh-water origin. Based on the carbon isotope analyses it is possible to state that a part of the fresh-water limestones is enriched in light ^{12}C isotope suggesting their organic origin. This is supported by the occurrence of fresh-water algae of *Rivularia* genus. The limestones, containing heavy carbon isotope, originated by precipitation of hydrothermal solutions enriched in $CaCO_3$. This is shown by increased Fe content in the rocks. Oxygen isotope content suggested the limestone origin in an environment 5 – 10° C warm. Occurrence of numerous onkoids in fresh-water limestone suggests a shallow-water, dynamic depositional environment.

Key words: West Carpathians, Danube Basin, Panonian, fresh-water limestone, stratigraphy, lithogeochemistry, genesis, C isotope, O isotope

Introduction

Fresh-water deposits of the Hlavina Bed, stratigraphically assigned to the Late Panonian (zone H), prevailingly consist of carbonates (lacustrine limestone, fresh-water limestone, travertine, Fordinál & Nagy 1997). They occur nearby marginal faults in the Tribeč and Považský Inovec Mts. According to the regional-geologic division (Vass et al. 1988) they occur in the Rišňov Furrow and Bánovce Depression.

In the mentioned area fresh-water limestones were studied at localities Malé Kršteňany (Bánovce Depression), Kližské Hradište and Sádok (Rišňov Furrow, Fig. 1).

We studied structure of fresh-water limestones, oxygen and carbon isotope content, trace element contents (Cu, Zn, Sr, Mn, K, Na, Ti, V, B) and we performed ma-

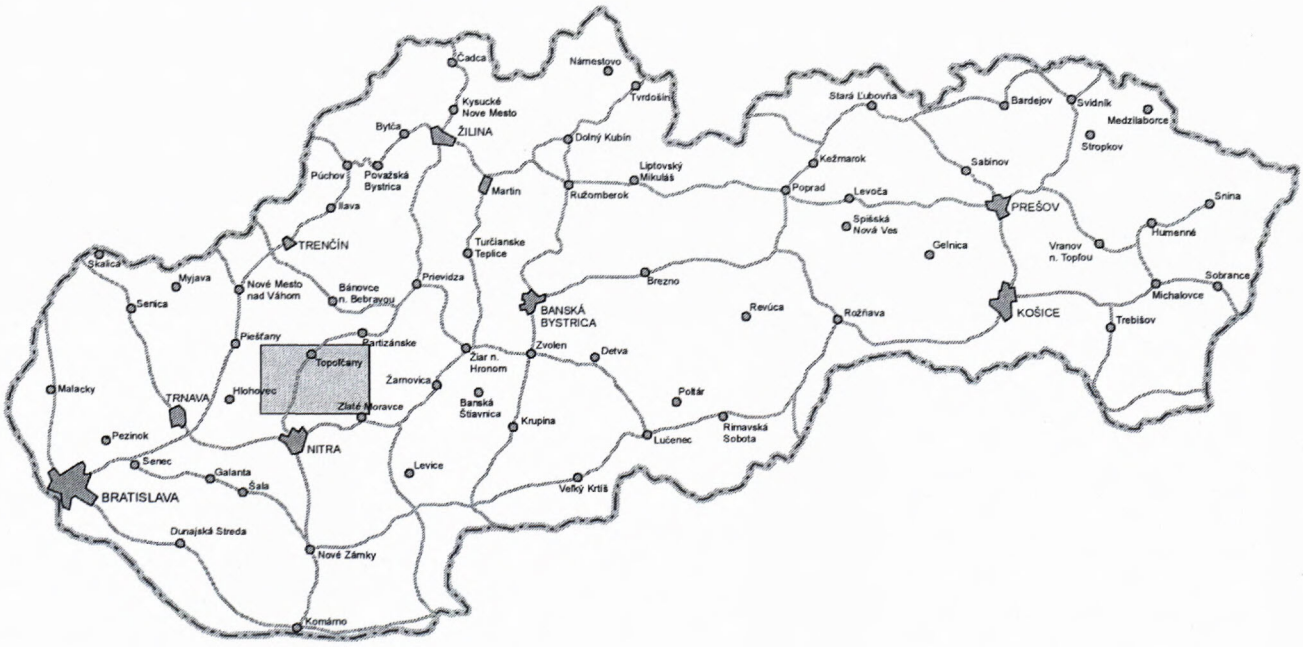


Fig. 1 Situation of studied localites

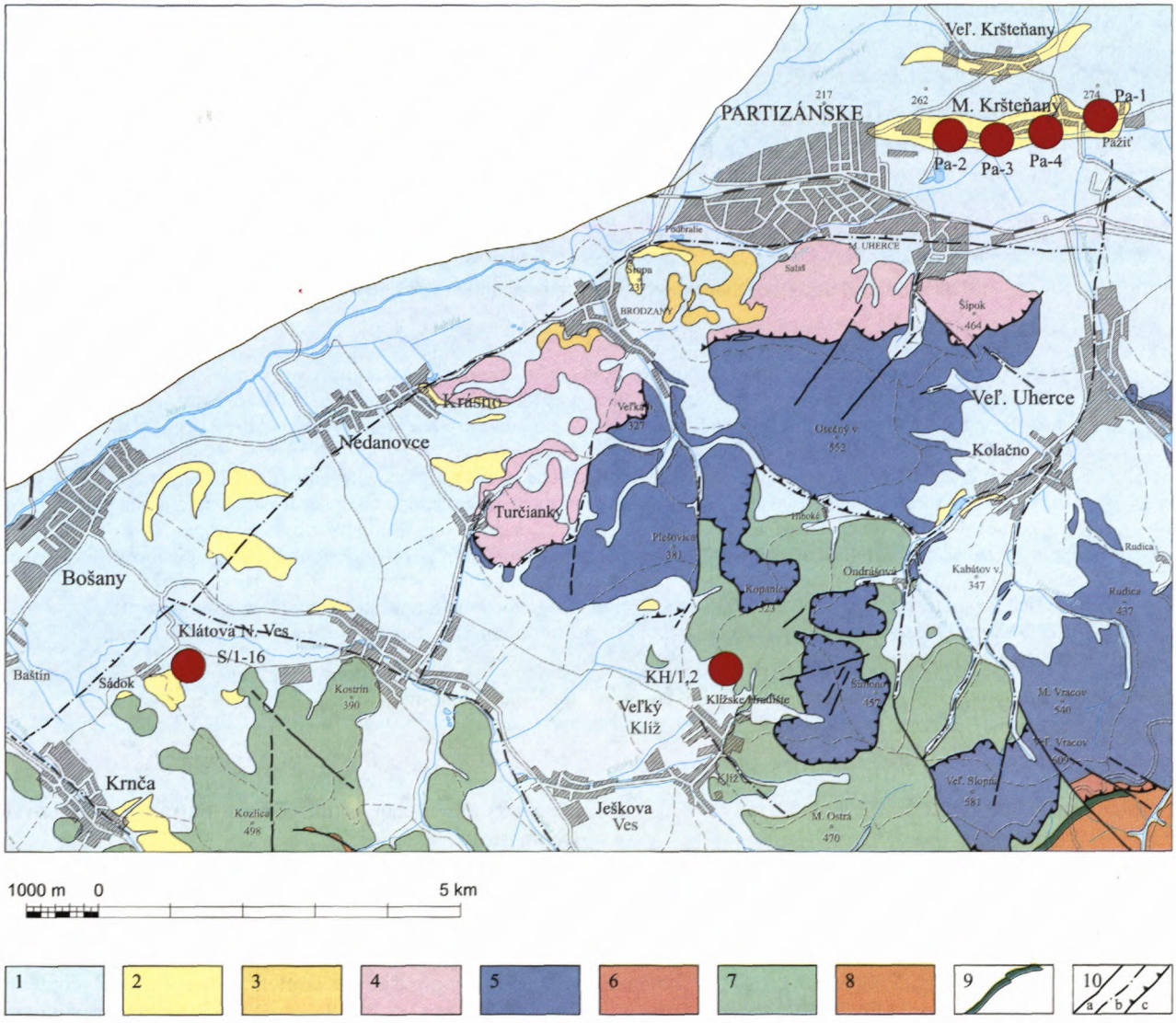


Fig. 2:Schematic of geologic map and location of studied localities
1 – Quatenary, 2 – Tertiary, 3 – Paleogene, 4 – Hronicum, 5 – Veporicum, 6 - Crystalline rocks, 7 – Tatricum (envelop unit), 8 – Crystalline rocks of Tatricum, 9 – Metamorfic rocks, 10 - Faults: a) faults assumed, c) trust lines.
The map modified based on the geological map of Tríbeč 1 : 50 000, Ivanička et al., 1998

