SLOVAK GEOLOGICAL MAGAZINE

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SLOVAK GEOLOGICAL MAGAZINE

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SLOVAK GEOLOGICAL MAGAZINE

Periodical of Geological Survey of Slovak Republic is a quarterly presenting the results of investigation and researches in a wide range of topics:

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authors are to be cited with initials following the family name.

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

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

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

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SLOVAK GEOLOGICAL MAGAZINE

SLOVAK GEOLOGICAL MAGAZINE is a wide-range quarterly published since 1995. Our journal takes an advantage of a long-run publishing tradition of the former Dionýz Štúr Institute of Geology, high quality scientific papers, written exclusively in English.

Slovak Geological Magazine replaces four volumes of the "Západné Karpaty" (Western Carpathians – Geology, Mineralogy-Petrography-Geochemistry-Metallogeny, Paleontology, Hydrogeology-Engineering Geology and Geothermal Energy series), all published in Slovak, English or other languages. The edition of the Geologické Práce, Správy (Geological Works, Reports) continues in Slovak language to summarize mostly the annual reports and to inform local geological community about the results of latest activities.

Apart from the above mentioned journal Geological Survey also published the EXPLANATIONS to geological maps, the MONOGRAPHS, the specialised volumes CONFERENCES-SYMPOSIA-SEMINARS, as well as a number of occasional publications.

SLOVAK GEOLOGICAL MAGAZINE is focused on presenting the results of investigations, preferably from the Alpine-Carpathian orogenic system. If appropriate, the issues may be arranged monothematic form.

The Dionýz Štúr Institute of Geology, the Geofond Bratislava and the Slovenská geológia (Slovak Geology state enterprise) Spišská Nová Ves merged to form a new national geological institution, the Geological Survey of Slovak Republic (GS SR). Since its establishment, on January 1996, the GS SR takes over all the editions of the former Dionýz Štúr Institute of Geology. To sustain the memory of our patron Dionýz Štúr, a world known Slovak geologist, paleontologist and botanist and appointed Director of the K. K. Geologische Reichsanstalt in Vienna during the period 1885-1892, we have established on 1 January 1996 the publishing house named ***Dionýz Štúr Publishers****, which is in charge of all the above mentioned editions, issued by the* ***Geological Survey of Slovak Republic****.*

SLOVAK GEOLOGICAL MAGAZINE

Terrestrial gastropods of the Upper Pannonian in the northern part of the Danube basin

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Abstract. The paper addresses to the terrestrial gastropods found in the Upper Pannonian sediments, intersected in the borehole PID-1, drilled at the eastern margin of the Považský Inovec Mts., near the Orešany village. 26 *Gastropoda* species are described.

The terrestrial gastropods in question were found together with the fresh water species, indicating that these represented an allochthonous component in this community. They were washed down from the nearby coast. On the basis of paleoecological requirements of each gastropods species it is possible to state that the hydrophilous species prevailed, while the forest species are less and the xerophilous are the least frequent species.

The fauna in the sediments of the PID-1 borehole may be correlated with the fauna of the Eichkogel locality, found in the Austrian part of the Vienna Basin and with the Öcs locality from the Hungarian part of the Pannonian Basin.

Key words: Pannonian basin - Danube basin - Upper Pannonian - terrestrial gastropods - paleoecology

Introduction

Sediments of the Upper Pannonian (sensu RÖGL et al. 1993) rarely contain fauna which could be used for stratigraphic purposes.

In the past, 2 important Upper Pannonian localities were evaluated. The first of them is Eichkogel (stratotype of the Pannonian H zone), found in the Austrian part of the Vienna Basin, the second one is Öcs from the Hungarian part of the Pannonian Basin.

The locality Eichkogel has been evaluated several times (SCHLOSSER 1907, WENZ-EDLAUER 1942, PAPP 1951 and LUEGER 1981). The locality Öcs was similarly the object of interest of the following authors: LÖRENTHEY (1911), HALAVATS (1911), SOÓS (1934), BARTHA (1954) and SCHLICKUM (1978, 1979).

The first occurrence of Upper Pannonian fauna (zone H) in the Slovak part of the Pannonian Basin has been found at the eastern margin of Považský Inovec Mts., near the village Orešany, in the borehole PID-1 (FORDINÁL 1994). In sediments from this borehole, abundant fauna of terrestrial and freshwater gastropods has been found.

The aim of this paper is to evaluate in detail terrestrial gastropods from Upper Pannonian sediments from the borehole PID-1.

The systematic classification is based on works of LUEGER (1981) and STOJASPAL (1990).

Paleoecology

The terrestrial gastropods studied were found in the borehole PID-1 along with freshwater ones, indicating that terrestrial gastropods are an allochtonous component of the communities. They were washed down from the nearby coast into the shallow part of the freshwater lake. Based on a study of paleo-ecologic requirements of individual species of terrestrial gastropods it is possible to reconstruct the character of the shore area.

Terrestrial gastropods found in sediments from the borehole PID-1 may be classified, in accordance with LUEGER (1981), in the following groups:

1. hydrophilous, shore species: *Carychium (Saraphia) pachychilus* SANDBERGER, *Vertigo (Vertigo) callosa* (REUSS), *V. (Vertilla) oecsensis* (HALAVATS), *Succinea (Succinella) oblonga* DRAPARNAUD, *Tropidomphalus (Mesodontopsis) doderleini* BRUSINA.
2. forest species: *Acicula (Acme) edlaueri* SCHLICKUM, *Argna (Argna) suemeghyi* (BARTHA), *Acantinula trochulus* (SANDBERGER), *Discus (Discus) pleuradrus* (BOURGUIGNAt), *Semilimax intermedius* (REUSS), *Clausilia (Clausilia) strauchiana* NORDSIECK.
3. probably xerophilous species living in open areas: *Vallonia subpulchella* (SANDBERGER), *Strobilops pappi* SCHLICKUM and *Fortuna clairi* SCHLICKUM-STRAUCH.

Dominant in the samples investigated were hydrophilous species, less abundant were forest and the least abundant xerophilous species.

On the basis of above data it may be stated that the shore of the freshwater lake was damp (swamps?). This environment was replaced at a greater distance from the shore by forest environment, in which there were probably open areas with xerophilous fauna.

Interregional correlation

The terrestrial gastropod fauna from Orešany, from the borehole PID-1, stratigraphically classified as the Pannonian zone H (FORDINÁL 1994) may be correlated with the localities Eichkogel (stratotype locality of the Pannonian zone H) from the Austrian part of the Vienna Basin and the locality Öcs from the Hungarian part of the Pannonian Basin.

Comparing the occurrences of various species of terrestrial gastropods on the above three localities (Tab. 1) it may be stated that most species determined in the borehole PID-1 (22 out of 26, i.e. 84.6%) are common with the locality Eichkogel (LUEGER 1981) and 16 (61.5%) with the locality Öcs (BARTHA 1954, SCHLICKUM 1978, 1979, LUEGER 1981).

The situation as far as the occurrences of the genus STROBILOPS is concerned is interesting. Of the three species described in the borehole PID-1, the species *S. pappi* SCHLICKUM is common with the locality Eichkogel and *S. pachychila* SOOS with the locality Öcs.

Systematic part

Class Gastropoda
Subclass Prosobranchia
Order *Mesogastropoda*
Family *Acmidae*
Genus *Acicula* HARTMANN, 1821
Subgenus *Acme* HARTMANN, 1821

***Acicula (Acme) edlaueri* SCHLICKUM, 1970**
(Tab. I, Fig. 1)

1954 *Pupula limbata* (REUSS) - BARTHA: p. 175, Tab. 1, Fig. 8-10
1970 *Acicula (Acicula) edlaueri* n. sp. - SCHLICKUM: p. 86, Abb. 4
1978 *Acicula (Acicula) irenae* n.sp. - SCHLICKUM: p. 246, Tab. 18, Fig. 2
1981 *Acme (Acme) edlaueri* (SCHLICKUM) - LUEGER: p. 11, Tab. 1, Fig. 16a-b

Material: 80 specimens
Description: SCHLICKUM (1970)p. 86
Dimensions: Tab. I, Fig.1; height = 2.74 mm, width = 1.1 mm
Occurrences: Orešany, borehole PID-1 (9.8-10.0m, 10.0-10.4 m, 13.0-13.1 m, 22.0-22.1 m, 28.7-28.8 m, 32.0-32.3 m, 36.0-36.1 m, 36.5-36.6 m)
Stratigraphic and geographic distribution: This species occurs in the Pannonian H zone in Austria (Eichkogel, Richardshof) and in the Upper Pannonian in Hungary (Öcs)

Subclass *Pulmonata*
Order *Archaeopulmonata*
Family *Ellobiidae*
Genus *Carychium* O. F. MÜLLER, 1774
Subgenus *Saraphia* RISSO, 1826

***Carychium (Saraphia) pachychilus* SANDBERGER, 1875**
(Tab. I, Fig. 2)

1875 *Carychium* pachychilus SANDB. - SANDBERGER: p. 715, Tab. 27, Fig. 12
1981 *Carychium* (Saraphia) pachychilus SANDBERGER - LUEGER: p. 14, Abb. 1, Tab. 1, Fig. 5-8, 9a-b, 10 (cum syn)

Material: 1100 specimens
Description: LUEGER (1981) p. 14
Dimensions: Tab. I, Fig. 2 height = 1.83 mm, width = 0.73 mm
Occurrences: Orešany, borehole PID-1 (4.0-4.2 m, 9.8-10.0 m, 10.0-10.4 m, 13.0-13.1 m, 22.0-22.1 m, 28.7-28.8 m, 32.0-32.3 m, 36.0-36.1 m, 36.5-36.6 m)
Stratigraphic and geographic distribution: The above species is known from zones B/C (Leobersdorf), D (Leobersdorf), E (Vösendorf), G/H (Velm), H (Eichkogel, Richardshof) of the Austrian Pannonian and from the Upper Pannonian of Hungary (Rudabánya, Öcs)

Order *Stylommatophora*
Family *Vertiginidae*
Subfamily *Truncatellinae*
Genus *Negulus* O. BOETTGER, 1889

***Negulus gracilis* GOTTSCHICK-WENZ, 1919**
(Tab. I, Fig. 3-4)

1967 *Negulus suturalis gracilis* GOTTSCHICK u WENZ - SCHÜTT: p. 204
1981 *Negulus suturalis gracilis* GOTTSCHICK u WENZ - LUEGER: p. 18, Tab. 2, Fig. 2a-b

Material: 27 specimens
Description: LUEGER (1981) p. 18
Dimensions: Tab. I, Fig. 3; height = 1.73 mm, width = 0.83 mm
Occurrences: Orešany, borehole PID-1 (13.0-13.1 m, 22.0-22.1 m, 32.0-32.3 m, 36.0-36.1 m, 36.5-36.6 m)
Stratigraphic and geographic distribution: The occurrences of this species are known from the Sarmatian (Stenheim, Hollabrunn), from zones B/C (Leobersdorf) and H (Eichkogel) in the Austrian Pannonian.
Remarks: The quotet taxon I mention in the sense of STOJASPAL (1990) as species

Subfamily *Vertigininae*
Genus *Vertigo* O. F. MÜLLER, 1774
Subgenus *Vertigo* s.str.

Vertigo (Vertigo) callosa **(REUSS, 1852)**
(Tab. I, Fig. 5)

1875 *Pupa collosa* REUSS - SANDBERGER: tab. 24, fig. 19
1911 *Pupa callosa* REUSS - HALAVATS: p. 60, Tab. 3, Fig. 9
1942 *Vertigo (Vertigo) callosa callosa* (REUSS) - WENZ-EDLAUER: p. 89
1956 *Vertigo (Vertigo) callosa* (REUSS) - BARTHA: p. 518, Tab. 3, Fig. 18-19
1967 *Vertigo (Vertigo) callosa* (REUSS) - SCHÜTT: p. 206, Abb. 8
1981 *Vertigo (Vertigo) callosa* (REUSS) - LUEGER: p. 20, Tab. 2, Fig. 3.5

Material: 100 specimens
Description: LUEGER (1981) p. 20
Dimensions: Tab.I , Fig. 5, height = 1.5 mm, width = 1.03 mm
Occurrences: Orešany, borehole PID-1 (9.8-10.0 m; 10.0 - 10.4 m; 13.0 - 13.1 m; 22.0 - 22.1 m; 28.7 - 28.8 m; 32.0 - 32.3 m; 36.0 - 36.1 m; 36.5 - 36.6 m)
Stratigraphic and geographic distribution: This species is known from the Upper Oligocene in Germany (Hochheim), Lower Miocene of Bohemia (Tuchořice), zone H of the Pannonian in Austria (Eichkogel) and Upper Pannonian of Hungary (Öcs, Várpalota, Tab).

Subgenus *Vertilla* MOQUIN-TANDOM, 1885

Vertigo (Vertilla) oecsensis **(HALAVATS, 1911)**
(Tab. I, Fig. 6)

1911 *Pupa öcsensis* n.sp. - HALAVATS: p. 60, Tab. 3, Fig. 10
1942 *Vertigo (Vertilla) angustior öcsensis* (HALAVATS) - WENZ - EDLAUER: p. 90, Tab. 4, Fig. 10
1956 *Vertigo angustior öcsensis* (HALAVATS) - BARTHA: p. 518, Tab.3, Fig. 20-21
1959 *Vertigo angustior öcsensis* HALAV. - BARTHA : p. 79, Tab. 15, Fig. 9-10
1981 *Vertigo (Vertilla) angustior oecsensis* (HALAVATS) - LUEGER: p. 22, Tab. 2, Fig. 8-9

Material: 110 specimens
Description: LUEGER (1981) p. 22
Dimensions: Tab. I, Fig. 6 height = 1.73 mm, width = 0.96 mm
Occurrences: Orešany, borehole PID-1 (4.0-4.2 m, 9.8-10.0 m, 10.0-10.4 m, 13.0-13.1 m, 22.0-22.1 m, 28.7-28.8 m, 32.0-32.3 m, 36.0-36.1 m, 36.5-36.6 m)
Stratigraphic and geographic distribution: Occurrences of the above species are known in the Sarmatian in Austria, in zones D (Leobersdorf), E (Vösendorf), G/H (Velm), H (Eichkogel) of the Pannonian in Austria and from the Upper Pannonian of Hungary (Öcs, Várpalota)
Remarks: The quotet taxon I mention in the sense of STOJASPAL (1990) as species

Family *Chodrinidae*
Genus *Gastrocopta* WOLLASTON, 1778

Subgenus *Albinula* STERKI, 1892

Gastrocopta (Albinula) acuminata **(KLEIN, 1846)**

1959 *Gastrocopta (Albinula) acuminata* (KLEIN) - BARTHA: p. 80, Tab. 15, Fig. 6
1976 *Gastrocopta (Albinula) acuminata acuminata* (KLEIN) - SCHLICKUM: p. 10
1981 *Gastrocopta (Albinula) acuminata acuminata* (KLEIN) - LUEGER: p. 23, Tab. 2, Fig. 10

Material: 130 specimens
Description: LUEGER (1981) p. 23
Occurrences Orešany, borehole PID-1 (9.8-10.0 m, 10.0-10.4 m, 13.0-13.1 m, 22.0-22.1 m, 36.0-36.1 m, 36.5-36.6 m)
Stratigraphic and geographic distribution: The species is known in Europe from the Badenian to the Upper Pannonian
Remarks: The quotet taxon I mention in the sense of STOJASPAL (1990) as species

Gastrocopta (Albinula) larteti **(DUPUY, 1850)**
(Tab. II, Fig. 1)

1942 *Gastrocopta (Albinula) acuminata larteti* (DUPUY) - WENZ-EDLAUER: p. 91, Tab. 4, Fig. 11
1979 *Gastrocopta (Albinula) acuminata larteti* (DUPUY) - SCHLICKUM : p. 408, Tab. 23, Fig. 3
1981 *Gastrocopta (Albinula) acuminata larteti* (DUPUY) - LUEGER: p. 24, Tab. 2, Fig. 11

Material: 25 specimens
Description: LUEGER (1981) p. 24
Dimensions: Tab. II, Fig. 1, height = 2.58 mm, width = 1.84 mm
Occurrences: Orešany, borehole PID-1 (10.0-10.4 m, 22.0-22.1 m, 32.0-32.3 m, 36.0-36.1 m)
Stratigraphic and geographic distribution: Occurrences of this species were found in all of the Miocene.
Remarks: The quotet taxon I mention in the sense of STOJASPAL (1990) as species

Subgenus *Sinalbinula* PILSBRY, 1916

Gastroconpta (?Sinalbinula) infrapontica **WENZ, 1927**
(Tab. I, Fig. 7)

1959 *Gastrocopta fisidens infrapontica* WENZ - BARTHA: p. 79, Tab. 15, Fig. 2
1979 *Gastrocopta (Sinalbinula) fisidens infrapontica* WENZ - SCHLICKUM: Tab. 23, Fig. 6
1981 *Gastrocopta (?Sinalbinula) fisidens infrapontica* WENZ - LUEGER: p. 27, Tab. 2, Fig. 20-21

Material: 10 specimens
Description:LUEGER (1981) p. 27
Dimensions: Tab. I, Fig. 7, height = 2.5 mm, width = 1.25 mm

Occurrences: Orešany, borehole PID-1 (10.0-10.4 m, 13.0-13.1 m, 36.5-36.6 m)
Stratigraphic and geographic distribution: The species is known from the Badenian to the Upper Pannonian in Austria and Hungary
Remarks: The quotet taxon I mention in the sense of STOJASPAL (1990) as species

Family *Pupillidae*
Genus *Argna* COSSMANN, 1899
Subgenus *Argna* s.str.

Argna (Argna) suemeghy **(BARTHA, 1956)**
(Tab. II, Fig. 2)

1956 *Agardia sümeghyi* n.sp. - BARTHA: p. 519, Tab. 4, Fig. 3-4
1959 *Agardia sümeghyi* BARTHA - BARTHA: p. 81, Tab. 15, Fig. 17
1978 *Argna oppoliensis* (ANDREAE - SCHLICKUM: p. 252, Tab. 19, Fig. 10
1981 *Argna (Argna) suemeghyi* (BARTHA) - LUEGER: p. 32, Tab. 3, Fig. 9, 10-11

Material: 50 specimens
Description: BARTHA (1956) p. 519
Dimensions: Tab. II, Fig. 2, height = 3.06 mm, width = 1.24 mm
Occurrences: Orešany, borehole PID-1 (13.0-13.1 m, 22.0-22.1 m, 36.0-36.1 m, 36.5-36.6 m)
Stratigraphic and geographic distribution: The species is known from zones G/H (Velm) and H (Eichkogel, Richrdshof) of the Pannonian in Austria and from the Upper Pannonian of Hungary (Tab, Öcs).