nometric analysis. The oxygen and carbon isotope content of limestones was done in the isotope laboratory at the Geologic Survey of Slovak Republic in Mlynská dolina in Bratislava by RND. Ivan Repčok. The results were interpreted by I. Töröková (Töröková 1998).

Gastropode fauna from limestones occurring at locality Malé Kršteňany (Tab. 1) was studied by K. Fordinál.

Overview of previous research

The oldest information on fresh-water limestone occurrence in the Bánovce Depression and Rišňov Furrow originate from the second half of the 19th century.

Stache (1865) refers an occurrence of Neogene deposits consisting of clay and fresh-water limestone from the Bánovce Depression. The limestone contains gastropods of genus *Helix, Bulimus, Planorbis* and *Lymnaeus*. He found it at localities Partizánske – Šimovany (Ssimnowany), Malé Bielice (Male Bilice) and in the area between villages Malé Kršteňany (Male Kŕstenany) and Veľké Kršteňany (Welke Kŕstenany). At the end of 70-ties the region of Bánovce Depression was geologicaly completely processed (Brestenská et al. 1980). The fresh-water limestone described from surroundings of Pravotice, Bielice, Malé and Veľké Kršteňany were assigned to the Dakian.

Occurrence of fresh-water limestone in the Rišňov Furrow was known from the surroundings of villages Kovarce (Kowarz), Sádok, Bošany (Bossany), Brodzany (Brogyán), Krásno (Szeplak) and Nedanovce (Nedanocz) (Winkler 1865). At the break of century Schafarzik (1900) refers an occurrence of the deposits from Sádok (Szádok) and from the area between the villages Kovarce (Kovarcz) and Čeľadince (Családka). He assigns them in the Pliocene.

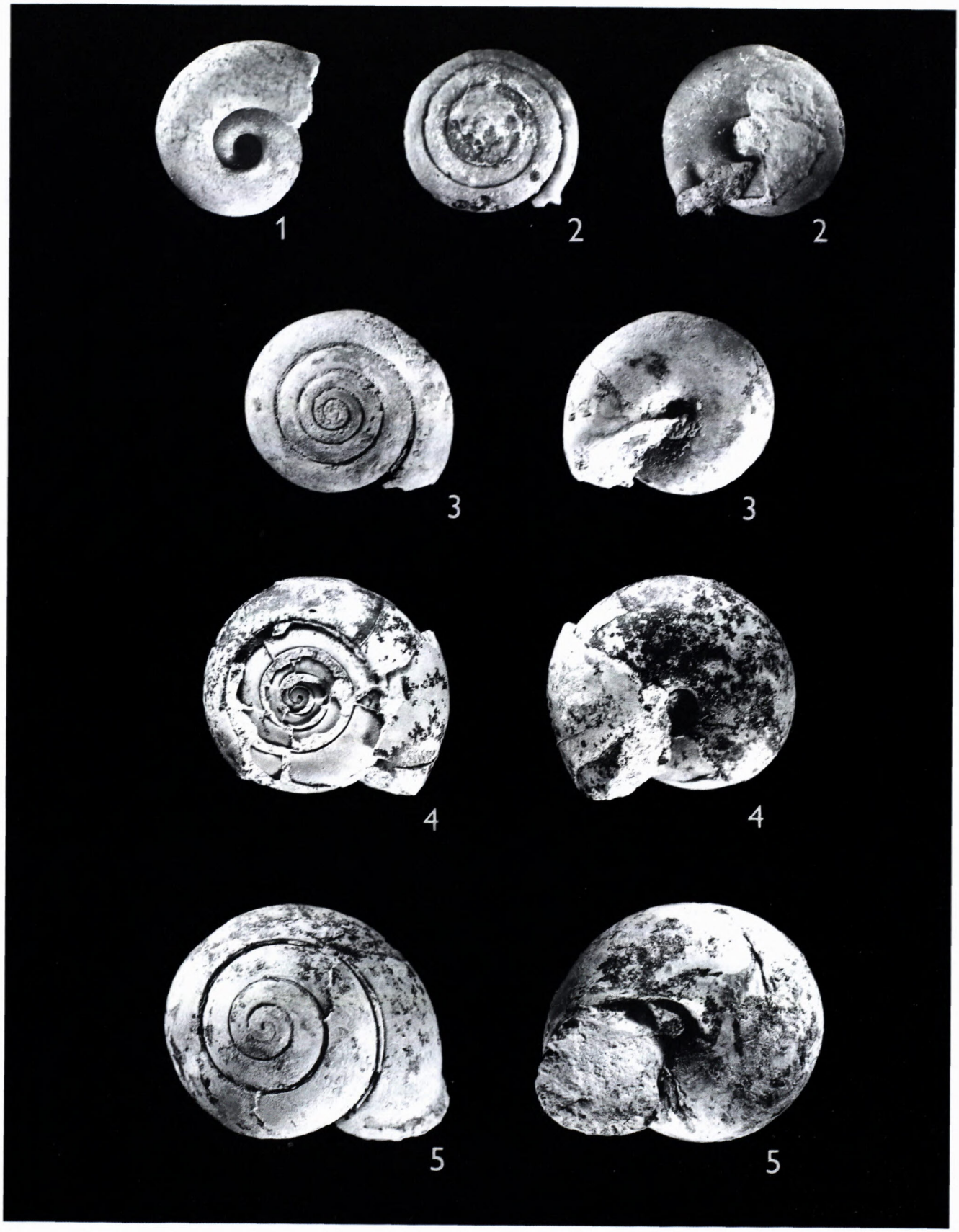


Table 1

1. *Planorbis* sp., Malé Kršteňany, Pa-3, enlarged 3,8x; 2. *Isognostoma* sp., Malé Kršteňany, Pa-2, enlarged 1,7x; 3. *Leucochroopsis kleini* (KLEIN) Malé Kršteňany, Pa-1, zv. 3x; 4. *Klikia* cf. *goniostoma* (SANDBERGER), Malé Kršteňany, Pa-2; enlarged 2,8x; 5. *Cepaea* cf. *etelkae* (HALAVÁTS), Malé Kršteňany, Pa-2, enlarged 2,7 x

Photo C. Michalíková

The western margin of the furrow (nearby Považský Inovec) was mapped by Brestenská (1962). She found remnants of fresh-water and terrestrial molluscs in the fresh-water limestones and pelitic sediments in the area. She assigned the sediments in the Pontian (Brestenská l.c.). The recent knowledge on the fresh-water limestone occurrence and molusk fauna from the area were mainly obtained by field research in the last years (Fordinál 1994, Fordinál in Maglay et al. 1997).