Family *Valloniidae*
Subfamily *Valloniidae*
Genus *Vallonia* RISSO, 1826

Vallonia subpulchella **(SANDBERGER, 1875)**
(Tab. II, Fig. 3)

1875 *Helix (Vallonia) subpulchella* SANDBERGER - SANDBERGER: p. 544, Tab. 29, Fig. 3a-c
1959 *Vallonia subpulchella* (SANDBERGER) - BODA: p. 739, Tab. 37, Fig. 1
1981 *Vallonia subpulchella* (SANDBERGER) - LUEGER: p. 33, Tab. 3, Fig. 13a-c

Material: 30 specimens
Description: LUEGER (1981) p. 33
Dimensions: Tab. II, Fig. 3, width = 2.48 mm, height = 1.42 mm
Occurrences: Orešany, borehole PID-1 (10.0-10.4 m; 22.0-22.1 m; 28.7-28.8 m; 32.0-32.3 m; 36.0-36.1 m; 36.5-36.6 m)
Stratigraphic and geographic distribution: Occurrences of this species are known from the H zone of the Austrian Pannonian (Eichkogel), Sarmatian and Upper Pannonian of Hungary (Öcs).

Subfamily *Acanthinulinae*
Genus *Acanthinula* BECK, 1847

Acanthinula trochulus **(SANDBERGER, 1875)**
(Tab. II, Fig. 6)

1875 *Pupa (Modicella) trochulus* SANBERGER - SANDBERGER: p. 601, Tab. 29, Fig. 25a-b
1907 *Pupa (Modicella) trochulus* SANDBERGER - TROLL: p. 76
1921 *Acanthinula trochulus* (SANDBERGER) - WENZ: p. 31
1981 *Acanthinula trochulus* (SANDBERGER) - LUEGER: p. 34, Tab. 3, Fig. 14

Material: 2 specimens
Description: LUEGER (1981) p. 34
Dimensions: Tab. II, Fig. 6; height = 1,8 mm, width = 1,8 mm
Occurrences: Orešany, borehole PID-1 (22.0-22.1 m)
Stratigraphic and geographic distribution: This species is known from zones D (Heilsamer Brunnen at Leobersdorf) and H (Eichkogel) of the Austrian Pannonian..

Subfamily *Strobilopsinae*
Genus *Strobilops* PILSBRY, 1893
Subgenus *Strobilops* s.str.

Strobilops (Strobilops) costata **(CLESSIN, 1877)**
(Tab. III, Fig. 2)

1915 *Strobilops (Str.) costata* (SBG. emend CLESSIN) - WENZ: p. 79, Tab. 4, Fig. 15a-c, 16a-c
1961 *Strobilops (Strobilops) costata* (CLESSIN) - STEKLOV: p. 4, Abb. 2-4
1966 *Strobilops (Strobilops) costata* (CLESSIN) - STEKLOV: p. 171 Tab. 5, Fig. 99-100
1967 *Strobilops (Strobilops) costata* (CLESSIN) - SCHÜTT: p. 213, Abb. 15

Material: 67 specimens
Description: STEKLOV (1966) p. 171
Dimensions: Tab. III, Fig. 2, height = 1.5 mm, width = 2.6 mm
Occurrences:Orešany,borehole PID-1 (13.0-13.1 m), 22.0-22.1 m, 36.0-36.1 m)
Stratigraphic and geographic distribution: Occurrences of this species are known from the Upper Miocene in Germany (Undorf), Poland Oppeln) and the Fore-Caucasian region.
Notes: The genus *Strobilops* occurred in Europe from the Eocene, its greatest development was reached in the Miocene and at the end of Pliocene it died out. At present there are known 19 species of this genus. They occur in SE Asia (China, Japan, Korea), on Philippines and on the American continent (from SE provinces of Canada to Venezuela, NE part of Brasil and on the Galapagos Islands (STEKLOV, 1961).

***Strobilops (Strobilops) pachychila* Soós, 1955**
(Tab. III, Fig. 1)

1934 *Strobilops tiarula* SBGR. - SOÓS: p. 196
1955 *Strobilops tiarula pachychilus* SOÓS n.v. - BARTHA-SOÓS: p. 65, Tab. 5, Fig. 11-13
1959 *Strobilops tiarula pachychilus* SOÓS - BARTHA: Tab. 15, Fig. 12, 14
1978 *Strobilops (Strobilops) pachychila* SOÓS - SCHLICKUM: p. 409, Tab. 23, Fig. 8

Material: 15 specimens
Description: BARTHA-SOÓS (1955), p. 65
Dimensions: Tab. III, Fig. 1, height = 1.6 mm, width = 2.2 mm
Occurrences: Orešany, borehole PID-1 (22.0-22.1 m, 36.0-36.1 m, 36.5-36.6 m).
Stratigraphic and geographic distribution: Up to now, the species has been known noly from the Upper Pannonian of Hungary (Öcs).

***Strobilops (Strobilops) pappi* SCHLICKUM, 1970**
(Tab. III, Fig. 3)

1970 *Strobilops (Strobilops) pappi* n.sp. - SCHLICKUM: p. 84, Abb. 2-3
1981 *Strobilops (Strobilops) pappi* SCHLICKUM - LUEGER: p. 36, Tab. 4, Fig. 1a-c

Material: 150 specimens
Description: SCHLICKUM (1970) p. 84
Dimensions: Tab. III, Fig. 3, height = 1.17m, width = 1.87 mm
Occurrences: Orešany, borehole PID-1 (4.0-4.2 m; 9.8-10.0 m; 10.0-10.4 m; 13.0-13.1 m; 22.0-22.1 m; 28.7-28.8 m; 32.0-32.3 m; 36.0-36.1 m; 36.5-36.6 m)
Stratigraphic and geographic distribution: This species occurs in zones D (Leobersdorf), E (Vösendorf), G/H (Velm) a H (Eichkogel, Richardshof) in Austria.

Suborder *Heterurethra*
Family *Succineidae*
Genus *Succinea* DRAPARNAUD, 1801
Subgenus *Succinella* MABILLE, 1870

***Succinea (Succinella) oblonga* DRAPARNAUD, 1881**

1964 *Succinea (S.) oblonga* DRAPARNAUD, 1801 - LOŽEK: p. 230, Tab. 12, Fig. 7-9
1975 *Succinea (Succinella) oblonga* DRAPARNAUD - SCHLICKUM: p. 58, Tab. 5, Fig. 29
1980 *Succinea (Succinella) oblonga* DRAPARNAUD - SCHLICKUM - GEISSERT: p. 234, Tab. 13, Fig. 23
1981 *Succinea (Succinella) oblonga* DRAPARNAUD - LUEGER: p. 38, Tab. 4, Fig. 13-14

Material: 1 specimen
Description: LOŽEK (1964) p. 230
Occurrences: Orešany, borehole PID-1 (22.0-22.1 m)
Stratigraphic and geographic distribution: Occurrences of this genus in Europe are know from the Pannonian to the Recent.

Subordo *Sigmuretha*
Superfamily *Enodontacea*
Family *Enodontidae*
Subfamily *Punctinae*
Genus *Punctum* MORSE, 1864
Subgenus *Punctum* s.str.

***Punctum (Punctum) propygmaeum* ANDREAE, 1904**
(Tab. II, Fig. 4)

1942 *Punctum (Punctum) pygmaeum* (DRAPARNAUD) - WENZ - EDLAUER: p. 92
1975 *Punctum (Punctum) propygmaeum* ANDREAE - SCHLICKUM: p. 59, Tab. 5, Fig. 30
1981 *Punctum (Punctum) pygmaeum propygmaeum* ANDREAE - LUEGER: p. 39, Tab. 4, Fig. 4a-c, 5a-

Material: 10 specimens
Description: LUEGER (1981) p. 39
Dimensions: Tab. II, Fig. 3, height = 0.9 mm, width = 1.73 mm
Occurrences: Orešany, borehole PID-1 (10.0-10.4 m; 36.0-36.1 m)
Stratigraphic and geographic distribution: The species occurs in the Upper Miocene **of Europe**.
Remarks: The quotet taxon I mention in the sense of STOJASPAL (1990) as species

Subfamily *Discinae*
Genus *Discus* FITZINGER, 1833
Subgenus *Discus* s.str.

***Discus (Discus) pleuradrus* (BOURGUIGNAT, 1881)**

1875 *Patula euglyphoides* SANDB. - SANDBERGER: p. 583, Tab. 29, Fig. 1
1907 *Patula euglyphoides* SANDB. - TROLL: p. 73
1967 *Discus (Discus) pleuradrus pleuradrus* (BOURGUINAT) - SCHÜTT: p. 213, Abb. 16
1981 *Discus (Discus) pleuradrus* (BOURGUIGNAT) - LUEGER: p. 40, Tab. 4, Fig. 6a-c, 7

Material: 40 specimens
Description: LUEGER (1981) p. 40
Occurrences: Orešany, borehole PID-1 (9.8-10.0 m; 13.0-13.1 m; 22.0-22.1 m; 32.0-32.3 m; 36.0-36.1 m; 36.5-36.6 m)
Stratigraphic and geographic distribution: This species occurs in the Upper Miocene (Sansan - type locality) of France, in the Badenian, Sarmatian (Stenheim, Hollabrunn, Oberdorf), in zones B/C of the Pannonian (Lanzendorf, Leobersdorf), D (Leobersdorf), E (Vösendorf), G/H (Velm), H (Eichkogel) in Austria and in the Upper Pannonian of Hungary (Öcs).

Superfamily *Zonitacea*
Family *Vitrinidae*
Subfamily *Vitrininae*
Genus *Semilimax* AGASSIZ, 1845

Semilimax intermedius **(REUSS, 1852)**

1954 *Daudebardia* cf. *praecusor* ANDREAE - PAPP-THENIUS: Tab. 4, Fig. 12
1981 *Semilimax intermedius* (REUSS) - LUEGER: p. 41, Tab. 5, Fig. 1a-b, 2-3

Material: 3 specimens
Description: LUEGER (1981) p. 41
Occurrences: Orešany, borehole PID-1 (13.0-13.1m; 36.0-36.1 m)
Stratigraphic and geographic distribution: Occurrences of this species are known in Europe from the Eggenburgian to the Upper Pannonian.

Subfamily *Zonitinae*
Genus *Oxychilus* FITZINGER, 1833
Subgenus *Oxychilus* s.str.

Oxychilus (Oxychilus) procellarius **(JOOSS, 1918)**

1934 *Oxychilus (Oxychilus) procellaria* JOOSS - SOÓS: p. 197
1942 *Oxychilus (Oxychilus) procellarium* (JOOSS) - WENZ - EDLAUER: p. 93
1981 *Oxychilus (Oxychilus) procellarium* (JOOSS) - LUEGER: p. 46, Tab. 6, Fig. 2a-c

Material: 580 specimens
Description: LUEGER (1981) p. 46
Occurrences: Orešany, borehole PID-1 (4.0-4.2 m; 9.8-10.0 m; 10.0-10.4 m; 13.0-13.1 m; 22.0-22.1 m; 28.7-28.8 m; 32.0-32.3 m; 36.0-36.1 m; 36.5-36.6 m)
Stratigraphic and geographic distribution: The species is known from the Lower Miocene (Morsingen), Sarmatian (Stenheim) the zones B/C (Leobersdorf), D Leobersdorf), H (Eichkogel) of the Pannonian of Austria and from the Upper Pannonian of Hungary (Öcs).

Family *Subulinidae*
Genus *Fortuna* SCHLICKUM-STRAUCH, 1972

Fortuna clairi **SCHLICKUM-STRAUCH, 1972**
(Tab. II, Fig. 5)

1970 *Rumina seringi* (MICHAUD) - SCHLICKUM: p. 87, Fig. 7-9 (non 5-6)
1972 *Fortuna clairi* n.sp. - SCHLICKUM-STRAUCH: p. 72, Fig. 3-4
1975 *Fortuna clairi* SCHLICKUM-STRAUCH - SCHLICKUM: p. 63, Tab. 6, Fig. 43

Material: 20 specimens
Description: SCHLICKUM - STRAUCH (1972) p. 72
Dimensions:Tab.II,Fig. 5, height=3.4 mm, width=1.7 mm
Occurrences: Orešany, borehole PID-1 (4.0-4.2 m; 13.0-13.1 m; 22.0-22.1 m; 32.0-32.3 m; 36.0-36.1 m; 36.5-36.6 m)
Stratigraphic and geographic distribution: Up to now, occurrences of this species have been known form the zone H of the Pannonian in Austria (Eichkogel) and the Pliocene of Germany.

Family *Clausillidae*
Subfamily *Phaedusinae*
Genus *Nordsieckia* TRUC, 1972
Nordsieckia pontica **LUEGER, 1981**

(Tab. II, Fig. 9)

1981 *Nordsieckia fischeri pontica* n.ssp. - LUEGER: p. 50, Tab. 7, Fig. 7,8a-c, 9-12
1981 *Nordsieckia pontica* LUEGER - NORDSIECK: p. 81, Tab. 9, Fig. 32-33

Material: 20 specimens
Description: LUEGER (1981) p. 50
Occurrences: Orešany, borehole PID-1 (13.0-13.1 m; 22.0-22.1 m; 36.0-36.1 m; 36.5-36.6 m)
Stratigraphic and geographic distribution:This species occurs in zones B/C (Leobersdorf) E (Vösendorf) G/H (Velm), H (Eichkogel, Richardshof) of the Pannonian in Austria.

Subfamily *Clausiliinae*
Genus *Clausilia* DRAPARNAUD, 1805
Subgenus *Clausilia* s.str.

Clausilia (Clausilia) strauchiana **NORDSIECK, 1972**
(Tab. II, Fig. 8)

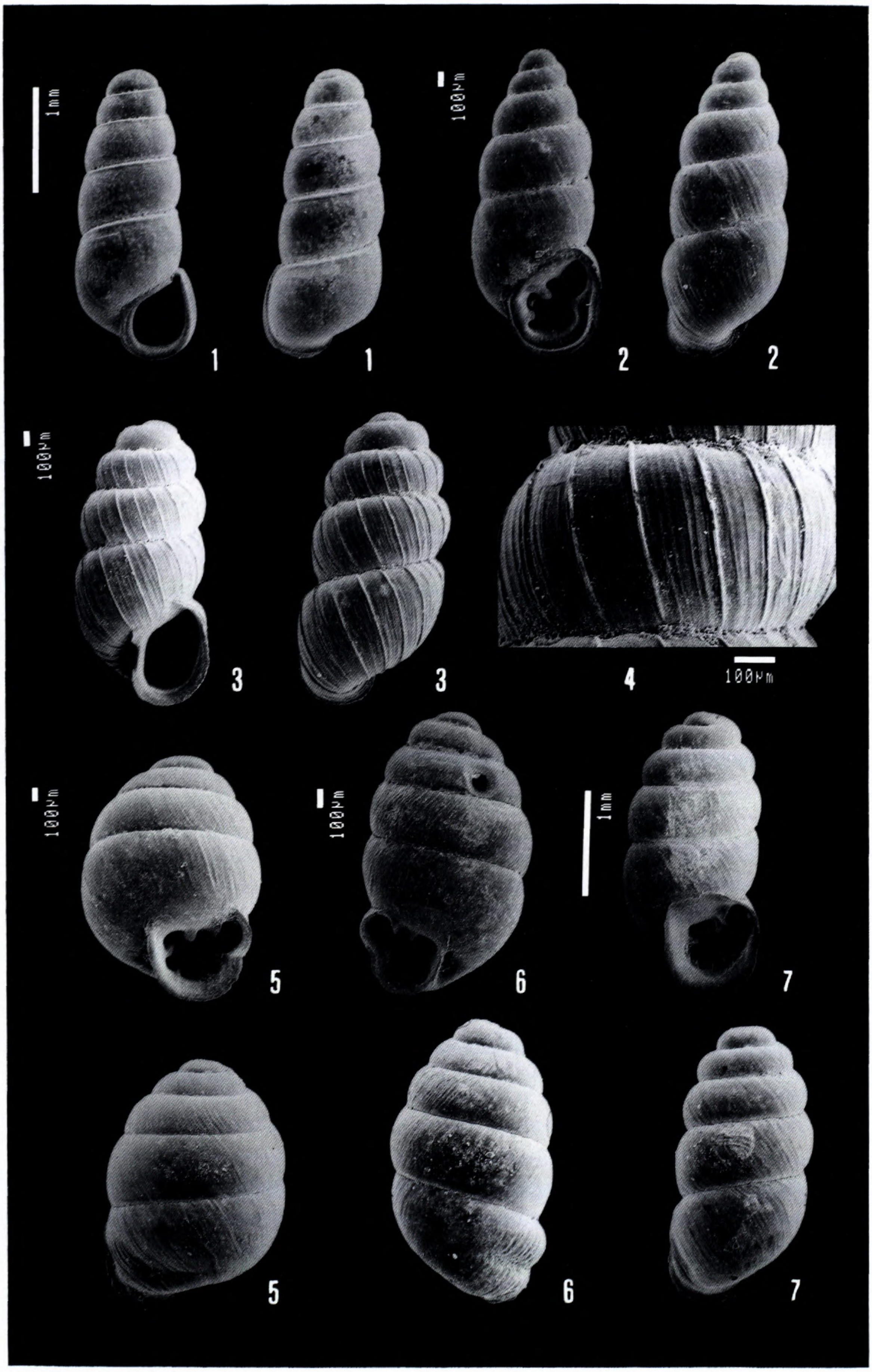
1972 *Clausilia strauchiana* n.sp. - NORDSIECK: p. 172, Tab. 10, Fig. 19-23, Abb. 3-4
1981 *Clausilia (Clausilia) strauchiana* NORDSIECK, 1972 - LUEGER: p. 51, Tab. 7, Fig. 14a-b

Material: 3 specimens
Description: NORDSIECK (1972) p. 172
Occurrences: Orešany, borehole PID-1 (13.0-13.1m)
Stratigraphic and geographic distribution: The species is known from the zone H of the Pannonian of Austria (Eichkogel) and the Pliocene of Germany.