The eastern margin of the Rišňov Furrow (neighbouring the Tribeč Mts.) was mapped by Brestenská and Priechodská (1969). They assigned the studied deposits in the Pontian. The latest knowledge from the area are summarized in the Explanation to geologic map of Tribeč 1:50 000 (Ivanička et al. 1998).

Characteristic of localities

Malé Kršteňany

In the Malé Kršteňany village and in the quarry localized NE of the village Hlavina Bed deposits consisting of fresh-water limestone crop out. A layer containing blocks of fresh-water limestones, floating in the unconsolidated calcareous matrix of lacustrine limestone type, occurs at the base of outcrops in the village (from Pa-2 to Pa-4, Fig. 2).

The limestones have micritic and biomicritic structure. Micrite consists of fine-grained calcite and it comprises the main part of limestone matrix. The sparite cement, consisting of coarse-grained crystalline calcite, fills numerous pores, gaps and veins. Numerous sections of gastropod fragments filled by crystalline calcite occur in the limestone structure (Figs. 3 and 4). Clastic grains are represented by quartz and occasional plagioclas. Dark spots of clay admixture occur in the micrite. Fe coatings occur in pores and fissures of limestones. They also occur in the form of sphere bodies.

Malé Kršteňany – quarry
(Pa – 1, Fig. 2)

Solid fresh-water limestone occur in the upper right section of the quary. The limestone locally pass to loose rocks resembling lacustrine limestones. Cores of terrestrial and fresh-water gastropods were found at the section. The following species were identified:

Terrestrial gastropods: *Leucochroopsis kleini* (Klein), *Tropidomphalus (Mesodontopsis)* cf. *doderleini* (Brusina)
Fresh-water gastropods: *Aplexa* cf. *subhypnorum* Gottsch, *Anisus sp.*, *Viviparus sp.*

Malé Kršteňany – village

Fresh-water limestones crop out on slope in the village at three places (Pa-2 to Pa-4). The limestone contains gastropods fauna in the core form.

Pa-2

At this locality (Fig. 2) cores of terrestrial gastropods occur in the fresh-water limestones. The following gastropods were identified: *Aegopinela orbicularis* (Klein), *Fortuna clairi* Schlickum-Strauch, *Klikia* cf. *goniostoma* (Sandberger), *Cepaea* cf. *etelkae* (Halaváts), *Cepaea sp.*, *„Helix" richarzi* Schlosser, *Isognostoma sp.*, *Claussilidae indet.* Monospecific assemblage consisting of tests of *Abida* species was found in a fragment (Figs. 5 and 6).

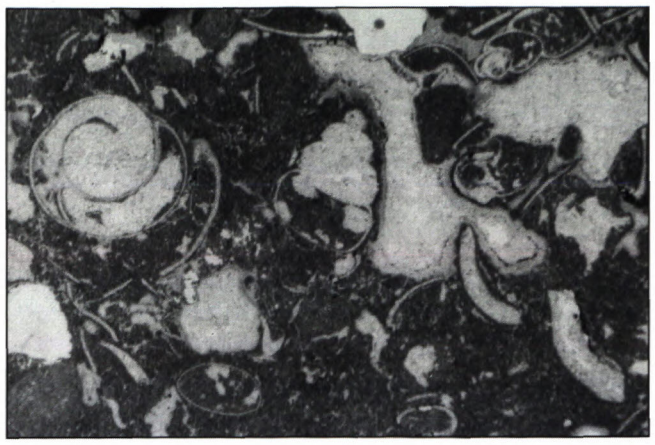


Fig. 3: Cross sections of gastropode and lamellibranchiata shells (locality Malé Kršteňany)

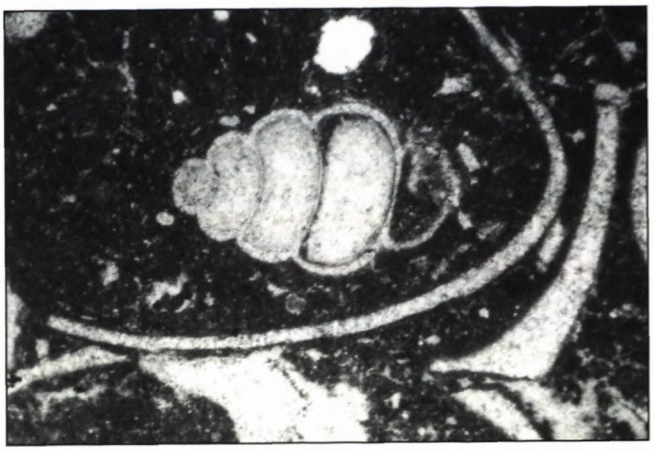


Fig. 4: Cross section of gastropode shell filled by crystalline calcite (locality Malé Kršteňany)

Pa – 3
(Figs. 7, Tab. 2)

Similarly to the previous locality cores of terrestrial and fresh-water limestones were found at the locality (Fig. 2). The following species were recognized:
terrestrial gastropods: *Aegopinella orbicularis* (Klein), *Leucochroopsis kleini* (Klein), *„Helix" richarzi* Schlosser, *Succinea* sp., *Cepaea* sp.
fresh-water gastropods: *Planorbis sp.*

Pa – 4
(Fig. 8, Tab. 3)

In the fresh-water limestones occurring at the locality (Fig. 2) cores of terrestrial gastropods of the *Cepea*, *Helicigona* and *Klikia* genus were found.

Fig. 5: Fresh-water limestone containing rich fauna of gastropodes (Abida sp.), locality Malé kršteňany Pa2, natural size, photo C. Michalíková

Fig. 6: Close-up of the Fig. 3, enlarged. 2x; photo C. Michalíková

Klížské Hradište

The studied locality represented by a quary wall occurs some 2 km NW of village Klížské Hradište (Fig. 9). In the lower part of the outcrop light-brown, baige, solid and compact fresh-water limestone with occasional porous layers occur (Fig. 10). Toward the overlying, about 20 cm thick bed, porous layers increase and the upper part is composed of weathered travertines containing red-coloured karst loams. The loams fill a few karst holes (Ivanička et al. 1998).

The limestone from the locality prevailingly has micrite structure which locally passes in to sparite structure. Numerous pores, holes and veins are filled by crystalline calcite. Onkoids, spheres of irregular form having concentric rims and central part filled by calcit, occur in the structure of the limestones (Fig. 11). Partly irregular form of micritic rim of onkoids suggests increased wave activity. According to classification of Logan et al. (1964) they may be assigned to the structural type SS – C, concentricaly growing spheroids. The clastic grains of quartz also have accretionary microcrystalline calcite consisting of thin layers. They have form of pizoids (Fig. 12).

Only fresh-water algae *Rivularia* cf. *haermatites* Shaffer & Stapf and traces after their activity represent fossil remnants. We found them in the form of clumps consisting of thin tubes filled by crystalline calcite (Fig. 13). They also form pillow forms (Fig. 14).

The mentioned algae are assigned to series *Cyanophytae* (blue-green alga) and family *Rivulariaceae*. The family is known from the pre-Cambrium.

The representants of the genus *Rivularia* prefer shallow lacustrine and fluvial environment with fresh-water. They also tolerate brackish water.

Sádok

SE of the village Sádok travertine pile occurs (Fig. 15, Tab. 4). The lower part of the pile consists of yellowish-brown coloured solid and compact layers of travertines having occasional up to 0.6 m thick interlayers of porous travertines. This passes into porous travertine with observable accretionary layers. The upper part is composed of variegated clay having 5 – 10 cm thick bed of loose sharp-edged quartz clasts without matrix at the base. Other clasts are composed of crystalline rocks. They are 1 – 2 mm in diameter. They probably represent deposits of a rapid wash of already sorted sediment from coast. The clay contains ostracods *Candona (Typhlocypris) roaixensis* Carbonell and *Candona sp.* (Fordinál in Ivanička et al. 1998).

The carbonate structure consists of micrite passing into sparite. Numerous pores are filled by crystalline calcite. In the unfilled pores calcite forms druse crystals. Occasionally pores are rimed by limonite pigment. Some pores are rimed by coarse-grained calcite. They form geopetal structures in which the lower part is composed of microsparite having a gradual transition to sparite.

Similarly to Klížske Hradište also onkoids, algae *Rivularia* cf. *haematites* Schaffer & Stapf and fragments of juvenile gastropode tests occur. Also quartz and plagioklas grains occur. A part of grains is of authigenic origin.

Fig. 7: Outcrop Malé Kršteňany Pa3

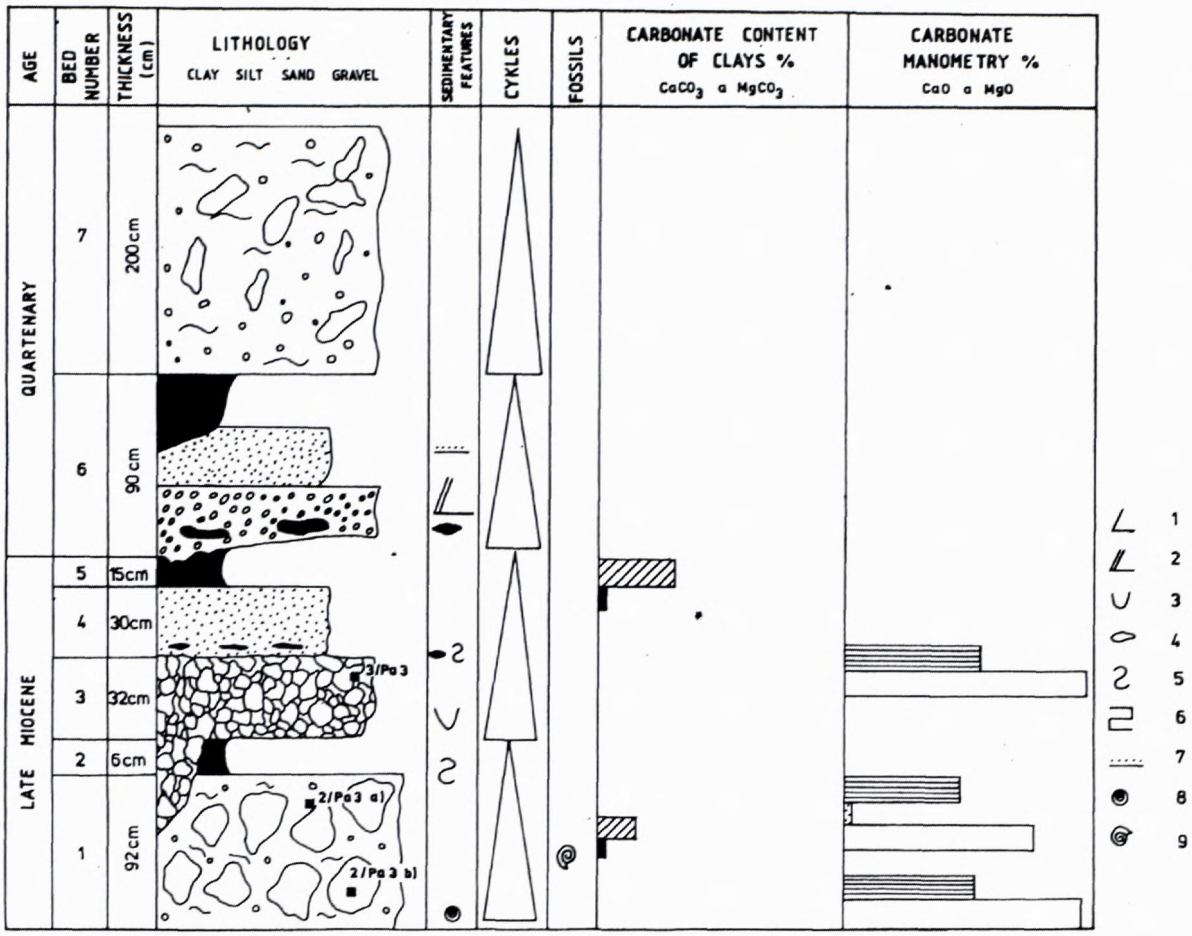
Fig. 8: Outcrop Malé Kršteňany Pa4

Biostratigraphic assignement

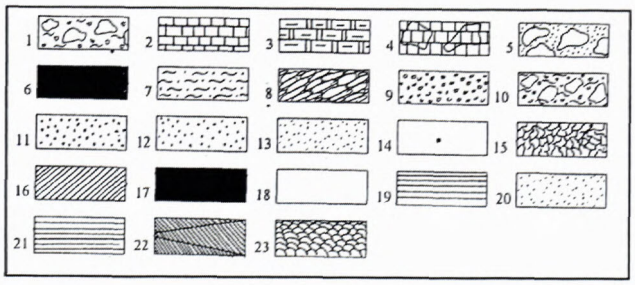
Only at locality Malé Kršteňany (Pa – 1 to Pa – 3) remnants of fresh-water and terrestrial gastropods were found which could by identified.

Gastropods with wider and narrower extent occurred in gastropod assemblages from the locality. For the biostratigraphic assignement of fresh-water limestone the occurrence of gastropods *Aegopinella orbicularis* (Klein), *Leucochroopsis kleini* (Klein), *Fortuna clairi* (Schlickum-Strauch), *Klikia* cf. *goniostoma* (Sandberger) and *Tropidomphalus (Mesodontopsis)* cf. *doderleini* (Brusina) are important.

Species *Aegopinella orbicularis* (Klein), *Leucochroopsis kleini* (Klein) generally suggest the Panonian age (sensu Rögl et al. 1993). The age is constrained by the occurrence of the species *Fortuna clairi* (Schlickum & Strauch), which stratigraphic range is the Late Panonian (zones G-H) and Pliocene (Lauger 1981). Based on the stratigraphic range of the species it is possible to state



Tab. 2: Profile of Pa3 outcrop
Sedimentary features and Fossils to the Tab. 2, 3,4: 1 – Cross stratification – normal, 2 – Cross stratification – large scale, 3 – Erosive channel, 4 – Intraclasts, rip-up clasts, 5 – Erosive surface, scor, 6 – Horizontal bedding, 7 – Gradded bedding - normal, 8 – Oolit, pisoid, 9 – Gastropode