Subfamily *Campylaeina*
Genus *Tropidomphalus* C.R. BOETGER, 1908
Subgenus *Mesodontopsis* PILSBRY, 1895

Tropidomphalus (Mesodontopsis) doderleini **(BRUSINA, 1897)**
(Tab. III, Fig. 5)

1897 *Helix (Tacheocampylea) Doderleini* BRUS. n.sp. - BRUSINA: p. 1, Tab. 1, Fig. 1-2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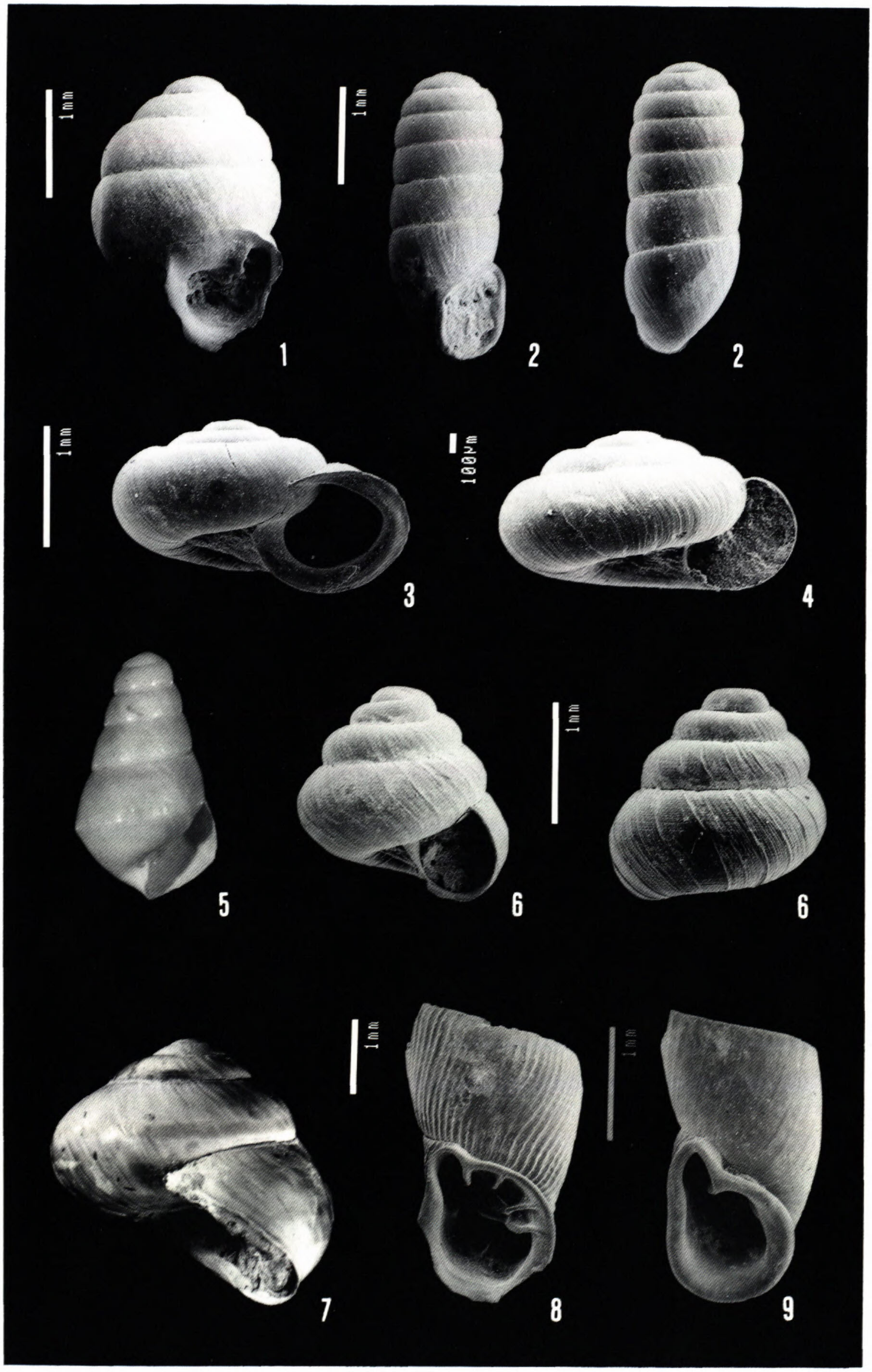
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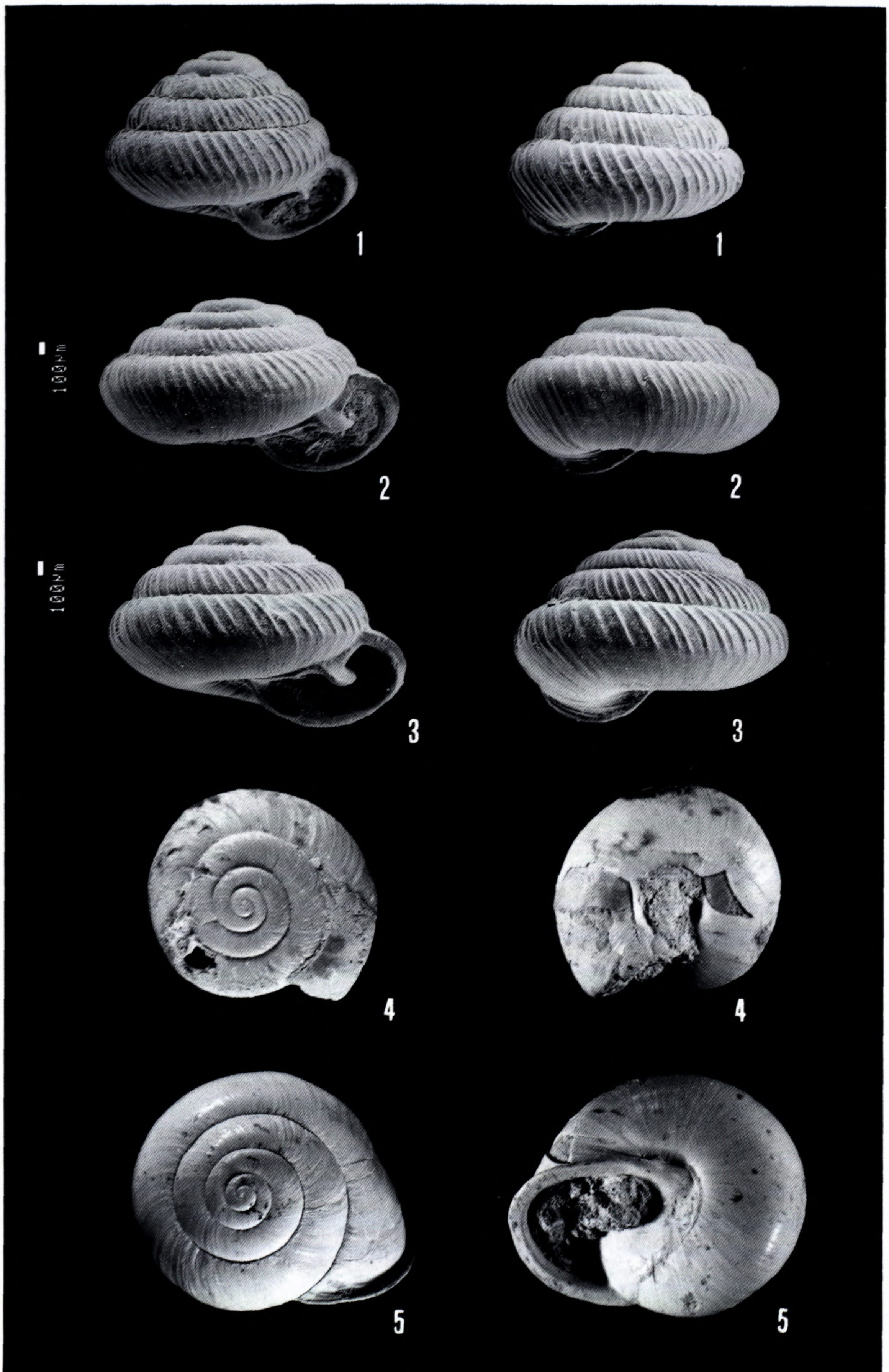
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5

1955 *Tacheocampylea (Mesodontopsis) doderleini* (BRUSINA) - BARTHA: p. 310
1956 *Tacheocampylea (Mesodontopsis) doderleini* (BRUSINA) - BARTHA: p. 520
1959 *Tacheocampylea (Mesodontopsis) doderleini* BRUSINA, 1897 - BARTHA: p. 82, Tab. 16, Fig. 1, 6
1973 *Mesodontopsis doderleini* (BRUSINA 1897) - SCHLICKUM - STRAUCH: p. 161, Abb. 3, 9-14
1981 *Tropidomphalus (Mesodontopsis) doderleini* (BRUSINA) - LUEGER: p.61, Tab. 10, Fig. 5, Tab. 11, Fig. 2-6

Material: 4 specimens
Description: LUEGER (1981) p. 61
Dimensions: Tab. III, Fig. 5, height = 20.0 mm, width = 35.4 mm
Occurrences: Orešany, borehole PID-1(32.0-32.3 m; 36.0-36.1 m; 36.5-36.6 m)
Stratigraphic and geographic distribution: Summarised in detail in SCHLICKUM-STRAUCH (1973). Pannonian of zones G-H.
Notes: This species was found also in the Western Carpathians (in the Danube Lowland), at the village Gbelce (former Köbölkút). It was classified as Helix (*Flemicla) robusta* REUSS (HORUSITZKY, 1898). It has been classfied as *Tacheocampylea (Mesodontopsis) doderleini* (BRUSINA) by WENZ (1923).

Genus *Helicigona* RISSO, 1826

***Helicigona wenzi* Soos, 1934**
(Tab. III, Fig. 4)

1934 *Helicigona (Helicigona)* WENZi n.sp. - SOÓS: p. 201, Fig. 12,
1981 *Helicigona wenzi* SOOS - LUEGER: p. 66, Tab. 8, Fig. 9a-c, 10a-c, Tab. 16, Fig. 8

Material: 1 exemplár
Description: LUEGER (1981) p. 66
Dimensions: Tab. III, Fig. 4, height = 5 mm, width = 12 mm
Occurrences: Orešany, borehole PID-1(36.0-36.1 m)
Stratigraphic and geographic distribution: The species occurs in zone F of the Pannonian in Austria (Götzendorf and in the Upper Pannonian of Hungary (Fonyod, Öcs, Várpalota).

Genus *Klikia* PILSBRY, 1895
Subgenus *Apula* C.R. BOETTGER, 1909

***Klikia (Apula) goniostoma* (SANDBERGER, 1875)**

1875 *Helix (Fruticola) goniostoma* SANDB. - SANDBERGER: p. 702, Tab. 32, Fig. 12
1979 *Apula (Steklovia) goniostoma* (SANDBERGER) - SCHLICKUM: p. 411, Tab. 23, Fig. 9
1979 *Apula (Steklovia) halavatsi* n.nom. - SCHLICKUM: p. 412, Tab. 23, Fig. 10
1981 *Klikia (Apula) goniostoma* (SANDBERGER) - LUEGER: p. 68, Tab. 10, Fig. 3a-c

Material: 1 specimen
Description: LUEGER (1981) p. 68
Occurrences:Orešany, borehole PID-1 (22,0-22,1 m)
Stratigraphic and geographic distribution: Occurrences of this species are known from zones G/H (Ebergassing, Velm, Gols, Angern), H (Eichkogel) of the Pannonian in Austria and from the Upper Pannonian of Hungary (Öcs, Nagy Vaszony, Várpalota, Tab, Balatonszentgyörgy).

Subfamily: *Helicinae*
Genus *Cepaea* HELD, 1837
Subgenus *Cepaea* s.str.

***Cepaea (Cepaea) etelkae* (HALAVATS, 1925)**
(Tab. II, Fig. 7)

1907 *Helix (Tachea)* cf. *hortensis* MÜLLER - TROLL: p. 74
1934 *Cepaea sylvestrina Etelkae* HALAV. - SOÓS: p. 202
1955 *Cepaea sylvestrina etelkae* HALAV. BARTHA: p. 311
1959 *Cepaea sylvestrina etelkae* (HALAVATS) - BARTHA: p. 82, Tab. 16, Fig. 3-4
1981 *Cepaea (Cepaea) etelkae* (HALAVATS) - LUEGER: p. 72, Tab. 13, Fig. 1a-c, 2a-c, Tab. 14, Fig. 1a-c, 2a-c, 3a-c, 4a-c, 5-6, 7a-c

Material: 4 specimens
Description: LUEGER (1981) p. 72
Dimensions: Tab. II, Fig. 7, height = 19.2 mm, width = 24.4 m
Occurrences: Orešany, borehole PID-1 (13.0-13.1 m; 32.0-32.3 m; 36.0-36.1 m)
Stratigraphic and geographic distribution: Occurrences are known from zone B/C to zone H in Austria and from the majority of Upper Pannonian localities in Hungary.

Conclusions

In sediments from the borehole PID-1, stratigraphically classified as the Pannonian zone H (FORDINÁL 1994) there have been described 26 species of terrestrial gastropods. The list of species known from the above borehole has been extended to include *Acanthicula trochulis* (SANDBERGER), *Strobilops costata* (CLESIN), *S. pachychila* SOOS, *Clausilia strauchiana* NORDSIECK, *Helicigona wenzi* SOOS.

On the basis of paleoecological requirements of different terrestrial gastropod species (LUEGER 1981) it may be stated that during the Pannonian zone H, humid climate (swamps?) existed on the shores of the lake, which was at a greater distance from the shore replaced by forest environment, in which there where probably open areas with xerophilous fauna.

The fauna of terrestrial gastropods from Orešany, from the borehole PID-1, has been compared with the localities Eichkogel (84.6% of species in common) and Öcs (61.5%).

Tab. 1 Occurrence of individual species of terrestrial gastropods at the Eichkogel, Öcs and Orešany localities

Druhy	Eichkogel Lueger 1981	Öcs	Orešany PID-1
Acicula edlaueri	+	+	+
Carychium pachychilus	+	+	+
Negulus gracilis	+		+
Vertigo callosa	+	+	+
Vertigo suevica	+		
Vertigo oecsensis	+	+	+
Truncatellina suprapontica	+		
Gastrocopta acuminata	+	+	+
Gastrocopta larteti	+	+	+
Gastrocopta nouletiana	+	+	
Gastrocopta infrapontica	+	+	+
Gastrocopta ferdinandi	+		
Gastrocopta serotina	+		
Abida schuebleri	+		
Pupilla rathi	+		
Argna suemeghyi	+	+	+
Vallonia costata	+		
Vallonia subpulchella	+	+	+
Acanthinula trochulus	+		+
Strobilops costata			+
Strobilops pachychila		+	+
Strobilops pappi	+		+
Ena sp.	+		
Succinea oblonga			+
Succinea sp.	+		
Punctum propygmaeum	+		+
Discus pleuradrus	+	+	+
Semilimax intermedius			+
Helicodiscus roemeri	+		
Perpolita disciformis	+		
Aegopinella orbicularis	+		
Oxychilus procellarius	+	+	+
Cecilioides aciculella	+		
Fortuna clairi	+		+
Nordsieckia pontica	+		+
Clausilia strauchiana	+		+
Leucochroopsis kleini	+		
Helicigona wenzi			+
Klikia trolli	+		
Klikia goniostoma	+	+	+
Klikia magna	+		
Tropidomphalus richarzi	+		
Tropidomphalus doderleini	+	+	+
Helicigona wenzi			+
Cepaea etelkae	+	+	+

Explanations to Plates I-III

Plate I

Fig. 1 *Acicula (Acme) edlaueri* SCHLICKUM PID-1 36,5-36,6 m
Fig. 2 *Carychium (Saraphia) pachychilus* SANDBERGER PID-1 13,0-13,1 m
Fig. 3 *Negulus gracilis* GOTTSCHICK-WENZ PID-1 13,0-13,1 m
Fig. 4 Detail of the sculpture of last but one whorl of the *Negulus gracilis* test (fig. 3)
Fig. 5 *Vertigo (Vertigo) callosa* (REUSS) PID-1 36,5-36,6 m
Fig. 6 *Vertigo (Vertilla) oecsensis* (HALAVATS) PID-1 36,5-36,6 m
Fig. 7 *Gastrocopta (?Sinalbinula) infrapontica* WENZ PID-1 22,0-22,1 m

Plate II

Fig. 1 *Gastrocopta (Albinula) larteti* (DUPUY) PID-1 22,0-22,1 m
Fig. 2 *Argna (Argna) suemeghyi* (BARTHA) PID-1 22,0-22,1 m
Fig. 3 *Vallonia subpulchella* (SANDBERGER) PID-1 10,0-10,4 m
Fig. 4 *Punctum (Punctum) propygmaeum* ANDREAE PID-1 6,0-36,1
Fig. 5 *Fortuna clairi* SCHLICKUM-STRAUCH PID-1 22,0-22,1 m
Fig. 6 *Acanthinula trochulus* (SANDBERGER) PID-1 22,0-22,1 m
Fig. 7 *Cepaea (Cepaea) etelkae* (HALAVATS) PID-1 36,0-36,1m, magn. 2,3x
Fig. 8 *Clausilia (Clausilia) strauchiana* NORDSIECK PID-1 13,0-3,1 m
Fig. 9 *Nordsieckia pontica* LUEGER PID-1 13,0-13,1 m

Plate III
Fig. 1 *Strobilops (Strobilops) pachychila* SOOS PID-1 22,0-2,1 m
Fig. 2 *Strobilops (Strobilops) costata* (CLESSIN) PID-1 13,0-13,1 m
Fig. 3 *Strobilops (Strobilops) pappi* SCHLICKUM PID-1 22,0-22,1 m
Fig. 4 *Helicigona wenzi* SOOS PID-1 36,0-36,1 m, zv. 3,6x
Fig. 5 *Tropidomphalus (Mesodontopsis) doderleini* (BRUSINA) PID-1 32,0-32,3 m, magn. 1,4x

Photographs in Table III, Fig. 4 and 5 were made by C. Michalíková in Fig. 7, in Table II the author of this paper. The remaining photographs were made by the 3SM-840 electron microscope, installed at the Dionýz Štúr Institute of Geology in Bratislava, operated by K. Horák.

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SLOVAK GEOLOGICAL MAGAZINE

New lithostratigraphic units in the Klippen Belt

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Abstract. New lithostratigraphic units distinguished in the Slovak part of the Pieniny Klippen Belt (Pienidic units only) are summarized in this paper. They are as follows: Lúty Potok Limestone represents Lower Jurassic (Sinemurian to Pliensbachian), Krasín Breccia (Upper Bajocian-Bathonian), Bohunice Limestone Formation (Oxfordian to Lower Tithonian), Horná Lysá Limestone (Upper Berriassian to Hauterivian), Samášky Formation (Bajocian to Bathonian), Horné Sŕnie Limestone Member (Berriassian to Lower Valanginian) and Revišné Limestone (Lower Tithonian).

Key words: Pieniny Klippen Belt, Jurassic, Lower Cretaceous, lithostratigraphy

During the last two years we have identified strata which were not included in the thorough list of the lithostratigraphic units concerning the Pieniny Klippen belt by BIRKENMAJER (1977). Concise definitions of the new members will be done here.

Lúty Potok Limestone

Lithology: Crinoidal limestones.
Thickness: 30 m. Light-grey biosparites with brown chert nodules represent their lower part; upper part is formed by red sandy biomicrite without cherts, with skeletal fragments of the siliceous sponges (bafflestone intraclasts) with a horizon containing dolomite clasts to 7 cm (tempestite?); rare neptunian dykes with mostly red laminated synsedimentary filling.
Fossils: brachiopods *Liospiriferina rostrata*, *Cirpa fronto* etc. (determined by M. SIBLÍK), ammonites *Juraphyllites* sp., *Androgynoceras* sp. (determined by M.RAKÚS), belemnites, crinoidal stems, sponges.
Age: Sinemurian - Pliensbachian.
Unit: Nižná Succession.
Locality: Lúty Potok W from Krivá, Skalka near Sedliacka Dubová (Orava), Pieniny Klippen Belt.
Terrigenous admixture: disintegrated granitoid material, small fragments of Permian acid volcanites, Triassic dolomites, Lower Triassic silicites. It is interesting that the material is identical with that one of the Middle Jurassic crinoidal limestones of the Czorsztyn Unit.
Further information: MIŠÍK, SÝKORA, SIBLÍK & AUBRECHT, 1995.

Krasín Breccia

Lithology: Breccia is composed by clasts to blocks of pink, grey, rarely violetish crinoidal limestones (mostly biosparites) in the crinoidal limestone matrix (mostly biomicrites); it is penetrated by neptunian dykes with synsedimentary filling.
Thickness: about 60 m. The clasts differ mutually by colour, amount of terrigenous admixture and micrite content. Krasín Breccia was laid down along the foot of a submarine scarp formed by synsedimentary fault with accompanying fissures (neptunian dykes). Fossils: crinoidal detritus, sponge spicules (mainly rhaxa), bryozoan fragments, nubecularid and lagenid foraminifers, rarely bivalvians and brachiopods. Voids and fissure fillings are represented by red laminated micrite containing coelobite ostracods *Pokornyopsis*; their recent descendants are also adapted to the life in the submarine caves.
Age: Upper Bajocian - Bathonian (established indirectly; in the immediate underlying strata ammonite *Teloceras* ex gr. *blagdeni* was found (determined by M. RAKÚS).
Locality: Krasín quarry near Dolná Súča.
Unit: Czorsztyn Succession.
Further information: MIŠÍK, SÝKORA & AUBRECHT, 1994.

Bohunice Limestone Formation

Lithology: creamy and pink biomicritic limestones, locally with bivalves and brachiopods.
Thickness: about 10 m.
Fossils: in the lower, Oxfordian part, the *Globuligerina* ("protoglobigerina") microfacies with radio-

larians and *Colomisphaera*; in the Kimmeridgian part *Saccocoma* microfacies with golobochets, juvenile ammonoids etc.; some brachiopods with internal sediment (polarity structures) *Nucleata bouei*, *Lacunosella* aff. spoliata (det. by M. SIBLÍK); the upper part belonging to Lower Tithonian with *Saccocoma*, *Globochaete*, *Parastomiosphaera malmica* and small originally aragonitic bivalvians coated by black Mn-Fe films.
Age: Oxfordian - Lower Tithonian.
Unit: Czorsztyn Succession. Locality: Babiná quarry near Bohunice, Mestečská skala klippe.
Further information: MIŠÍK, SIBLÍK, SÝKORA & AUBRECHT, 1994.

Horná Lysá Limestone

Lithology: Micritic limestones with dispersed crinoidal detritus and calciturbidite intercalations.
Thickness: 20 m. Light-grey, pink, rarely violet to reddish layered limestones; in their upper part with black and brown chert nodules.
Fossils: crinoidal detritus, small aptychi, skeleton fragments of lithistid sponges, radiolarians, foraminifers, *Cadosina fusca* etc. The allodapic intercalations are not sharply limited. Shallow-water bioclasts were repeatedly transported into the shallower bathyal; they represent thin-bedded channelized grain-flows and debris-flows. Small lithoclasts of biomicrites with *Crassicollaria* (Upper Tithonian) and microoncolites with *Saccocoma* (Kimmeridgian - Lower Tithonian) are noteworthy.
Age: Upper Berriassian - Hauterivian (based in the upper part on radiolarians extracted from the cherts, U.A.14, Upper Valanginian-Upper Hauterivian - Lowermost Barremian ?).
Locality: Horná Lysá, Vršatec area near Pruské.
Unit: Kysuca Succession (adjacent to Czertezik succession).
Another locality: Zadné Skálie klippe near Kyjov (Eastern Slovakia) belonging to the Czertezik Succession.
Further information: MIŠÍK, SÝKORA, OŽVOLDOVÁ & AUBRECHT, 1994.

Samášky Formation

Lithology: rythmical alternation of the grey and yellowish layers of crinoidal limestones (calciturbidites) with claystones, marlstones and fine-grained sandstones.
Thickness: 35-40 m. In the lower parts of the crinoidal limestone layers a fine-grained conglomerate sometimes occurs; the top of the beds possess often parallel lamination, sometimes selectively silicified.
Fossils: crinoidal detritus, thick-shelled ostracods, fragments of punctuate brachiopods, bryozoans, echinoid spines, lagenid foraminifers, sponge spicules. The heavy mineral assemblage is garnet-dominated, less with zircon, rutile, tourmaline and apatite.
Age: Bajocian-Bathonian (without direct paleontological evidence).
Locality: Horné Sŕnie Samášky, Pruské Succession (AUBRECHT & OŽVOLDOVÁ, 1994). Older evidence: ANDRUSOV (1945) considered it as an equivalent of the Birkenmajer's "flysch-Aalenian" (present Szlachtowa Formation). Samášky Formation represents a facial link between Smolegowa + Krupianka Limestone Formations of the Czorsztyn Unit (shallow-water, sedimented on the elevation) and Flaki Limestone Formation of the Kysuca (Branisko) Unit (distal turbidites in the pelagic environment)
Further information: AUBRECHT & OŽVOLDOVÁ, 1994.

Horné Sŕnie Limestone Member

Lithology: massive pink micritic limestone.
Thickness: 140 cm. Skeletal debris and cross-sections of ammonoids are visible macroscopically.
Fossils: ammonoids, calcified radiolarians, crinoidal fragments, bivalve shells, aptychi, bryozoan fragments (*Trepostomata*) and foraminifers e.g. *Lenticulina* sp. are present. Foraminifers *Globuligerina* sp. are relatively frequent in the limestone, which is atypical for this stratigraphical level. Tintinids *Calpionellopsis oblonga* (CADISCH), *Calpionellopsis simplex* (COLOM), *Remaniella dadayi* (KNAUER), *Tintinopsella longa* (COLOM), *Tintinopsella carpathica* (MURGEANU et FILIPESCU) and rare *Calpionella alpina* LORENZ can be observed in thin sections also. No siliciclastic admixture has been observed.
Age: Berriassian to Lower Valanginian.
Locality: Horné Sŕnie-Samášky, Pruské Succession (AUBRECHT & OŽVOLDOVÁ, 1994). Older evidence: It ranks most probably to the Lysa Limestone Formation sensu BIRKENMAJER (1977) according to its stratigraphical position. No one from the members mentioned by BIRKENMAJER (l.c.) has the features characteristic for this member. According to the description it is most similar to the Harbatova Limestone Member, which differs by the thin bedding.
Further information: AUBRECHT & OŽVOLDOVÁ, 1994.

Revišné Limestone

Lithology: white to light-grey nodular limestone with thin (1 cm) greenish clay intercalations.
Thickness: indetermined.

Fig. 1 KLIPPE IN THE LÚTY POTOK VALLEY

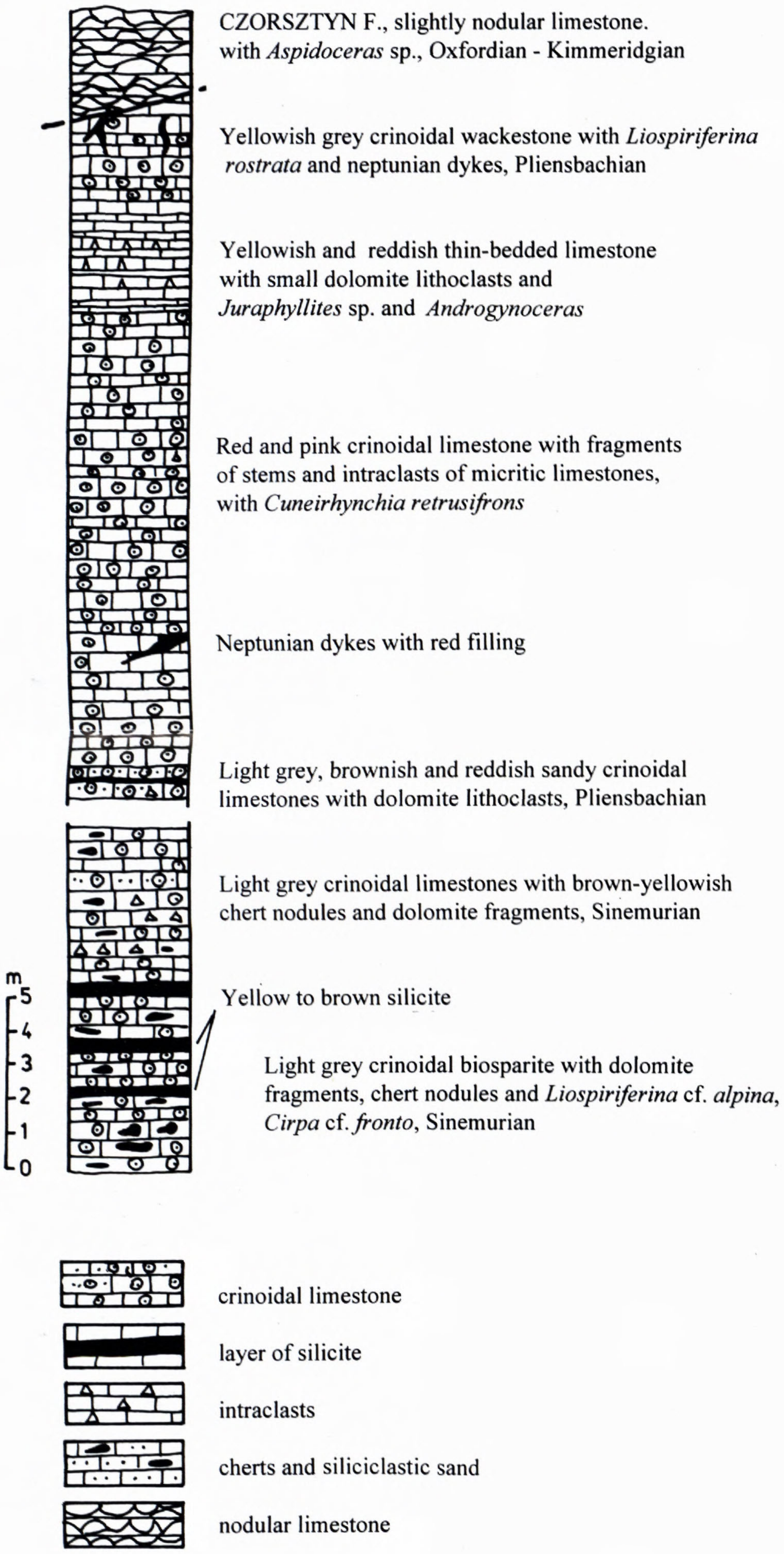


Fig.2 Krasín Breccia (Krasín - Dolná Súča section)

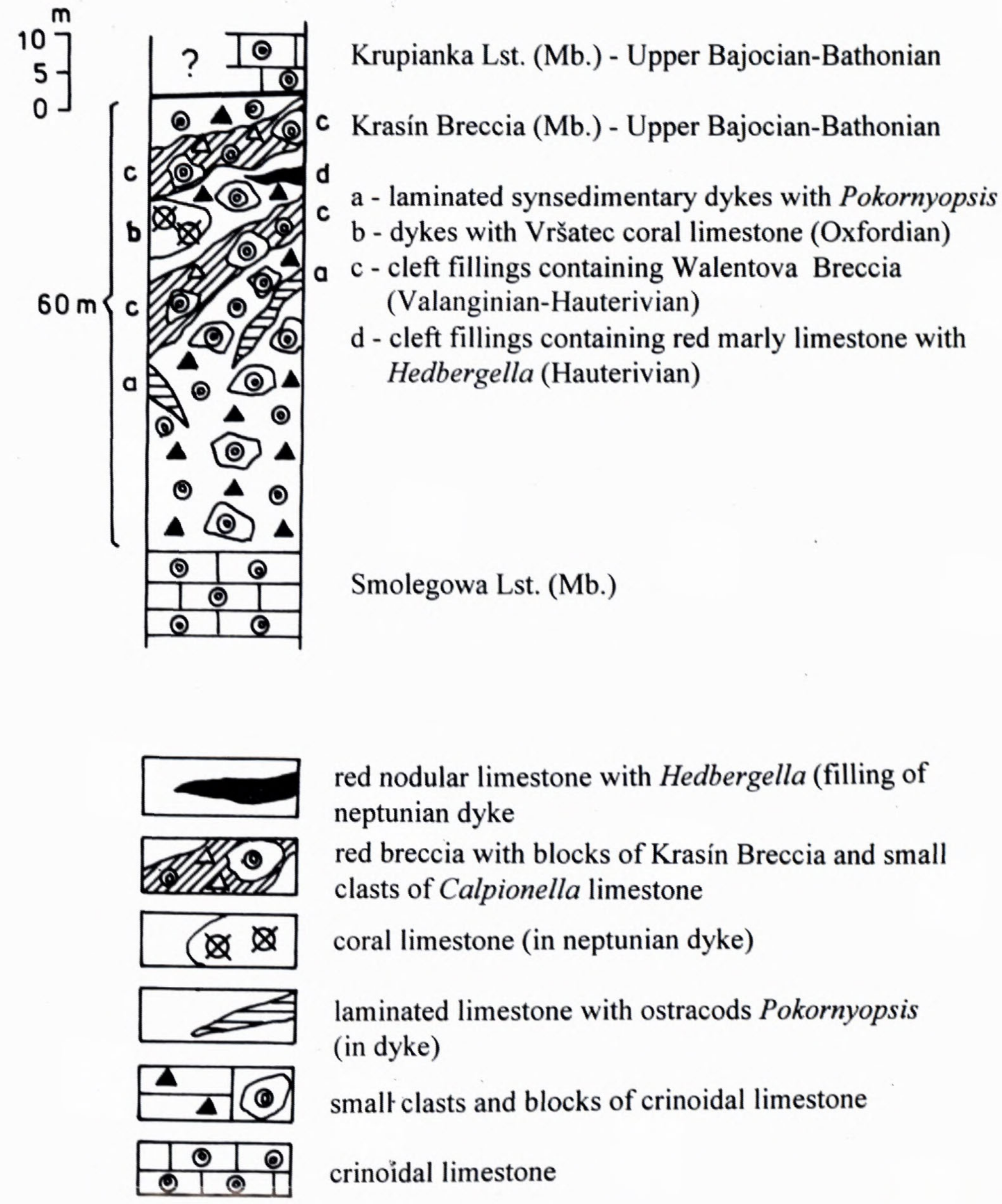


Fig. 3 Bohunice Formation (Babiná section)

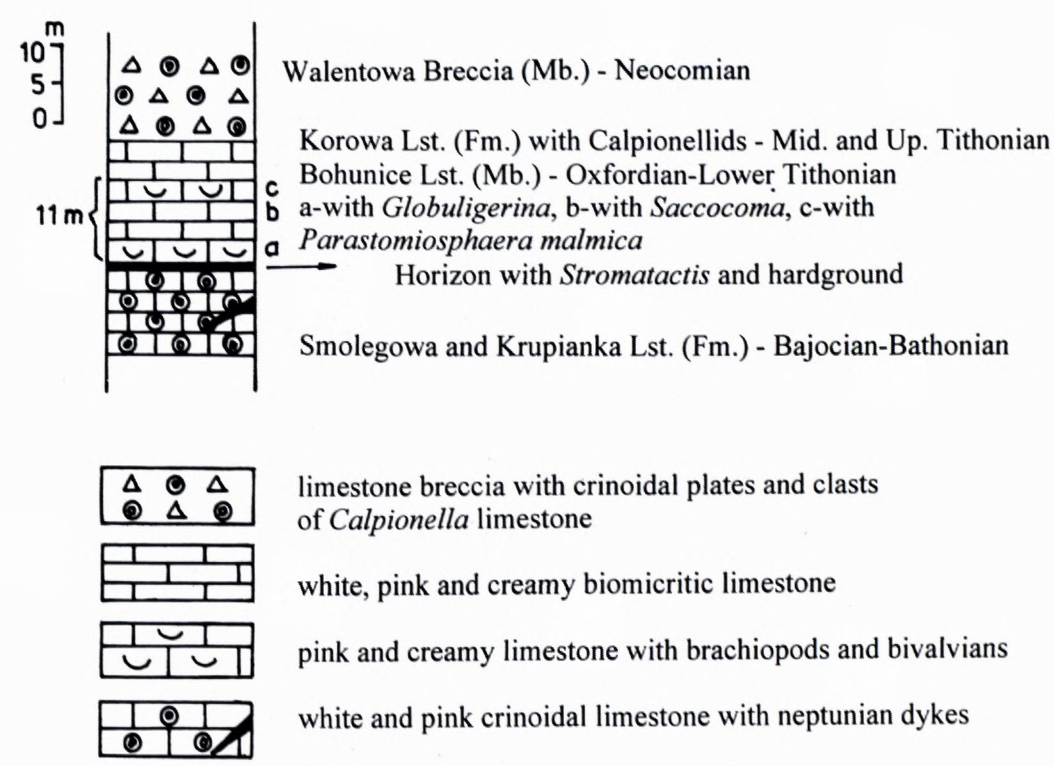
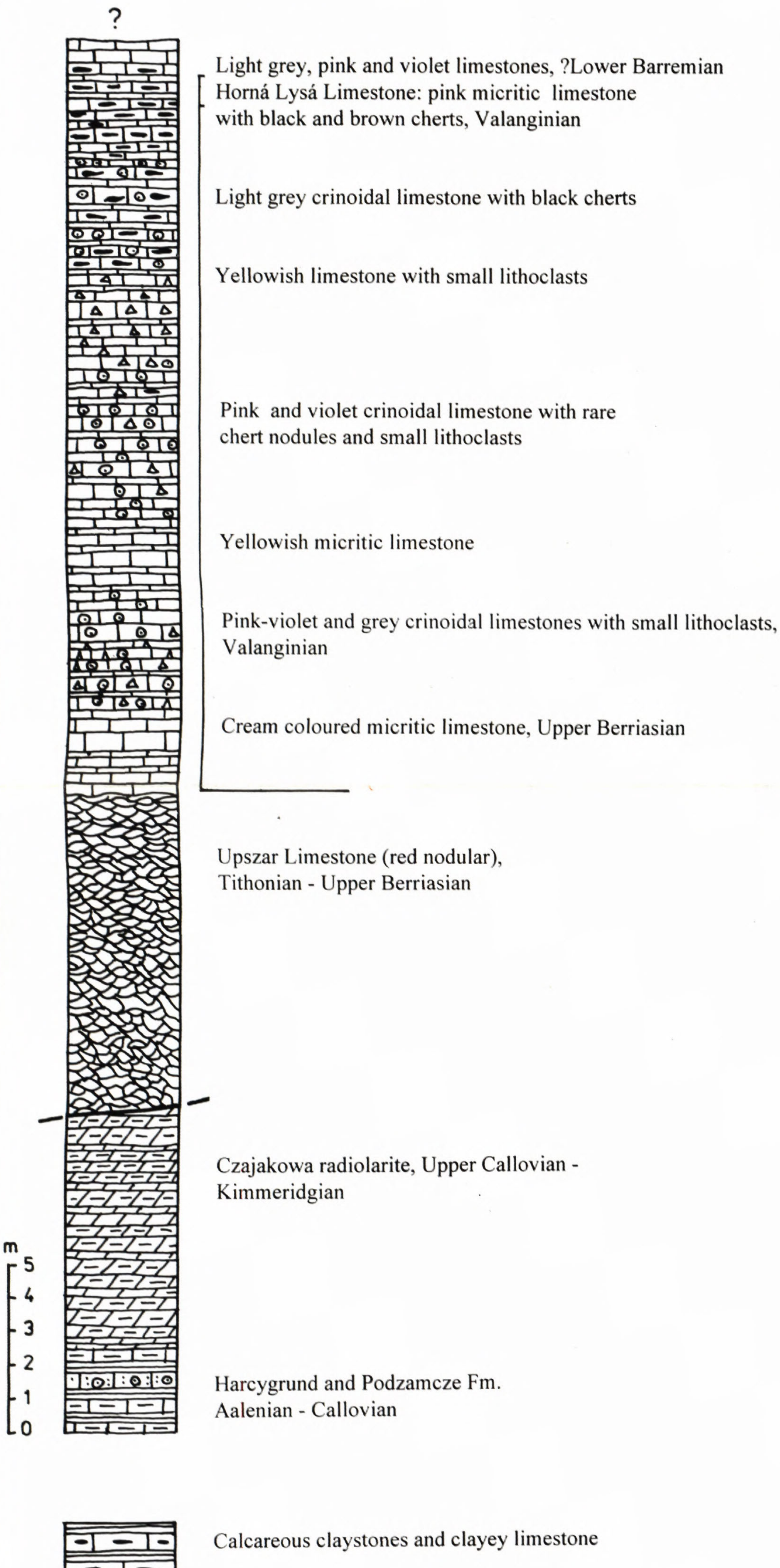


Fig. 4 KLIPPE HORNÁ LYSÁ



Other explanations see fig.1.