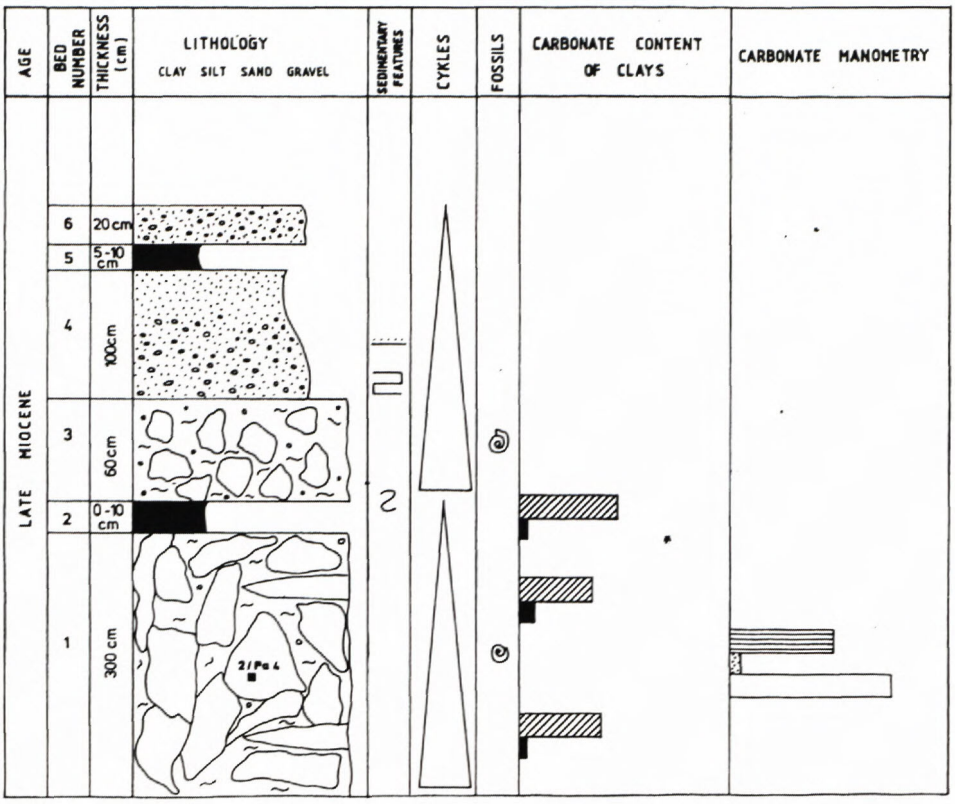
Legend to the Tabs. 2, 3 and 4
1 – oolitic limestone, 2 – massive carbonate beds, 3 – porous carbonate, travertine, 4, 5 – fine-grained carbonate with calcareous matrix, 6 – grayish clay, 7 – lake marl, 8 – conglomerate, 9 – fine-grained conglomerate, 10 – gravelly loam containing occasional pebbles,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

that the fresh-water limestones are of the Late Panonian age and they represent Hlavina Bed stratigraphically assigned to zone H (Fordinál & Nagy 1997). The stratigraphic assignement is also confirmed by the occurrence of gastropods *Klikia* cf. *goniostoma* (Sandberger) *and Tropidomphalus (Mesodonntopsis)* cf. *doderleini* (Brusina) which were up to now only found in the mentioned zone in the Danube Basin (Fordinál 1996).

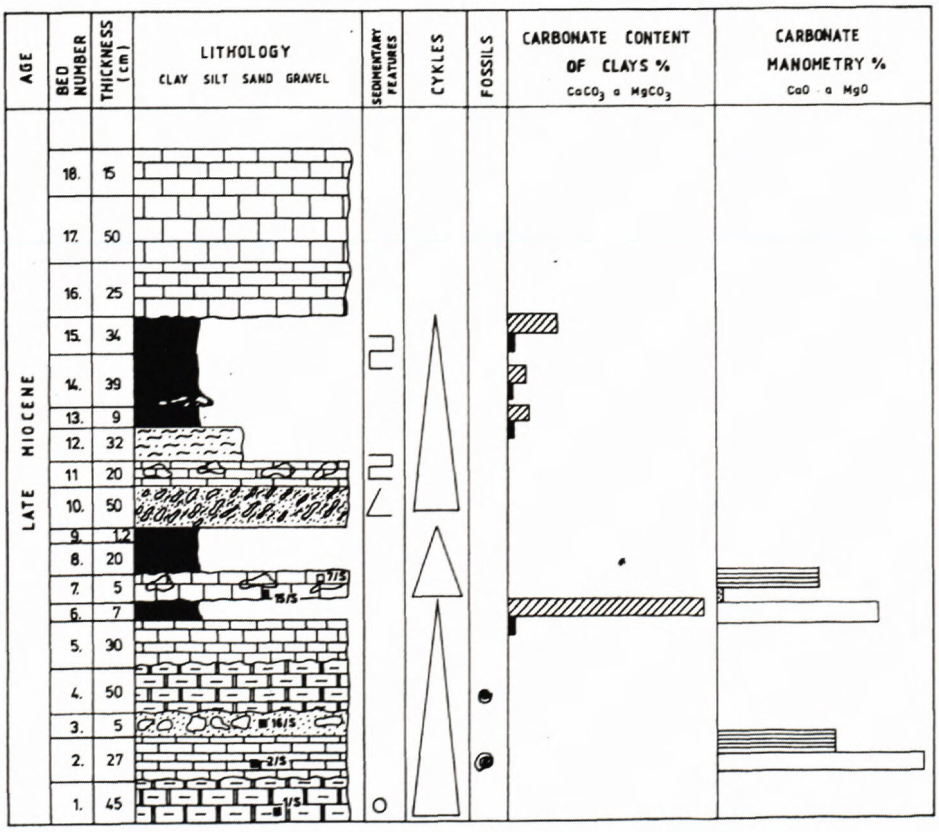
Lithogeochemistry of carbonates

Manometric analysis (Tab. 5) of studied limestones from the above mentioned localities showed that they contain 70 –98% of pure calcite. The part of them besides calcite also contains Fe dolomite (21% - 23%). The insoluble rest, represented by clay minerals, clastic quartz and feldspat grains, limonite and authigenic quartz, varies in volume from 0.30% to 6.25%. The non-carbonate part contains an essential amount of insoluble rest which does not release carbonates. Its content in limestone varies from 1.69 to 7.29%.

The $CaCO_3$ value varies from 45.59 to 54.06% while the content of molar calcium is relatively high (81.4% to 98%). The MgO content is low (1.11 to 1.20%). The molar amount of magnesium is also very low (2.7 – 3%). The FeO value is relatively high considering fresh-water



Tab. 3: Profile of Pa4 outcrop



Tab. 4: Profile of the Sádok outcrop

Fig. 9: Quarry Klížske Hradište

Fig. 10: A layer of porous limestone, locality Klížske Hradište

Table 5: Manometric analysis of carbonates

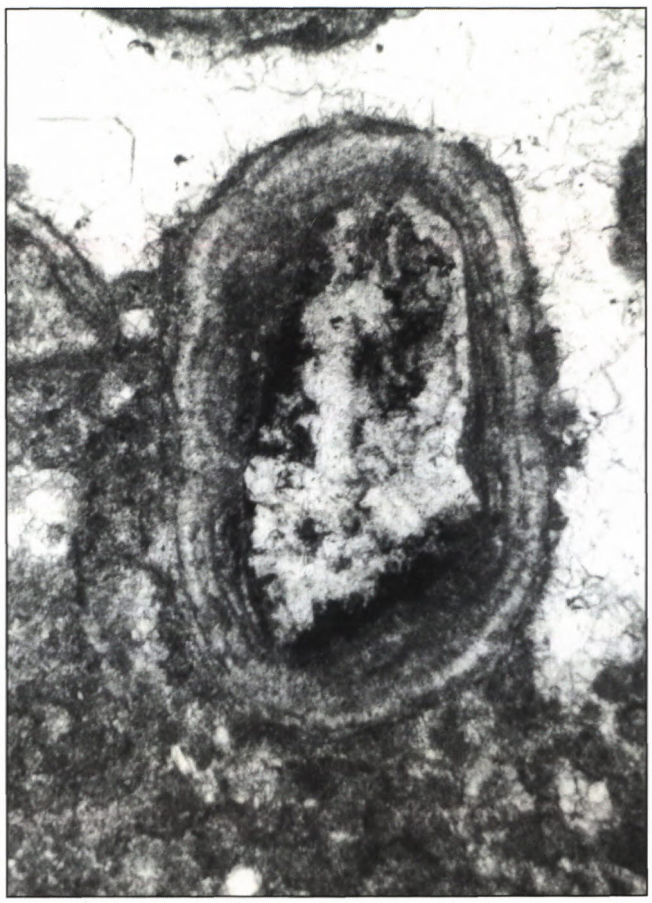
Sample No.	Locality	Calcite %	Fe - dolomite%	Nz %	Np %	CaO %	MgO %	FeO %	Co_2 %	Sr/Ca %	Mg/Ca %
1/KH	Klížske Hradište	70, 03	23, 53	5, 18	6, 43	45, 59	1, 20	6, 00	40, 77		0, 036
2/KH	Klížske Hradište	75, 26	22, 35	3, 33	2, 38	48, 20	1, 14	5, 70	42, 57	5, 345	0, 032
2/Pa3 a	M. Kršteňany	92, 71	0	3, 43	7, 29	51, 95	0	0	40, 77	60, 53	/
2/Pa3 b	M. Kršteňany	76, 56	21, 75	2, 15	1, 69	48, 77	1, 11	5, 54	42, 89	/	0, 031
3/Pa3	M. Kršteňany	97, 94	0	1, 60	2, 06	54, 88	0	0	43, 06	35, 81	/
2/Pa4	M. Kršteňany	71, 34	21, 74	6, 25	6, 91	45, 84	1, 11	5, 54	40, 59	66, 09	0, 032
2/S	Sádok	96, 48	0	1, 80	3, 52	54, 06	0	0	42, 42	45, 72	/
7/S	Sádok	74, 96	21, 74	0, 30	3, 29	47, 87	1, 11	5, 54	42, 18	30, 47	0, 031