Fig. 5 Samášky Formation
Horné sŕnie Member (Samášky section)

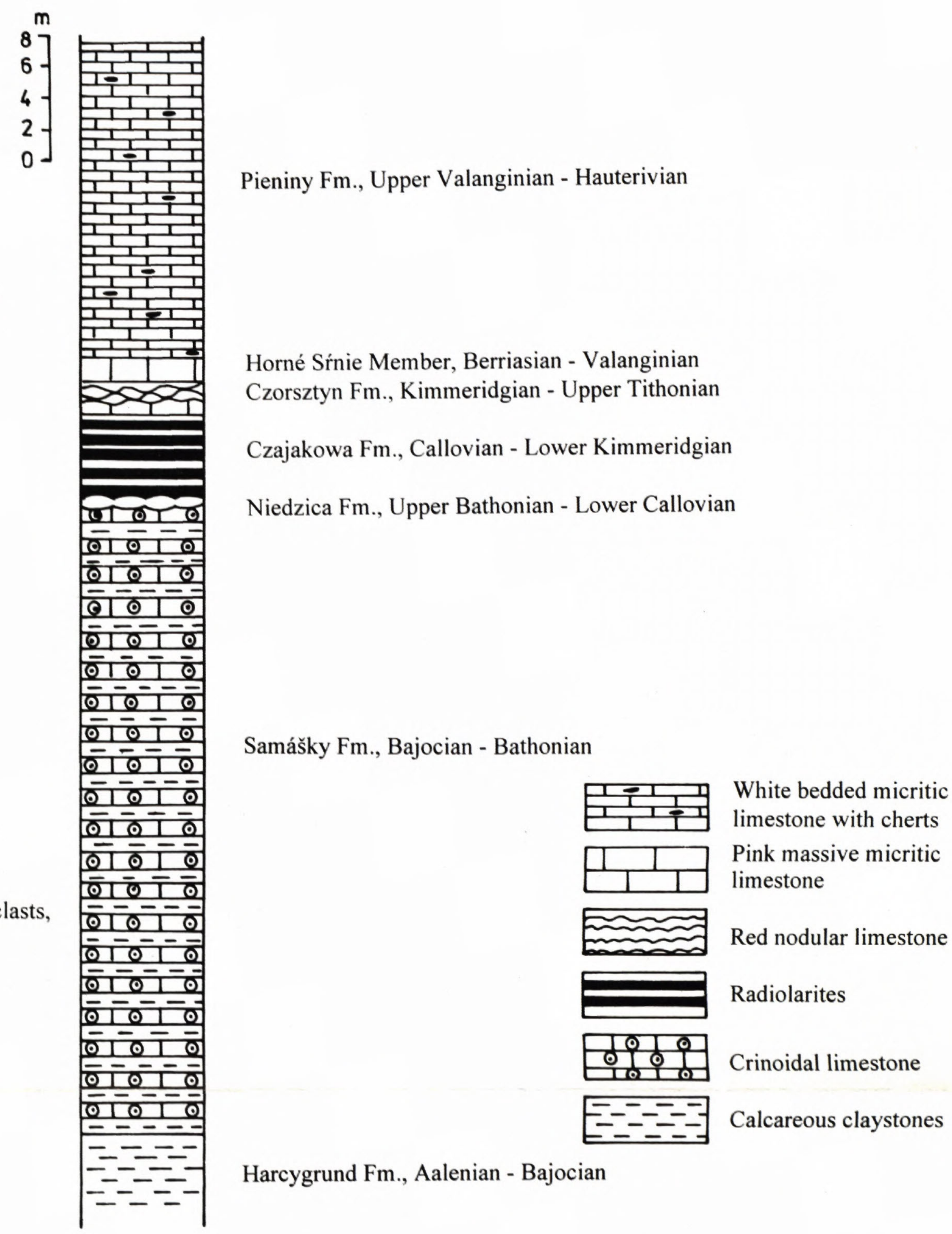
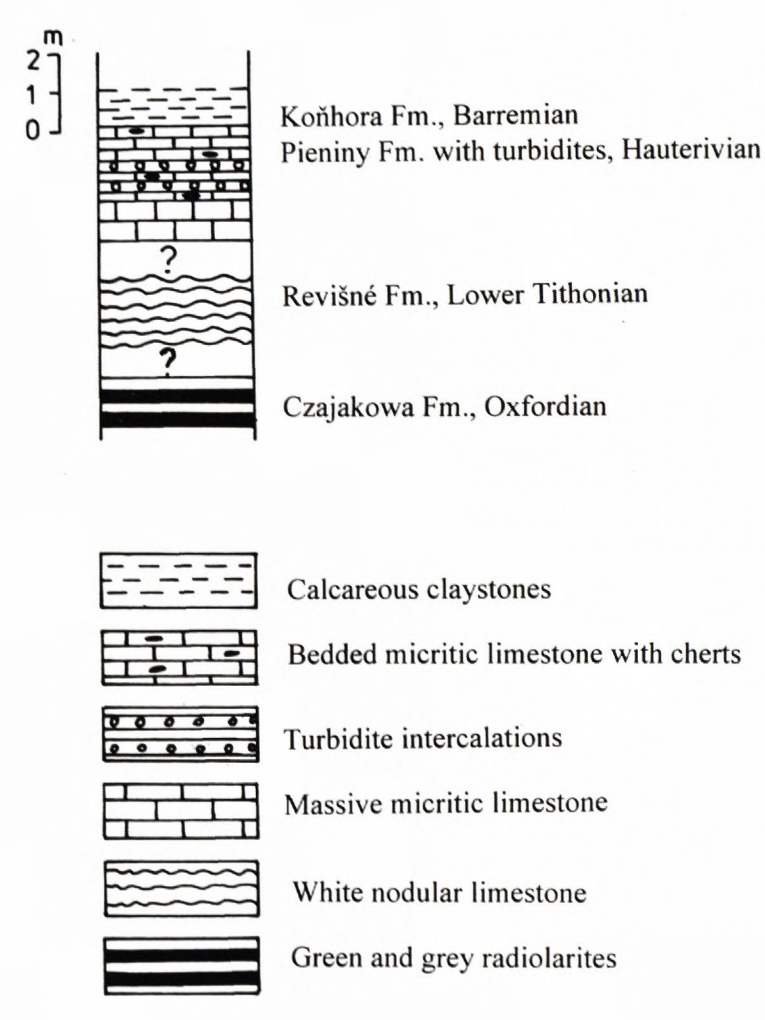


Fig. 6 Revišné Formation
(Istebné section)



Fossils: aptychi, dissolved casts of ammonoids, *Parastomiosphaera malmica* (BORZA), *Colomisphaera pulla* (BORZA), *Colomisphaera minutissima* (COLOM), *Cadosina parvula* NAGY and seldom *Saccocoma*. Less frequent detritus from bivalvian shells and radiolarian ghosts are observable. No calpionellids have been found.

Age: Lower Tithonian. Locality: Istebné, Kysuca Succession Further information: AUBRECHT, 1994.

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SLOVAK GEOLOGICAL MAGAZINE

New data about the age of radiolarites from the Belice Unit
(Považský Inovec Mts., Central Western Carpathians)

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Abstract: Upper Jurassic radiolarites in the northern part of the Považský Inovec Mts. form the lower member of the eupelagic Lazy Formation ranging up to the late Lower Cretaceous. They are constituent of the Belice Unit which includes also the Upper Cretaceous "thickening and coarsening upward" flysch complex (Horné Belice Formation). The key section at the Lazy locality has been investigated for radiolarians. Poor preservation of radiolarians allows only approximate age determination as Upper Callovian (Upper Oxfordian according to another study) – pper Tithonian. However, the upper part of the radiolarite sequence reaches the Calpionella zone which is unusual for other Western Carpathian radiolarites. This fact, together with the position of the Belice Unit below the Tatric basement nappe, is interpreted in terms of its South Penninic - Vahic oceanic provenance.
Key words: Western Carpathians, Považský Inovec Mts., Vahic, Belice Unit, Late Jurassic, Radiolarians

Introduction

The radiolarites under question were described for the first time by KULLMANOVÁ & GAŠPARIKOVÁ (1982), who, based on foraminifers, dated them as Albian. Later PLAŠIENKA et al. (1994) investigated the profile in more detail and found that radiolarites are part of the Upper Jurassic – Lower Cretaceous eupelagic, almost carbonate-free sequence - the Lazy Formation. Dark siliceous slates with scarce Cretaceous foraminifers form a younger member of the formation, while Upper Jurassic radiolarians were determined in the radiolarite sequence (PETERČÁKOVÁ in PLAŠIENKA et al., 1994). Based on the presence of species *Podocapsa amphitreptera* FOREMAN and rare intercalations of white pelagic limestones with *Calpionella alpina* LOMBARD, it was suggested that the stratigraphic range of radiolarites is from the Upper Oxfordian to the lowermost Berriasian. However, this time span contradicts the hitherto determined ages of Western Carpathian radiolarites, as it is significantly younger than ages of comparable radiolarites from the Tatric Unit (Upper Bathonian to Callovian; POLÁK & ONDREJÍČKOVÁ, 1995), the Krížna Unit (Upper Callovian to Oxfordian; POLÁK & ONDREJÍČKOVÁ, 1993) and the Pieniny Klippen Belt (Upper Callovian to Kimmeridgian; OŽVOLDOVÁ, 1988, 1991). Therefore, new samples have been collected and investigated from the profile Lazy described by PLAŠIENKA et al. (1994).

Geological setting

The Považský Inovec Mts., typical "core mountains" of the Tatra-Fatra Belt of the Central Western Carpathians, form an asymmetric, N-S elongated Late Tertiary horst structure in western Slovakia. The horst is surrounded by Neogene basins, its NE margin approaches the Pieniny Klippen Belt (Fig. 1). The northern part of the mountains is built up mostly by the Tatric pre-Alpine crystalline basement composed of mica-schists and gneisses, its sedimentary cover involves thick Upper Paleozoic rocks, mostly Permian red-beds and Scythian quartzose clastics. The Middle Triassic is locally represented by carbonate platform sediments. Jurassic and Lower Cretaceous sandy limestones occur only as clasts and olistoliths in the Senonian flysch deposits of the underlying Belice Unit. The Tatric complexes create an extensive allochthonous body – the Inovec basement-cover nappe. It overrode Jurassic and Cretaceous sedimentary rocks of the Belice Unit during the latest Cretaceous – earliest Paleogene shortening and thrust stacking along the northern Tatric edge PLAŠIENKA et al., 1994; (PLAŠIENKA, 1995a). The outstanding key position of the Belice Unit in the Carpathian edifice has been emphasised also by PLAŠIENKA (1995b, c). According to these views, the Belice Unit represents an element of the Vahic (South Penninic) oceanic superunit, which only occasionally crops out in the northern part of the Považský Inovec Mts.,

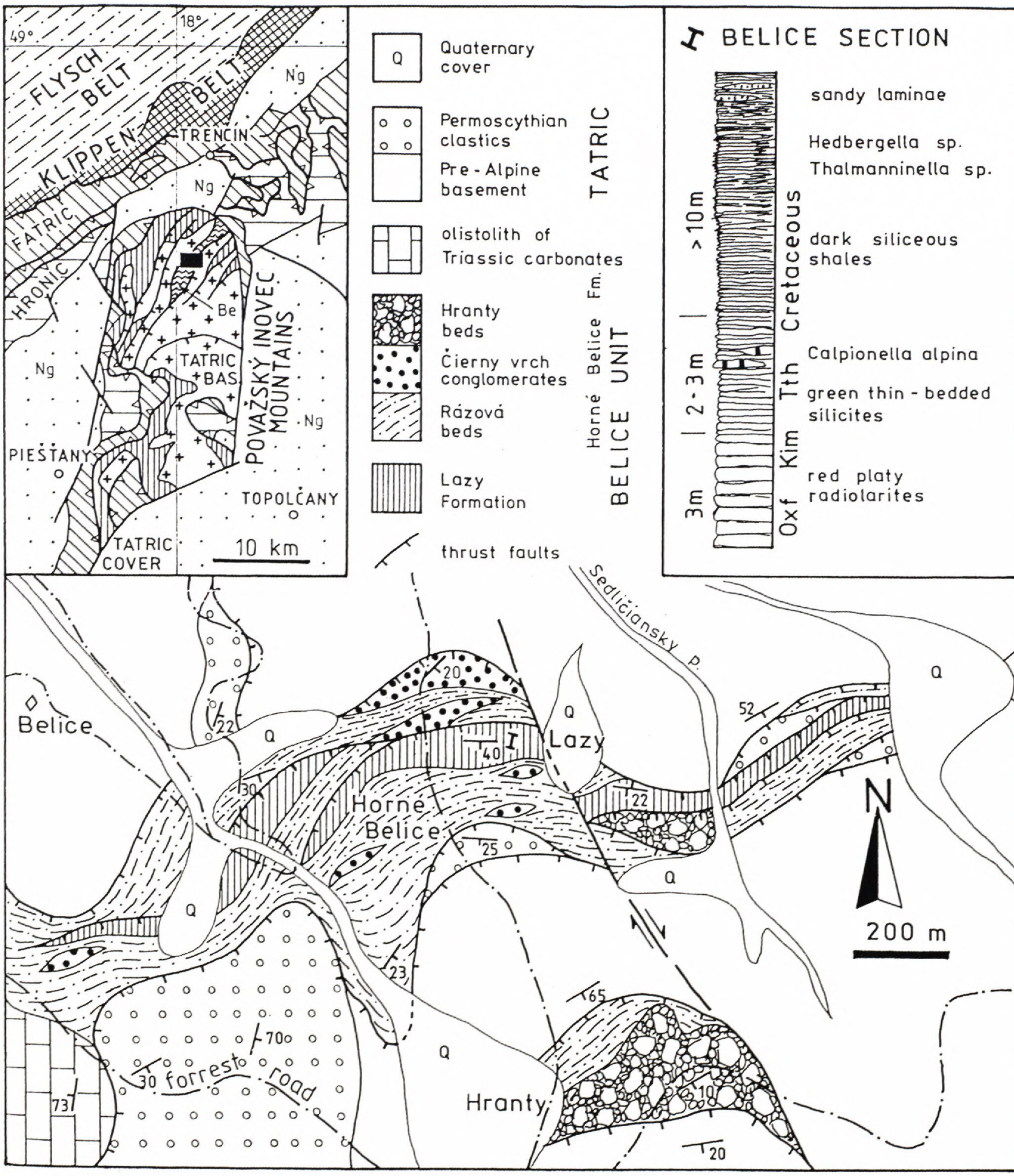


Fig. 1. Tectonic sketch of the Považský Inovec Mts. (Be – Belice Unit), geological map of the studied area with the position of the Lazy section and its lithostratigraphical column.

thanks to anomalous tectonic conditions (antiformal thrust stack, enormous Neogene uplift). Elsewhere, the Vahic oceanic elements completely disappeared by southward subduction below the northern, i.e. Tatric edge of the Central Western Carpathians and nowadays they create their middle crustal levels (TOMEK, 1993). Reconstruction of the lithostratigraphic succession of the Belice Unit is difficult because of its dismembering into numerous slices, small areal extent and poor outcrop conditions. Fossils are very rare due to low-grade metamorphic recrystallization, most of biostratigraphic data have been obtained by the study of foraminifers and radiolarians (KULLMANOVÁ & GAŠPARIKOVÁ, 1982; PLAŠIENKA et al., 1994). The last quoted authors defined new formal lithostratigraphic units within the Belice Succession: (1) the Upper Jurassic -- Lower Cretaceous pelagic Lazy Formation, (2) the Turonian "couches-rouges" type Svinica marlstones, and (3) the Senonian flysch Horné Belice Formation with several members.

Lithology of the Lazy Formation

The Lazy Formation is composed of eupelagic silicitic sediments consisting of three members: purple-red platy radiolarites (not more than 5 m thick), greenish-grey thin-bedded silicites (radiolarian cherts) with scarce intercalations of white micritic limestones (some 5-10 m thick), passing gradually into dark-grey siliceous slates (20-30 m) with sandy laminae in the uppermost part. Red radiolarites often exhibit features of hydrothermal alteration with Fe and Mn-bearing oxids. This succession is seldom well exposed, the best outcrop is at the locality Lazy on the northern slopes of the Mt. Inovec, where, however, the succession is in an overturned position (cf. PLAŠIENKA et al., 1994, Fig. 4). The geological position and lithostratigraphical profile of the locality Lazy is outlined in Fig. 1.

Fossil content

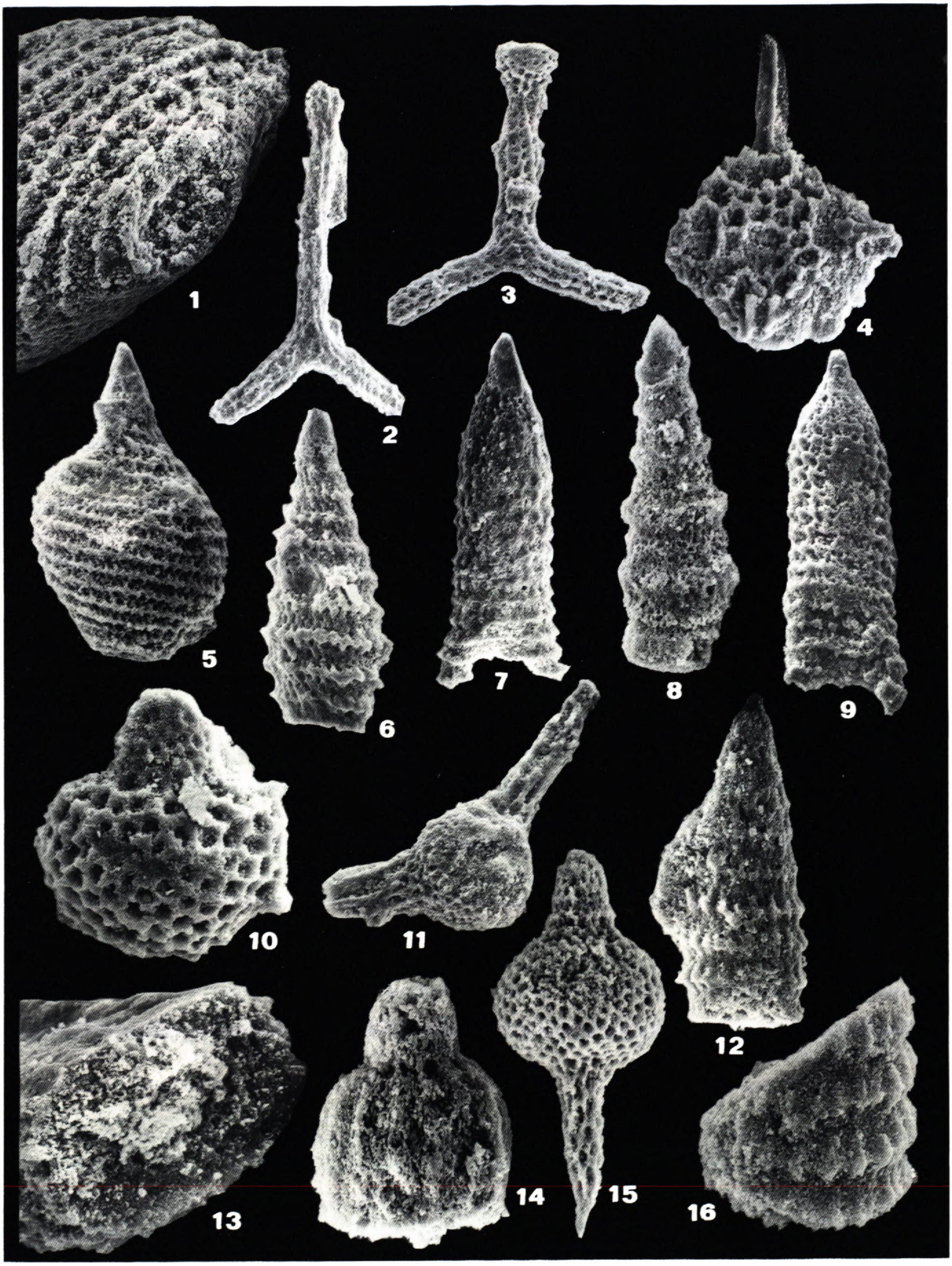
Radiolarian fauna extracted from the investigated samples is poorly preserved, tests are ductilely deformed into ellipsoidal forms (Pl. I, Figs. 1, 13) which are parallelly aligned in thin-sections. Tests are filled with silica, the matrix is formed by microcrystalline quartz, without calcite admixture. Thin syntectonic veinlets filled with fibrous quartz are common. Two samples yielded valuable fossils.

The sample No. L-6 comes from red radiolarites, from a lenticular specimen with pale-green core. The following species have been identified (Pl. I, Figs.1-15): *Cinguloturris carpatica* DUMITRICA *Eucyrtidiellum ptyctum* RIEDEL et SANFILIPPO, *Homoeoparonaella argolidensis* BAUMGARTNER, *Mirifusus dianae* (KARRER), *Parvicingula dhimenaensis* BAUMGARTNER, *Podobursa triacantha* (FISCHLI), *Ristola altissima* (RÜST), *Ristola procera* (PESSAGNO), *Pseudodictyomitrella* sp., *Staurosphaera antiqua* RÜST, *Sethocapsa leiostraca* FOREMAN, *Transhsuum brevicostatum* (OŽVOLDOVÁ), *Triactoma jonesi* (PERSSAGNO), *Tritrabs* cf. *hayi* (PESSAGNO), *Zhamoidellum* cf. *mikamense* AITA. The presence of the species *Ristola procera* (PESSAGNO) provides important age constraints for the studied radiolarites. In the Western Carpathians, this species has not been found in rocks younger than Oxfordian. BAUMGARTNER (1984, 1987) also limited its last occurrence to the Oxfordian, GORIČAN (1994) prolonged its presence up to the Kimmeridgian. Therefore, the whole association should not be younger than Kimmeridgian. The lower limit is given by the species *Podobursa triacantha* (FISCHLI) which appears for the first time in the Late Callovian. Summing up the above data, the extracted radiolarian association indicates the Upper Callovian – Oxfordian (?Kimmeridgian) age of red platy radiolarites.

The other positive sample, No. L-18, comes from green radiolarian cherts intercalated by micritic limestones, from the specimen depicted in Pl.III, Fig. 8 by PLAŠIENKA et al. (1994). Radiolarians are badly preserved, the species *Transhsuum brevicotatum* (OŽVOLDOVÁ), shown in Pl. I, Fig. 16, indicates that the rock is not younger than Upper Tithonian.

Discussion and conclusions

The radiolarian association identified by our study partly differs from that of PETERČÁKOVÁ (in PLAŠIENKA et al., 1994). The presence of the species *Podocapsa amphitreptera* FOREMAN, based on which the Upper Oxfordian – Lower Berriasian age of radiolarites was suggested, has not been confirmed, but also not excluded, by our investigation. Intercalations of Calpionella-bearing limestones in radiolarian cherts containing *Transhsuum brevicostatum* (OŽVOLDOVÁ) indicate Upper Tithonian age of these rocks.Unfortunately, specimens of Calpionella limestones were found only in the debris on foot of the rock cliff of the Lazy Formation, hence their exact position in the profile is not known. Moreover, a detailed stratigraphic profile of the section is difficult to obtain due to low-grade metamorphic recrystallization and most of the in-situ taken samples were negative. Thin-section study of radiolarites indicates their partial reworking by bottom currents (SOTÁK in PLAŠIENKA et al., 1994),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hence the succession is probably stratigraphically strongly condensed.

Based on micropaleontological investigation (this study, KULLMANOVÁ & GAŠPARIKOVÁ, 1982; PLAŠIENKA et al, 1994), the lithostratigraphical succession of the Lazy Formation can be reconstructed as follows:

- red platy radiolarites are the oldest member (Upper Oxfordian, possibly Kimmeridgian) of the formation tectonically detached from an unknown (oceanic?) substratum;
- green thin-bedded silicites are of Kimmeridgian? – Tithonian age, their upper parts intercalated by Calpionella limestones were deposited during the latest Tithonian;
- dark clayey-siliceous shales are Lower Cretaceous in age, probably up to the Albian.

In spite of problems with the exact determination of the age of the radiolarites under study, several features point to their "exotic" character compared to other Upper Jurassic radiolarites occuring in the Western Carpathians. First of all, they are typical radiolarites free of calcite (except rare intercalations of Calpionella limestones) and clastic admixture. Central Carpathian "radiolarites" (Fatric and Tatric units) are only radiolarians-bearing siliceous limestones with chert lenses and layers. Radiolarites from the Klippen Belt Kysuca Succes sion are more pure, however, overlain by Tithonian – Neocomian pelagic nodular and maiolica-type limestones. On the contrary, the deposition, mostly bellow CCD, continued in the Lazy Formation probably until the Albian. From this point of view, the Lazy Formation, and the Belice Succession as a whole, has no equivalents in the present surface structure of the Western Carpathians. The eupelagic oceanic character of the Lazy Formation throughout the Late Jurassic – Early Cretaceous, the correlation of its Cretaceous shaly part with the Palombini shales of Ligurian-Piemont units of the Apennines and Western Alps (PLAŠIENKA, 1995a), and the position of the Belice Unit below the Tatric basement thrust stack, would suggest South Penninic (Vahic in the Carpathian nomenclature) provenance of the Belice Unit.

Acknowledgements

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Plate I. Radiolarians extracted from samples L-6 and L-18.

Fig. 1 Mirifusus dianae KARRER - antapical view of Fig. 5, showing the flattened test, 7428, 255x magn., sample No. L-6č;

Fig. 2 Tritrabs cf. hayi (PESSAGNO), 7414, 100x magn., L-6č;

Fig. 3 Homoeoparonaella argolidensis BAUMGARTNER, 7439, 100x magn., L-6č;

Fig. 4 Staurosphaera antiqua RÜST, 7410, 145x magn., L-6;

Fig. 5 Mirifusus dianae (KARRER), 7427, 110x magn., L-6;

Fig. 6 Parvicingula dhimenaensis BAUMGARTNER, 7436, 160x magn., L-6;

Fig. 7 Ristola procera (PESSAGNO), 7440, 120x magn., L-6;

Fig. 8 Cinguloturris carpatica DUMITRICA, 7438, 165x magn., L-6;

Fig. 9 Ristola altissima (RÜST), 7416, 135x magn., L-6;

Fig. 10 Sethocapsa leiostraca FOREMAN, 7419, 290x magn., L-6;

Fig. 11 Triactoma jonesi (PESSAGNO), 7415, 155x magn., L-6;

Fig. 12 Transhsuum brevicostatum (OŽVOLDOVÁ), 7418, 205x magn., L-6;

Fig. 13 Transhsuum brevicostatum (OŽVOLDOVÁ) - antapical view of Fig. 12, showing the flattened test, 7433, 470x magn., L-6;

Fig. 14 Eucyrtidiellum ptyctum (RIEDEL et SANFILIPPO), 7435, 410x magn., L-6;

Fig. 15 Podobursa triacantha (FISCHLI), 7437, 155x magn., L-6;

Fig. 16 Transhsuum brevicostatum (OŽVOLDOVÁ), 7514, 290x magn., L-18.

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Stable isotope composition of carbon in selected carbonaceous units of Slovakia with reference to Úrkút (Hungary) and Copperbelt (Zambia) examples

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Abstract Although sufficient information exists on the isotope composition of carbonate carbon in several sedimentary rock units and mineral deposits of the Slovak Carpathians, no comprehensive isotopic study has yet been carried out on the reduced carbon found in carbonaceous units. To fill this gap authors have summarized and evaluated in this paper all available isotopic results and attempted to update the fragmentary information. Foreign reference samples, including those from Úrkút Mn ore deposit and Copperbelt Cu-Co district, have also been analyzed in order to compare the results and to contribute to resolution of some genetic aspects in the respective deposits. It is shown that most carbons are enriched in ^{12}C isotope and have organic matter as precursor. In a number of samples, however, pyrolitic reactions and/or re-equilibration between organic and carbonate carbon resulted in a shift to a more ^{13}C enriched variety. The intensity of re-equilibration depended mainly from the degree of metamorphism of the host rocks and availability of heavy carbon isotope in the process. The heavy carbon isotope could have been released from coexisting carbonates, or from "juvenile" sources. Relatively strong ^{12}C depletion has been observed in the samples collected from the shear zones, where organic carbon reacted with water, or a heavy carbon containing gas phase. The reaction with water lead to the formation of a ^{12}C enriched carbon oxide, leaving the original organic carbon, or graphite, relatively enriched in the heavy isotope. The most intense ^{13}C enrichment (average $\delta\ ^{13}C$ of -15.59 ‰) display the samples from the "Magnesite Carboniferous". Furthermore, the average δ values for Gemericum Unit are also less negative compared to the other major units of the Western Carpathian system, thus, authors propose a different paleoenvironmental development for this unit. Extreme enrichment in ^{13}C in one graphite sample (-8.66‰) indicates that it could have formed in a process of carbonate, or carbon dioxide reduction.

Key words: carbonaceous matter, stable carbon isotopes, evolutionary pathways, rock metamorphism, re-equilibration, origin of carbon, genetic considerations.

Introduction

This study has been motivated by almost complete lack of the carbon isotope data from the carbonaceous units of the Slovak Carpathians and an urge to attain a deeper insight into the genetic and metamorphic history of carbon in this important lithotype. In addition to the Slovakian samples, 16 foreign reference samples, out of which 10 come from the manganese deposit of Úrkút (Hungary) and the world known Cu/Co district of Copperbelt (Zambia), have also been assayed in order to compare the results from different environments and epochs, and to contribute to modelling genetic aspects of the respective mineral deposits.

The evaluation of results of this isotopic study has been preceded by an analysis of available literature concerned with stable carbon isotopes in the geological environment. Following lines are a review of available information and a summary of important features used in our interpretations.

The results of numerous isotope studies have shown that organic carbon found in geological materials is markedly enriched in the light isotope, while the heavy isotope associates with inorganic carbon, such as carbonate, bicarbonate or carbon dioxide. This is based on the fact that all pathways of biologic carbon fixation entail such types of isotope fractionation, which discriminate against ^{13}C and lead to preferential incorporation of the light carbon isotope into cell material. The $^{13}C/^{12}C$ ratios of both organic and carbonate carbon are preserved in sediments with but minor alterations though the ages, so the isotopic signature can be traced back to the beginning of the rock record (SCHIDLOWSKI in: JOHNS, 1986). A graphic summary of the isotope age functions of both carbon isotopes, spanning the time from Early Archean to present day, are shown in Fig. 1.

Isotopic changes, which take place during burial and diagenesis of organic matter are generally low, summing up to several permil over the maturation pathway, and never seriously obscure the isotopic signature of the primary biological material. The end product of the maturation process is kerogen - a polycondensed acid-insoluble carbonaceous residue, which contains slightly heavier carbon isotope relative to the progenitor material (SCHIDLOWSKI l.c.).

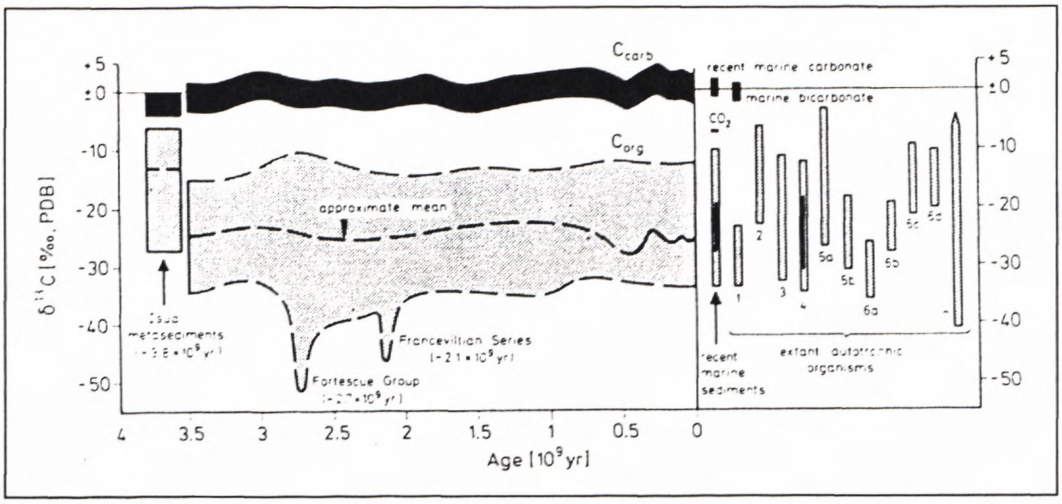


Fig. 1. Isotope age functions of sedimentary carbonate (C_{carb}) and organic carbon (C_{org}) as compared to the isotopic composition of their progenitors in the contemporary environments. Spreads shown for extant autotrophs are those of: 1) C_3 plants; 2) C_4 plants; 3) CAM plants; 4) eucaryotic algeae; 5) cyanobacteria from (a) natural communities and (b) culture experiments; 6a-d) non-oxygenic photosynthetic bacteria (Chromatiaceae, Rhodospyrillaceae, Chlorobiaceae, Chloroflexaceae); 7)chemoautotrophic bacteria (methanogens). After SCHIDLOWSKI (in: JOHNS 1986).

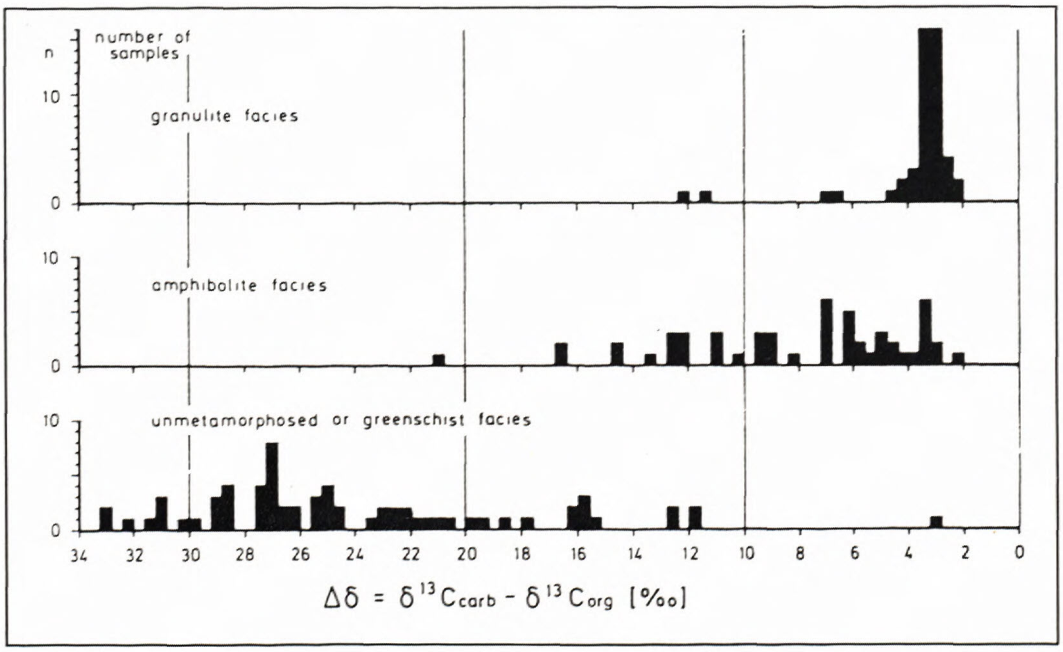


Fig.2. Isotopic re-equilibration between coexisting sedimentary carbonate (calcite) and organic carbon in response to rock metamorphism. The exchange is caused by mobilization of "heavy" CO_2 during decarbonation of primary carbonate rocks, which commences in the green schist facies (300-450 °C), becomes rather pronounced in amphibolite-grade rocks (450-650 °C) and thermodynamic re-equilibration is almost attained in the granulite facies (≥650 °C). After VALLEY and O'NEIL (1981).

Much more important are isotopic changes brought about by rock metamorphism. Temperatures exceeding 400 °C initiate pyrolitic reactions in primary organic matter, accompanied by release of CO_2, carbohydrates and water and by progressive carbonification (ANDREAE 1974). Escape of methane, CO_2 and other volatiles, enriched in ^{12}C, results in relative enrichment in ^{13}C isotope in the carbonaceous matter (CM).