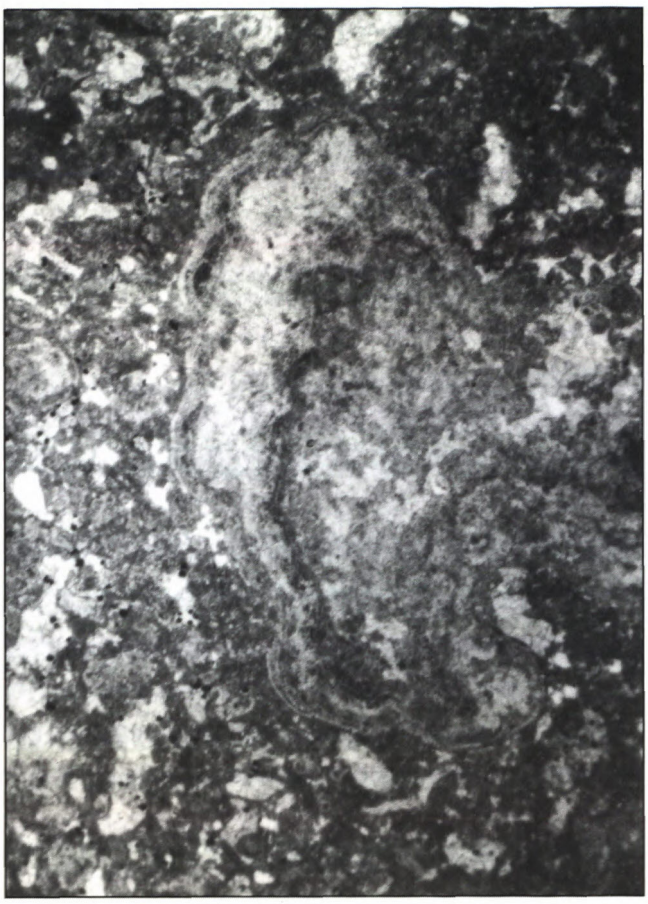
limestones (5.54% - 6.0%). FeO was probably brought by warm springs circulating on the bottom of sedimentary basin. The carbon dioxide content varies from 40.59 to 43.06%.

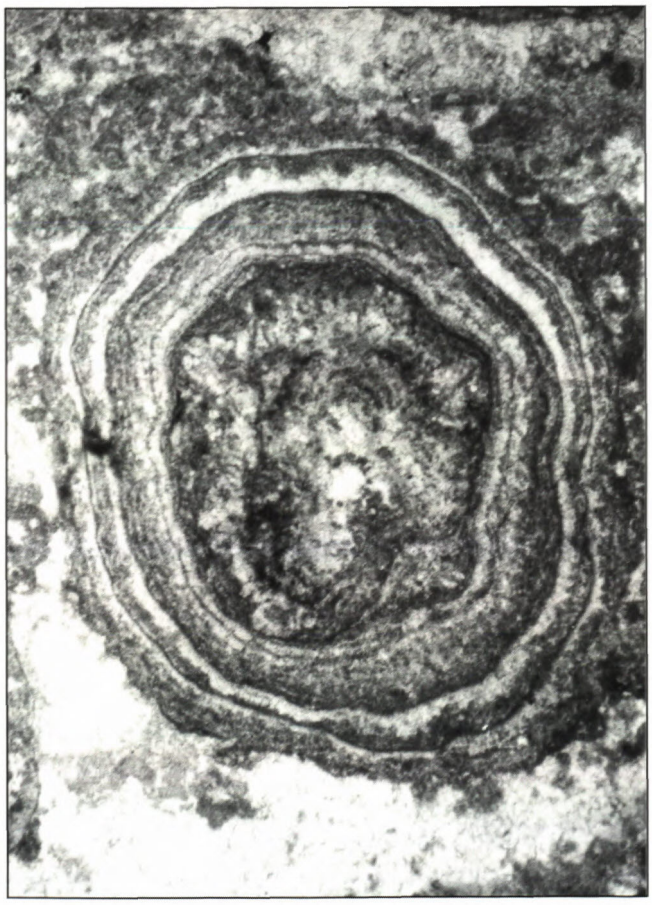
The mutual rate Sr/Ca shows high values up to 66.09. The reason may be high content of carboniferous part because Sr has tendency to bind to high-carboniferous components. The lowest value was observed in limestones from Klížske Hradište (5.34).

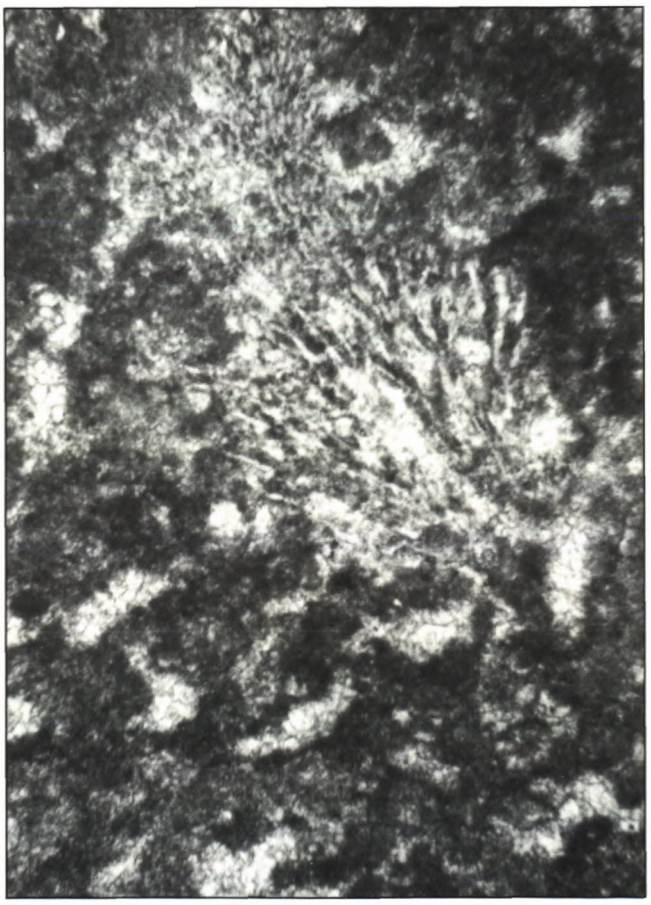
The rate Mg/Ca varies from 0.001 to 0.036 and the contents of individual samples does not show big differences. Mean value for marine carbonates is considerably higher (0.80 - 0.95) suggesting fresh-water origin of carbonates.