Further changes take place due to re-equilibration with the heavy carbon. While the metamorphic alterations of the $^{13}C/^{12}C$ ratios in carbonate-fee rocks are negligible, isotopic re-equilibration between CM and coexisting carbonates at increased metamorphic conditions shifts the $\delta^{13}C$ values of carbon from around -26 to -10 ‰, or even more positive ones (SCHIDLOWSKI l.c.). This shift is caused by $^{13}C/^{12}C$ exchange with isotopically heavy CO_2 released from carbonates during metamorphic decarbonation reactions which start in the lower green schist facies and increase with metamorphic grade (VALLEY and O'NEIL 1981). As a function of metamorphic grade, the magnitude of fractionation between C_{org} and C_{carb} becomes progressively smaller, with equilibrium closely approached in the granulite facies (BOTTINGA 1969). Fig. 2 displays the variations in isotopic composition between coexisting calcite and organic carbon in response to increasing rock metamorphism (VALLEY and O'NEIL 1981).

Considerable isotopic changes occur in CM contacted with hydrothermal fluids. In such cases carbon equilibrates with ^{12}C depleted CO_2, contained in the fluid, or with water to form ^{12}C enriched CO gas and to leave the outcoming carbon relatively reacher in heavy isotope.

Another process shifting the original isotopic composition of reduced carbon to more positive values is associated with the presence of uranium in the system and the resulting interaction of α-particles with the organic matter. LANDAIS et al. (1990) reported a 10 ‰, deviation of $\delta^{13}C$-value in rocks containing 2 to 11.5% of U. On the other hand, LEWAN and BUCHARDT (1989) did not observe any effect on the carbon isotope composition of organic matter from uranium concentrations below 500 ppm.

Application of carbon isotope studies

The isotopic composition of reduced carbon have been studied by a number of authors worldwide with the objective to:

- find biological markers in the rocks (e.g. SCHIDLOWSKI in: JOHNS 1986),
- study the variations in carbon isotope composition through geological time (e.g. GALIMOV in: DURAND 1980, VEIZER et al 1980),
- assess metamorphic temperatures from the degree of isotopic exchange between carbonates and reduced carbon (e.g. BOTTINGA 1969, VALLEY and O'NEIL 1981),
- solve other geological tasks.

In order to correlate our results with more generalized data, we present below the following scheme of KROPOTOVA et al. (1976). From literature, they classified carbon isotopic data for graphites and graphitoide materials found in various geological environments into three ranges:

1. graphites in carbonatites with $\delta^{13}C$-values from -6 to -3 ‰,
2. mantle derived graphite from kimberlite pipes with $\delta^{13}C$-values from -10 to -7 ‰ and
3. graphite characterized by the composition of organic carbon with $\delta^{13}C$-values from -25 to -30 ‰.

Correlation of our isotopic data (see Table 1) with this scheme shows that the majority of them fall within the range of the third group. However, a shift to less negative values can be observed in several samples, indicating the presence of processes leading to incorporation of various amounts of heavy carbon. These processes could either be acquired in the primary sedimentary and/or diagenetic stages or, what is more important, by subsequent metamorphic re-equilibration reactions with the carbonate, the juvenile carbon, or with water. As the contents of uranium in our samples are considerably lower than 500 ppm, we cannot expect any significant effects of α-particles upon the isotopic composition of the CM.

Some of our reference samples can be used as examples to demonstrate the re-equilibration processes related to metamorphism (Table 1).

The first example is C-1 sample of carbonaceous marble exposed to a medium grade metamorphism, which resulted in a re-equilibration of the CM with carbonate carbon and a reduction of the $\delta^{13}C$ value to 40-50 % of its original value.

A similar degree of re-equilibration has been achieved in the SL-1 graphite due to a reaction with juvenile carbon in a gaseous phase. This process occurred under metamorphic conditions of granulite facies.

The SF-1 sample is a tuff intercalated with dolomite metamorphosed under conditions of amphibolite facies. In this case the reduction of $\delta^{13}C$-value due to the re-equilibration with a carbonate or a gaseous carbon phase changed the original carbon isotope composition by some 40% .

Table 1 Stable isotope composition of carbons

SAMPLE	TYPE	ROCK	AGE	LOCALITY	UNIT	TOC	ISOTOPE-C
G-1	G	black schist	Lower Paleozoic	Jasenie, Melicherka	TNT	1.00	-25.13
G-3	SG	black schist	Lower Paleozoic	Jasenie, Soviansko	TNT	0.97	-30.46
G-4	SG	grey schist	Lower Paleozoic	Jasenie, Biela voda, Viržing	TNT	0.09	-24.51
G-5	G	grey schist	Lower Paleozoic	Jasenie, Biela voda, Viržing	TNT	0.06	-27.46
G-7		grey schist	Lower Paleozoic	Jasenie, Kyslá, Čremošnô	TNT	0.11	-24.92
G-8	SG	grey schist	Lower Paleozoic	Jasenie, Suchá, dol. Medveďová	TNT	0.12	-22.06
G-9	SG	grey schist	Lower Paleozoic	Sopotnická dol. Ramženô	TNT	0.16	-22.60
HE-1	MA	grey schist	Lower Paleozoic	Jasenie, Hor. Erenštanka	TNT	0.13	-23.10
HE-1	MA	grey schist	Lower Paleozoic	Jasenie, Hor. Erenštanka	TNT		-22.89
HE-2	MA	grey schist	Lower Paleozoic	Jasenie, Hor. Erenštanka	TNT	0.07	-23.46
HM-1a	SG	grey schist	Lower Paleozoic	Jasenie, Hor. Erenštanka	TNT		-25.26
HM-5	SG	grey schist	Lower Paleozoic	Jasenie, Hor. Erenštanka	TNT	0.35	-25.80
HM-8		grey schist	Lower Paleozoic	Jasenie, Melicherka	TNT	0.10	-27.49
HM-9		grey schist	Lower Paleozoic	Jasenie, Melicherka	TNT	0.13	-25.57
HUS-5		mylonite + graphite	Lower Paleozoic	Jasenie, Husárka	TNT		-18.89
MAT-1	G	gneiss + graphite	Lower Paleozoic	Bukovec, Pod Matúšovou	TNT	0.45	-30.72
MAT-2	G	quartz.gneiss + graphite	Lower Paleozoic	Bukovec, Pod Matúšovou	TNT	0.08	-28.97
MEDZ-1	G	phyllonite + graphite	Lower Paleozoic	Medzibrod-Močiar, dump	TNT	0.46	-28.78
MEL-21	MA	2-mica.schist + graphite	Lower Paleozoic	Jasenie, Melicherka	TNT	0.10	-27.84
NT-1	G	granitoide + graphite	Lower Paleozoic	Jasenie, Gelfúsová (Štefan adit)	TNT		-24.10
NT-6/2	G	paragneiss + graphite	Lower Paleozoic	Jasenie, Gelfúsová (Štefan adit)	TNT		-18.60
SOV-1		black shale	Lower Paleozoic	Jasenie, Sova-Haliar	TNT		-25.88
SOV-2	SG	mylonite + graphite	Lower Paleozoic	Jasenie, Sova-Haliar	TNT	0.24	-20.60
V-1 (419.5 m)		2-mica schist + graphite	Lower Paleozoic	Jasenie, Prostredná dol., Bauková	TNT	0.01	-25.12
VNT-11 (81-92)	G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.32	-29.66
VNT-12 (14 m)	SG,G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.34	-28.50
VNT-12 38.5 m)	G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.90	-29.54
VNT-12 (96 m)		graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.10	-28.38
VNT-13 (22-27 m)	SG,G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.40	-28.19
VNT-14 (101-112 m)		graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.10	-24.49
VNT-14 (24-33 m)		graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.10	-25.24
VNT-15 (114-115,8 m)	G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	1.85	-26.33
VNT-15 (179 m)	G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.40	-27.91
VNT-15 (235-236,5 m)	SG,G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT	0.10	-27.02
VNT-15 (235-236.5 m)	SG,G	graphitic schist	Lower Paleozoic	Sopotnická dol. valley	TNT		-29.63
VNT-7 (81.5 m)	SG,G	graphitic schist	Lower Paleozoic	Medzibrod, Močiar, drill hole	TNT	0.97	-30.26
VNT-7B (133.3 m)	SG,G	graphitic schist	Lower Paleozoic	Medzibrod, Močiar, drill hole	TNT	0.64	-28.93
VPB-5 (194.5 m)		grey schist	Lower Paleozoic	Bukovec, near E of SNP memorial	TNT		-27.44
VŽ-1	G,MA	schist+graphite	Lower Paleozoic	V. Železnô, pod Kliniskom	TNT	0.13	-29.43
Š-3, MB 100,75 m S		dark schist	Lower Paleozoic	Jasenie,Š-3 adit,75 m S of SP100	TNT	0.01	-27.42
P-24	G	granitoide	Variscan	Malá Fatra Mts. (Lúčna part)	TMF		-23.50
P-39	G	granitoide	Variscan	Malá Fatra Mts. (Lúčna part)	TMF		-24.30
P-45/1	G	aplite	Variscan	Malá Fatra Mts. (Lúčna part)	TMF		-19.00
P-53	G	pegmatite	Variscan	Malá Fatra Mts. (Lúčna part)	TMF		-22.60
P-60/2	G	paragneiss	Variscan	Malá Fatra Mts. (Lúčna part)	TMF		-25.70
AUG-1	SA	black shale	Lower Paleozoic	Pezinok, Augustín adit	TMK		-30.30
52/75	G	graphitic schist	Lower Paleozoic	Ostrica, slope S of trig. p. 684 m	TSM	0.90	-32.88
NEVIDZ.-1	G	graphitic phyllonite	Lower Paleozoic	Nevidzany, cca 1 km S from vill.	TSM	1.99	-32.25
JEŽ-1	G	q. -biot. gneiss+graphite	Lower Paleozoic	Bujakovo, nad Ježovou	VEP		-28.39
KS-1 (154,6 m)	SG	bi. -alb. gneiss+graphite	Lower Paleozoic	Klenovec, d. h. KS-1	VEP	0.05	-8.66
KS-1 (237,5 m)	SG	bi. -alb. gneiss+graphite	Lower Paleozoic	Klenovec, d.h. KS-1	VEP	0.40	-30.99
KI-108/86	SG	garnet. schist+graphite	Lower Paleozoic	Klenovec, 500 m N from Hôra	VEP	0.12	-23.38
KI-42/86	SG	garnet. schist+graphite	Lower Paleozoic	Klenovec, 2 km N of Pavlínka	VEP	0.51	-27.42
BAC-1/R	SG	grey schist	Lower Paleozoic	Bacúch, Ramžová dolina valley	VEP	0.37	-23.70
BYS-2		black schist	Lower Paleozoic	confluence Bystr. & Štiavnička	VNT	0.23	-26.22
JAN-1		grey schist	Lower Paleozoic	Jančíkova dol. valley	VNT		-28.71
KLI-1		black schist	Lower Paleozoic	Bystrá, Bystr. & Štiav. confluence	VNT		-29.80
POL-1	SG	q. phyllite+graphite	Lower Paleozoic	Polomka, P. & Ľ. Ráztoka confl.	VNT	2.50	-32.60
DB-252	MA	vein-quartz+stib.+graph	Lower Paleozoic	Spiš. Baňa (Sb), Margita, dump	GE		-26.70
DB-488	A	vein-quartz+stib.+graph	Lower Paleozoic	Čučma (Sb), Rozália adit, dump	GE		-24.69
MG-1		black shale	Lower Paleozoic	N. Slaná Mine (Fe)	GE		-23.33
NS-1		black shale	Lower Paleozoic	Nižná Slaná Mine, IX. horizon	GE		-24.62
NS-2	SA	black shale	Lower Paleozoic	N. Slaná Mine, Manó, X. horizon	GE		-26.61
S-1	A	black shale	Lower Paleozoic	Smolník, d. h. Rb-3 (87 m)	GE		-27.25
B-1	SA	black shale	Lower Paleozoic	Brádno (Slov. Nat. Museum)	GSZ		-23.54
KAD-1		black shale	Lower Paleozoic	Kadlub (relinguish. graphite mine)	GSZ		-21.79
Ro-3 (101-101,5 m)	MA	black shale	Carboniferous	Rochovce, d.h. Ro-3	GSZ	1.10	-20.71
Ro-3 (133,2 - 133,4 m)	SG	black shale	Carboniferous	Rochovce, d.h. Ro-3	GSZ	1.40	-19.96
Ro-3 (190-191 m)		black shale	Carboniferous	Rochovce, d.h. Ro-3	GSZ		-22.71
Ro-3 (75,3-76,7 m)	MA	black shale	Carboniferous	Rochovce, d.h. Ro-3	GSZ	1.34	-21.03
Ro-4 (155,4 m)		black shale	Carboniferous	Rochovce, d.h. Ro-3	GSZ	0.80	-23.43
16 b/IV		black shale	Carboniferous	Burda, III. hor. 50 m S from N. Adit	GMC		-13.83
32 b/VI		black shale	Carboniferous	Burda, III. hor. 50 m S from N. Adit	GMC		-17.30
33 b/IV		black shale	Carboniferous	Burda, III. hor. 50 m S from N. Adit	GMC		-14.29

SAMPLE	TYPE	ROCK	AGE	LOCALITY	UNIT	TOC	ISOTOPE-C
Pb 30b/72		black shale	Carboniferous	Podrečany, open pit (magnesite)	GMC		-17.40
Pb 30a/72	A	black shale	Carboniferous	Podrečany, open pit (magnesite)	GMC		-15.11
DRŽ-1/2 (90,5-90,8 m)	A	black shale	Jurassic	Držkovce, d.h. DRŽ-1	SIL	0.60	-27.46
DRŽ-1/7 (700,4-700,5 m)	SA	black shale	Jurassic	Držkovce, d.h. DRŽ-1	SIL	0.50	-24.84
N-2 (3447 m) (HF,GCL)	SA	anthracit coal	Carboniferous	Nemčičky, drill hole N-2	K		-24.73
JŠ-1	SG	coal in andesite	Miocene	B. Štiavnica, N schaft, 2. h., Bieber	NV	13.62	-22.60
PŘI-1	G	pegmatite + graphite	Variscan	Přibyslavice	CZM		-29.44
VT-1	G	graphitic schist	Lower Paleozoic	Velké Třesné (Slov. Nat. Museum)	CZM		-25.29
ČK-MV	G	graphitic gneiss	Precambrian	Č. Krumlov, Městský vrch hill	CZM	18.00	-21.93
C-1	G	marble + graphite	Jurassic	Rincón Naranjo, Z. Trinidad, Cuba	CUB		-8.62
SL-1	L	graphite semitreated	Precambrian	Sri Lanka (graphite concentrate)	SL	95.00	-7.21
UR-162	L	black shale + Mn	Toarcian	Úrkút (Hungary), open pit	U	2.63	-30.78
UR-165	L	black shale + Mn	Toarcian	Úrkút (Hungary), open pit	U	4.56	-31.20
UR-172	L	black shale + Mn	Toarcian	Úrkút (Hungary), open pit	U	3.09	-30.29
UR-176	L	black shale + Mn	Toarcian	Úrkút (Hungary), open pit	U	3.35	-29.42
UR-OP-1	G	black shale + Mn	Toarcian	Úrkút (Hungary), open pit	U	5.65	-31.97
SF-1	G	graphitic tuff (Finland)	Precambrian	Vihanti, Hauterämi O/B + 460	V	1.53	-14.02
KAN-2	SG	black schist (Zambia)	Precambrian	Kansanshi open pit, S wall	Z	1.33	-24.62
MUF-GW/1	G	greywacke (Zambia)	Precambrian	Mufulira, "B" O/B, 60 MP2, 895 mL	Z	0.10	-23.92
NCHA-1	SG	black schist (Zambia)	Precambrian	Nchanga OP, 217 mL, 12E, S wall	Z	5.63	-22.73
S-15123	G	greywacke (,) (Zambia)	Precambrian	Muf. 43MP8, 895mL + 60 N, "B"O/B	Z	2.16	-27.34
X-680		black schist(Zambia)	Precambrian	Mufulira, 56P4,880 mL, 40S, "A" O/B	Z	1.34	-27.02

Caption to Table 1: Most column headings are selfexplanatory. The abbreviations in the second column are explained in the chapter on carbon modifications and those in the fifth column stand for: TNT- Nízke Tatry Mts., Tatricum Unit; TMF-Malá Fatra Mts., Tatricum Unit; TMK-Malé Karpaty Mts.,Tatricum Unit; TSM-Suchý and Malá Magura Mts., Tatricum Unit; VEP-Southern part of Veporicum Unit; VNT- Nízke Tatry Mts., Veporicum Unit; GE-Gemericum Unit; GSZ-Zone of contact between Veporicum and Gemericum Units; GMC-"Magnesite Carboniferous", Gemericum Unit; SIL-Meliaticum Unit; K-Carboniferous, Inner flysch basement; NV-Neovolcanic rocks; Foreign samples: CZM-Czech massif; CUB-Cuba, Escambray; SL-Sri Lanka; U-Úrkút, Hungary; V-Vihanti mine, Finland; Z-Zambian Copperbelt. TOC - total organic carbon.

The smallest re-equilibration, to 80-90% of its original value, experienced the graphite in the sample ČK-MV (Fig.9a). Although the gneissic host rock was here exposed to amphibolite facies metamorphism and carbonates do occur within the area of this deposit, the intensity of re-equilibration process was limited due to unknown reasons.

Our presumption that the degree of re-equilibration under contact metamorphic conditions should be considerably smaller compared to that attained under regional conditions can be supported by observation of the sample JS-1. It was collected from a coal seam entrapped in a neovolcanic andesite body of Miocene age. Extreme temperatures, which undoubtedly accompanied the emplacement of this andesite, did not convert local coal into graphite, but only to semianthracite, which can be explained by a relatively short time span and too low pressures to allow for its better recrystallization. Moreover, the $\delta^{13}C$-value did not deviate considerably from that of the original coal.

Carbon modifications

The carbon modifications in the samples under study range from lignite (L), semianthracite (SA), anthracite (A) and metaanthracite (MA) through semigraphite (SG) to a well-ordered graphite (G)(see abbreviations in Table 1), with the following ranges of interlayer distances (in Å): L, SA, A > 3.40, MA 3.38-3.40, SG 3.37-3.38 and G 3.354-3.37. Their structural ordering reflects in the majority of cases the degree of metamorphic overprinting that the host rocks have undergone during their metamorphic evolution. The degree of crystalline perfection has been studied using the x-ray and the TEM methods and the results were reported by MOLÁK et al (1986, 1989) and MOLÁK (1990). These were recently supplemented by few STOE powder diffraction analyses.