A layer of clayey sediment having white colour and high carbonate value with $CaCO_3$ up to 92.34% and $MgCO_3$ 0.92%. The sediment is identified as lacustrine limestone.









Also content of trace elements Cu, Zn, Sr, Mn, K, Na, Ti, V, B was analysed in limestones from studied localities (Tab. 6).

Cu – copper is biophillous element and it binds to rock-building minerals. It is a part of biologic processes. The mean values of copper in limestones are around 4 ppm (Rosler & Lange 1972). The copper content in the studied limestones varies from 1 to 6 ppm.

Zn – zincum is mainly bound with sheet silicates, oxids and Fe hydroxides. The mean value in fresh-water limestones varies from 16 to 19 ppm, the value for marine limestones varies from 18.6 to 31 pm (Wedepohl 1969). In the studied limestones the zincum value varies from 7 to 17 ppm suggesting their fresh-water origin.

Sr – stroncium is an element with afinity to high-carbonate components and it is diadochic with Ca and K elements. In the studied limestones the stroncium contents vary considerably. The lowest value occurred in the limestone from the Klížske Hradište (46 ppm). The highest value was obtained from the limestones from Malé Kršteňany (563 pm). The values in the rest of limestones varies from 259 to 542 ppm. Rosler and Lange (1972) refer the mean value for fresh-water limestone around 610 ppm. Wedepohl (1969) refers stroncium values for marine limestones form 452 to 765 ppm. The recorded values of Sr confirm fresh-water environment during the limestone origin and higher amount of Sr occurring in the samples from Malé Kršteňany may be resulted by high Ca content to which Sr has ability to bind.

Mn – manganium mainly concentrates in marine deposits what is suggested by high Mn contents more than 385 ppm in various areas (Rankama & Sahama 1952). In the studied limestones the Mn content is very low (5–76 ppm) suggesting their fresh-water origin.

Fig. 15: The outcrop Sádok

Tab. 6: Trace elements and their contents in fresh-water carbonates

No.	Sample label	Locality	(ppm) Cu	(ppm) Zn	(ppm) Sr	(ppm) Mn	ppm) K	ppm) Na	(ppm) Ti	(ppm) V	(ppm) B	(%) H_20
1.	2/Pa3	M. Kršteňany	6	12	563	7	80	20	16	<5	5	0, 24
2.	3/Pa3	M. Kršteňany	3	8	351	9	30	10	11	<5	3	0, 13
3.	2/Pa4	M. Kršteňany	5	17	542	8	230	20	34	6	12	0, 37
4.	1/S	Sádok	2	7	487	7	30	20	6	<5	<3	0, 24
5.	2/S	Sádok	1	8	439	5	30	20	4	<5	<3	0, 23
6.	7/S	Sádok	2	11	259	10	40	30	7	<5	<3	0, 27
7.	2/KH	Klížske Hradište	6	7	46	76	120	10	27	28	9	0, 32

12 14
11 13

Fig. 11: Onkoid (locality Klížske Hradište)
Fig. 12: Clastic quartz grain with concentric layers of calcite – pisoid (locality Klížske Hradište)
Fig. 13: Patches of fresh-water algae of genus Rivularia cf. haematites (locality Klížske Hradište and Sádok)
Fig. 14: Traces after activities of fresh-water algae (Klížske Hradište)

K, Na, Ti – content of the elements is generally very low. The values for kalium are 30–230 ppm (marine limestones 2700 ppm), natrium 10–30 ppm (marine limestones 370 ppm) and titanium 4–34 ppm. Concentration of the elements in marine sediments is essentially higher and the low values confirm a fresh-water origin of the studied limestones.

V – vanadium is diadochic with Fe^{3+} and it binds to organic matter and phyllosilicates. The vanadium values in the studied fresh-water limestones varies from 5 – 28 ppm. Rosler & Lange (1972) refer values obtained from Carboniferous and Mesozoic carbonates 2.5 to 10 ppm. The higher value of vanadium (28 ppm) was obtained from a sample from Klížske Hradište. It may be a result of admixture of organic matter in limestones to which vanadium is bound.

B – borum is an important element for the palaeoenvironment reconstruction and for the palaeosalinity indication. In the fresh-water environment the contents varies from 15 to 45 ppm and in marine environments it varies from 20–55 ppm (Rosler & Lange 1972). The borum value in the analyzed limestones is low (3–12 ppm) suggesting their fresh-water environment.

Content of trace elements in the studied limestones are considerably lower than referred by some authors for marine limestones. The low concentrations of individual elements in the limestones suggest their fresh-water origin.

Oxygen and carbon isotopes in limestones

Isotopic composition of oxygen (^{18}O) and carbon (^{13}C) was analyzed from four carbonate samples. Two samples were from the locality Sádok and two samples were from the locality Klížske Hradište. In the studied are limestones were also analyzed at localities Veľké Kostoľany, Bojnice, Sádok, Krásno, Záhrada nearby Veľké Tesáre, Veľký Kríž and Podhorany (Töröková 1988, Tab. 7).

Tab. 7: Values of oxygene and carbon isotopes in carbonates

Locality	Age	$^{18}O_{PDB}$	$^{13}C_{PDB}$
V. Kostolany	Quaternary	- 1, 387	2, 012
Bojnice	Riss - Würm	0, 747	- 0, 437
Sádok	Pannonian	2, 004	- 3, 285
Krasno	Pannonian	2, 838	- 3, 375
Záhrada pri V. Tesároch	Pontian - Quaternary	2, 866	- 8, 476
V. Klíž	Pannonian	3, 085	- 9, 126
Podhorany	Pannonian	3, 321	- 10, 478
Podhorany	Pannonian	3, 181	- 10, 251
Sádok 1 5	Pannonian	2, 542	- 7, 891
Sádok 1 6	Pannonian	2, 012	1, 117
Klížské Hradište	Pannonian	3, 092	- 9, 061
Klížské Hradište	Pannonian	3, 252	- 9, 165

Isotopic content of oxygen ^{18}O (Tab. 7, Fig. 16) from limestones sampled in Klížske Hradište has values $\delta^{18}O_{PDB}$ from 3.092 to +3.52 per mile. It suggest that the limestones are enriched in heavy oxygene isotope (^{18}O) and during their formation only small temperaturer fluctuation not exceeding 5°occurred. The limestones probably originated in cooler water having temperature 5–10°C.

Isotope content of ^{13}C carbon in the studied limestone, which values is $\delta^{13}C_{PDB}$ from – 9,061 to –9.165 per mile, suggests enrichment in light carbon isotope ^{12}C which is of organic origin. It showes more intensive input of organic carbon also confirmed by macrofauna occurrence and abundant occurrence of algae identified by microscopic study of limestones.

The limestones from the locality Veľký Klíž, Záhrada, Podhorany have very homogenous oxygen and carbon isotope composition (Tab. 4) and they probably originated in very similar environment like limestones from Klížske Hradište. It is possible to consider them as coeval (Pannonian) and they probably had similar origin. (Fig. 16)

Oxygen isotope composition at the locality Sádok ($\delta^{18}O_{PDB}$ from 2.012 to +2.542 per mile) shows that the limestones are enriched in heavy oxygen isotope (^{18}O) and they also originated in cooler waters having temperature 5 to 10°similarly to limestones in Klížske Hradište.

Carbon ^{13}C and its isotope composition in the limestones at the studied locality is different ($\delta^{13}C_{PDB}$ form – 7.891 to + 1.117 per mile). The values show big differences indicating possible change of the carbon source. The value ($\delta^{13}C_{PDB}$ + 1.117 per mile obtained from sample Sádok 16 shows that the limestone is enriched in heavy carbon isotope ^{13}C thus originally it is of organic origin. It is probable that it originates from warm springs. It is consisting with increased content of FeO in the limestones. The negative carbon value ($\delta^{13}C_{PDB}$ – 7.891 per mile obtained from sample S/15 (Sádok) shows the enrichment of the limestone in light carbon isotope ^{12} having organic origin. The organic carbon originates from found algae and fragments of gastropod tests.

The special distribution of oxygen and carbon isotopes in the carbonates have the samples of the Quaternary age from Veľké Kostoľany and Bojnice. The measured values of oxygen varies from ($\delta^{18}O_{PDB}$ form 0. 777 to –1.387 per mile showing their origin in warmer waters with temperature 15 to 20° C becuase they are enriched in heavy carbon isotope ^{13}C having anorganic origin. This type of carbon isotope prevailingly accumulates in warm waters (Hudson 1977). The values of carbon isotopes ^{13}C varies in the limestones ($\delta^{13}C_{PDB}$ from – 0.437 to +2.012 per mile suggesting their enrichment in heavy carbon isotope ^{13}C which is of anorganic origin. It may originate from warm hydrotherms similarly to the locality Sádok (sample no. S/16) which have content of heavy carbon isotope.

Kantor and Mišík (1992) studied travertines at locality Dubná Skala. They assigned them to the Pliocene. The recent research showed that they have originated since the Late Miocene (Hók et al. 1998). Based on carbon isotope composition they found (Kantor & Mišík 1992) that the origin of the travertines was influenced by input of anorganic carbon from warm springs and that the Quaternary

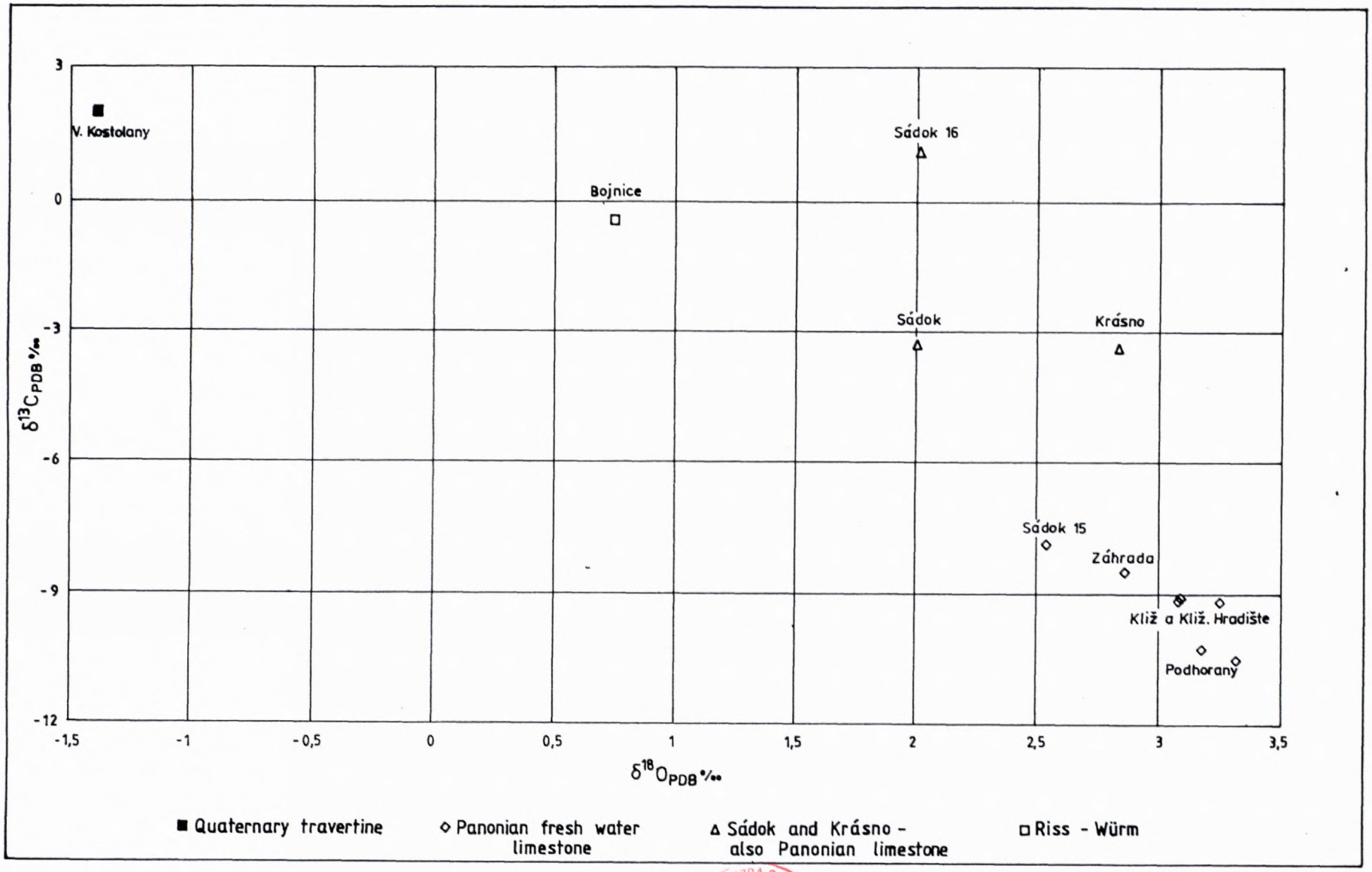


Fig. 16: Isotopic composition of oxygene and carbon in fresh-water limestones

travertines from localities Veľké Kostoľany and Bojnice and a part of the Late Pliocene travertines from locality Sádok where higher enrichment in heavy carbon isotope ^{13}C originated by similar way.

Conclusion

Studied fresh-water limestones and travertines from localities Malé Kršteňany (Pa-3, Pa-4), Sádok and Klížske Hradište originated by different ways.

Thick basal layers of boulder carbonates from Malé Kršteňany probably originated by their breaking and sliding. The occurrence of gastropode fauna in both limestone clasts and matrix proves synsedimentary origin of the boulder carbonates. Broken, chaotically arranged carbonate boulders may suggest a change of sedimentary conditions. The change might cause movement of carbonate beds and their subsequent breaking.

Beds of fresh-water limestones from localities Sádok an Klížske Hradište are prevailingly of organodetritic origin. However, a part of limestones has anorganic origin.

The organic origin of limestones is confirmed by occurrence of fresh-water algae of *Rivularia* genus and debris of gastropode shells. Layers of travertine limestone (Sádok and Klížske Hradište), having anorganic origin, occur between organogenic carbonates. They originated by precipitation of mineral springs and by hydrotherm effects at the bottom of sedimentary basin. Some percentage of Fe and limonite aggregates suggest their enrichment in Fe. Results of oxygene and carbon isotope analyses showed that except the limestones from Veľké Kostoľany and Bojnice, all the limestones probably originated in waters 5°C - 10°C warm. The first ones originated in 15°C - 20°C warm water. The water temperature could be influenced by warm mineral springs.

The depositional environment of limestones was influenced by increased wave activity. It is suggested by numerous bodies – onkoids with concentric structure. The cooler waters and climate is also evidenced by clay minerals in clays alternating with limestone layers. From clay minerals smectite prevails above illite and kaolinite. The content of trace elements in limestones proves their fresh-water origin.

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