Geological setting and metamorphism

The majority of the studied domestic samples have been collected from the Central and Inner Western Carpathians (WC), namely from the Tatricum (or the Core Mountain Zone), the Veporicum and the Gemericum Units. Their assignment to a zone, unit or a mountain is listed in Table 1 and their locations are shown in the attached simplified geological sketches (Figs. 3-7). Few samples come from the Jurassic cover, from the Neogene volcanic rocks, or other lithostratigraphic units. No sketches

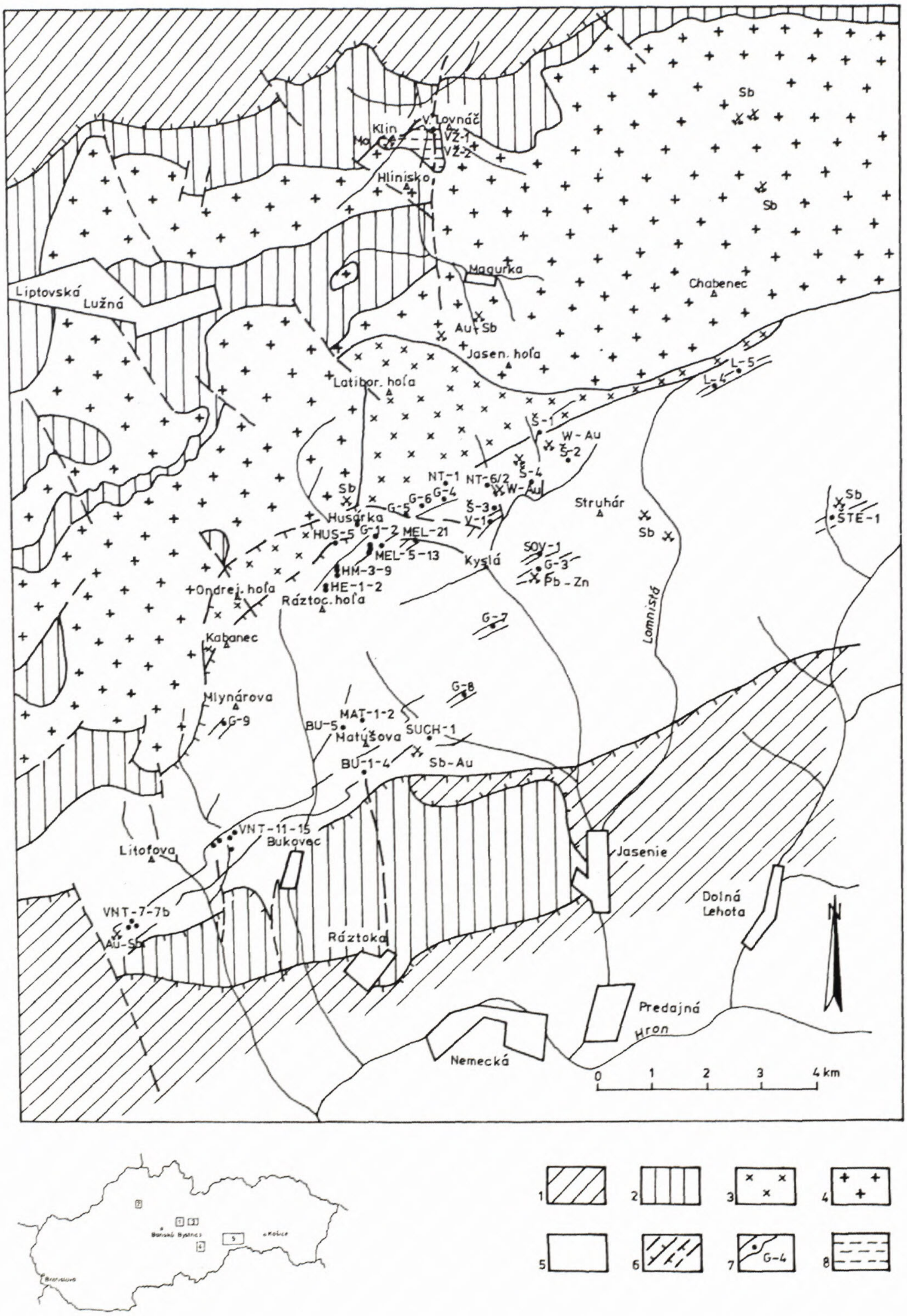


Fig. 3. Schematic geologic map of the central-western part of the Nízke Tatry Mts. (after A.BIELY, O.MIKO, I.LEHOTSKÝ, E. LUKÁČIK, A. KLINEC, B. MOLÁK, J. MICHÁLEK et al.) with sample locations. Legend: 1-Mesozoic nappes; 2-Mesozoic cover; 3-nebulitic migmatite; 4-granitoids; 5.crystalline schists; 6-tectonic lines; 7-layers of SAMP, CFM and graphitic schists; 8-biotitic schist "Klinisko". Crossed hammers: abandoned mines with the main metals extracted.
Inset shows the areas of collected samples: 1-Nízke Tatry Mts., Tatricum Unit; 2-Malá Fatra Mts., Tatricum Unit; 3-Nízke Tatry Mts., Veporicum Unit; 4- souther part of Veporicum Unit; 5-southern part of Gemericum Unit.

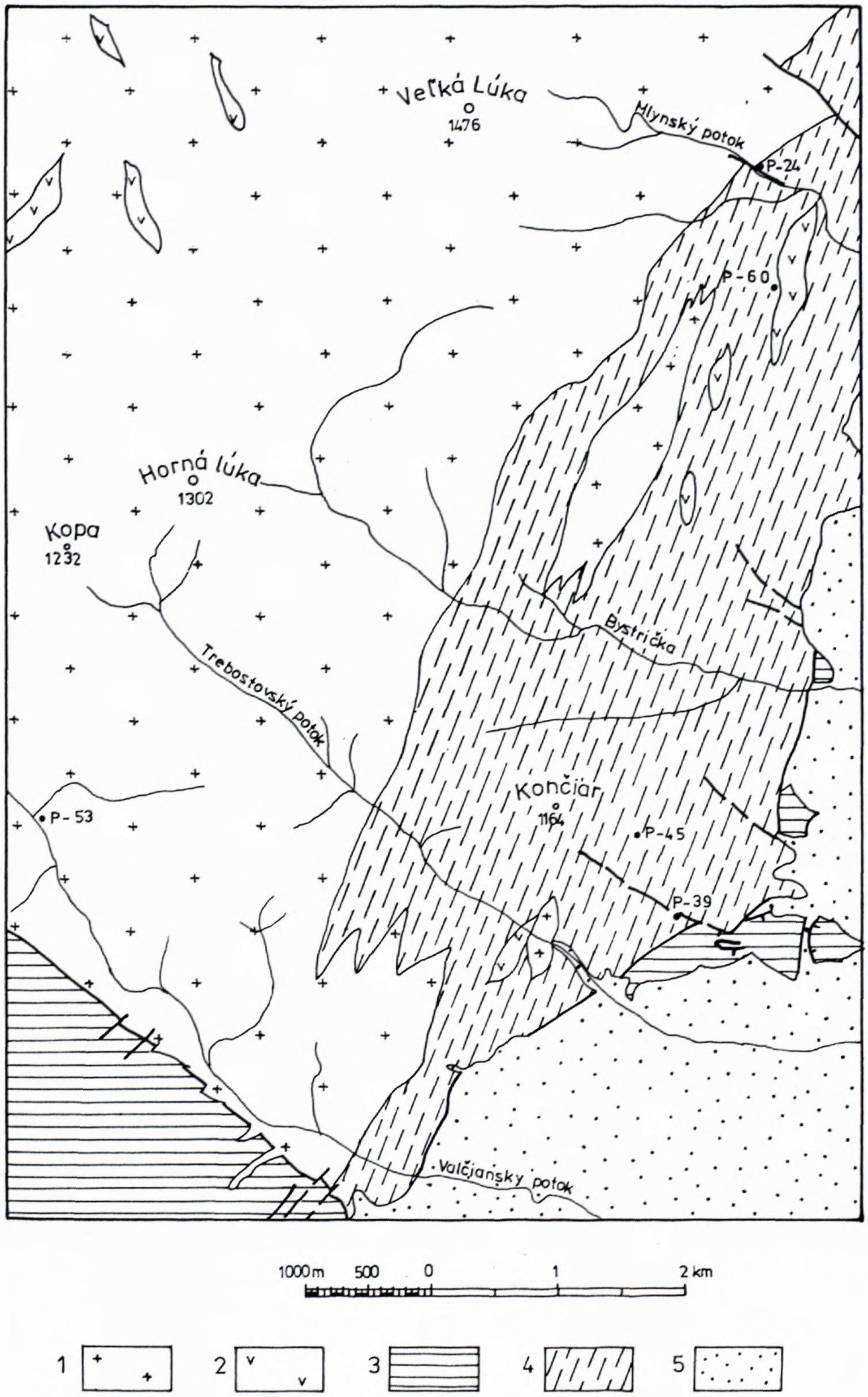


Fig.4: Geologic sketch map of the Lúka part of Malá Fatra Mts.,Tatricum Unit, (after RAKÚS et al. 1993), with sample locations. Legend: 1-Medium grained granodiorite ± pegmatites, aplites (Variscan);2-Amphibolites; 3-Mesozoic carbonate rocks; 4-Garnetiferous biotitic paragneisses ± amphibolites; 5- Neogene and Quaternary sediments.

are presented to show the location of foreign and solitary samples.

Tatricum Unit

According to our metamorphic reconstruction (MOLÁK et al 1986, 1989, KORIKOVSKY - MOLÁK 1995) the CM in the rocks of Tatricum part of the Nízke Tatry Mts. (Fig.3) have been subjected to: 1) Pre-Variscan ultrametamorphism and granitization, accompanied by graphitization of CM; 2) Variscan metamorphism, observed in two levels - a deeper level, exposed to conditions of biotite subzone to amphibolite facies, characterized by a graphitic ± semigraphitic variety of the CM and a shallower level, corresponding to the conditions of chlorite-ankerite-muscovite subfacies, or more precisely, to a depth of burial of 12-13 km, with temperatures of 320-330 °C and pressures of at least 3.5 kbar. The CM has been transformed into anthracite; 3) Alpine anchi- to epizonal metamorphism, accompanied by coalification and anthracitization of the CM. Apart from siderite-ankerite-bearing metasediments, no carbonates occur in the crystalline rocks of the Nízke Tatry Mts. Both Variscan and Alpine stages were characterized by shearing deformations and mylonitization, the former with prevailing ductile and the latter with mostly brittle conditions. Shearing deformations, especially those, of the Variscan stage, were accompanied by migration of mineralized fluids. These were responsible for subsequent development of local Sb, Au, W, base metal and Fe mineralizations, as well as for a re-equilibration with the heavy carbon isotope, or a reaction with water.

In the other mountains of the Tatricum Unit - the Malá Fatra and Suchý - Malá Magura Mts., the well ordered graphites occur in the granitoide, gneissic, schistose and phyllonitic rocks (Fig.4). Probably during the Pre-Variscan orogenetic events the crystalline rocks have been here exposed to amphibolite facies metamorphism. As the schists and the phyllonites contain a completely graphitized CM, they are obviously Variscan diaphthorites.

A sample from the Malé Karpaty Mts., collected from a black shale horizon in an Sb-ore mine near Pezinok, markedly differs from the above samples from the Tatricum Unit by its low metamorphism. The CM was here transformed into semianthracite, which indicates the green schist conditions of metamorphism, and supports the view that the black shales here do not represent an autochthonous cover of the granite core. This is at variance with the situation in the majority of WC core mountains and more reminiscent to that in the Gemericum Unit and in the Eastern Alps.

Veporicum Unit

The Veporicum part of the Nízke Tatry Mts. comprises the Paleozoic volcanisedimentary Jánov Grúň Formation, defined by MIKO (1981). It is composed of the CM bearing dark phyllites and black schists (Fig.5), metasandstones, metagreywackes and metavolcanics. These rocks floor the area south of the Čertovica line, which divides this mountain into the Tatricum and the Veporicum parts. No carbonate rocks are involved. The progressive Variscan metamorphism reached the conditions of green schist facies, with temperatures ranging from 350 to 380 °C and pressures from 3.4 to 4 kbar (MIKO and KORIKOVSKY 1994). Local CM has been converted into semigraphite.

The rocks of the southern Veporicum Unit crop out along the NW side of the Lubeník tectonic line, a line of the first order, separating this unit from the Gemericum Unit. These rocks are composed of Lower Paleozoic metasediments, Variscan and Alpine granitoids and Late Paleozoic sedimentary and volcaniclastic rocks. The studied SG bearing gneisses and schists belong to the Klenovec and Ostrá Complexes - the lowest of the three major stratigraphic and structural horizons (Fig. 6). The reconstruction of Variscan metamorphism has always been hampered by overwhelming presence of Alpine metamorphism and deformational features, by re-orientation of the older structures and by complete resetting of the K/Ar clock. However, the petrologic, structural and fluid inclusion studies indicate that it was characterized by conditions reaching at least the level of biotite isograde, by local emplacements of leucocratic granitoids and by intense shearing. These events markedly affected the southern Veporicum rocks and are considered to have been a consequence of microcontinental collision and obduction of the mobile Paleo-tethian microplate (represented by the Gemericum Unit) over the Alpine-Carpathian microplate, represented by the Veporicum Unit. Shearing deformations were initially compressional, however, progressive erosion of the overthrusted unit resulted in an isostatic uplift of the subducted and geophysically lighter unit, changing the sense of the deformation to extensional. The peak regional metamorphic conditions operated under medium- to high pressures, reaching 6-8 kbars and temperatures exceeding 400 °C (VRÁNA 1964, MAZZOLI et al. 1992). These events were locally overprinted by a contact metamorphism, characterized by zoning of contact minerals within the contact aureole of the Alpine granite intrusions. VOZÁROVÁ (in VÁCLAV et al.1990 inferred) the metamorphic temperatures of 560 °C and the pressures of 2 kbar. CM has been converted into metaanthracite and/or semigraphite.

Gemericum Unit

The Gemericum Unit is composed of Early and Late Paleozoic volcanisedimentary rocks overlain by the Mesozoic Meliata Unit and the Silicicum nappe. This unit comprises prolific deposits and occurrences of polymetallic, Sb, Au, Ag, Hg and Fe ores and sparry magnesite, all mined or explored in the past, but only few mines kept in operation until present day. These mineralizations are frequently located within, or in the vicinity of ubiquitous black shales and lydites, which yielded some of the sam-

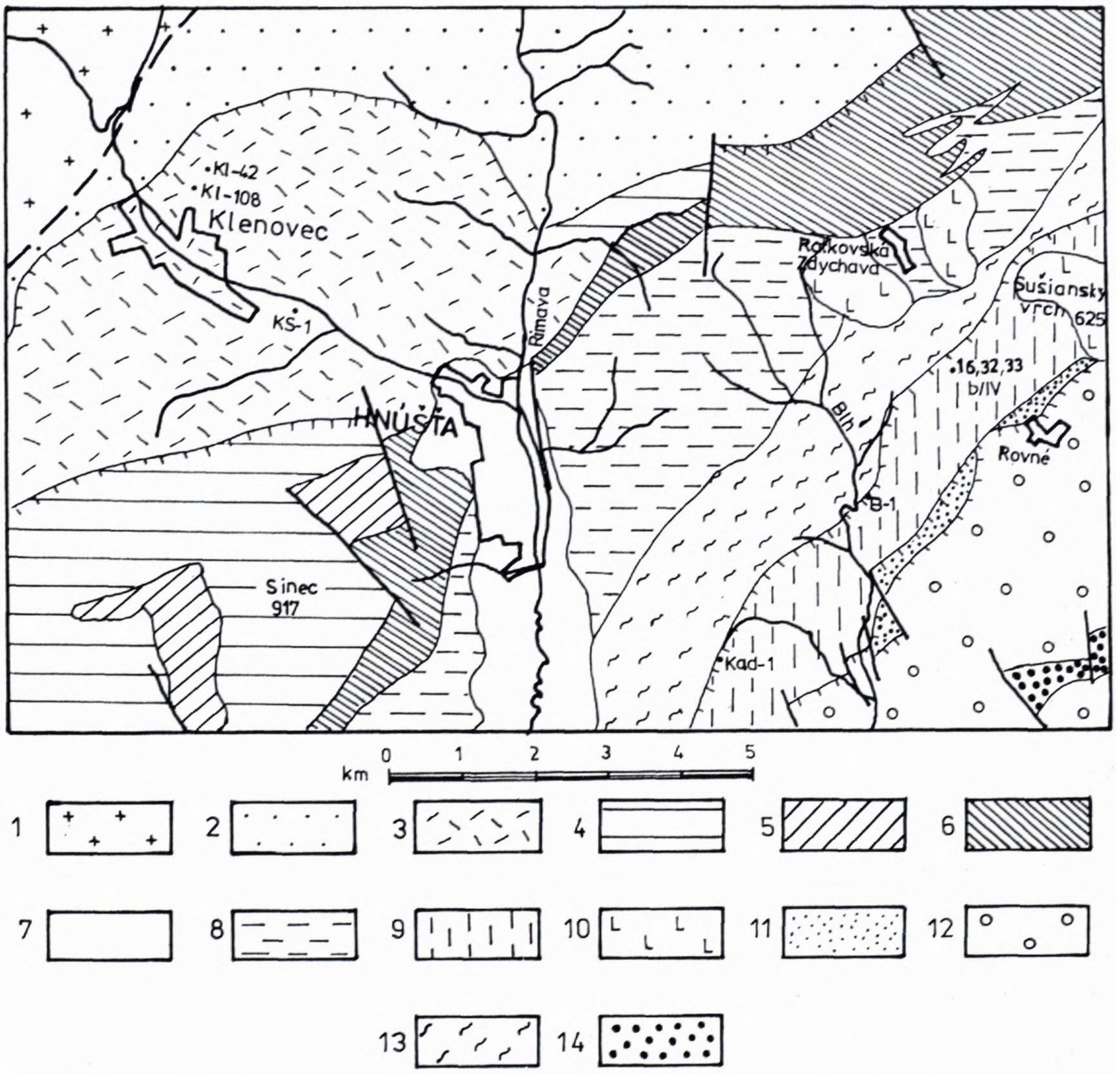


Fig. 5: Geologic sketch map of SW part of the Veporicum Unit (after SLAVKAY et al. 1995), with sample locations. Legend: 1-Hybrid granitoids with transitions to migmatites, locally porphyric (Variscan) 2-Garnetiferous schists, the Ostrá Complex (Paleozoic); 3-Biotitic albitized gneisses, the Klenovec Complex (Paleozoic); 4-White mica-chloritic schists, the Sinec Complex (Paleozoic); 5-Biotitic phyllites, the Hladomorná dolina Complex (Paleozoic); 6- Leucocratic granitoids, the Rimavica Complex (Variscan); 7-Quaternary and Neogene sediments; 8-Dark grey shales, sandstones, phyllites, the Slatvina Formation (Stefanian); 9- Sanstones, shales, basic volcanics, metamorphosed limestones, dolomites, magnesites and ankerites, the Ochtiná Formation, (Late Carboniferous); 10-Volcanics, andesites with pyroclastics(Miocene); 11-Metamorphosed carbonates with basalts, Meliata Group (Triassic-Jurassic); 12-Sandstones, shales, quartzites argillitic limestones, rhyolites, andesites, pyroclastics, the Turnaicum and Silicicum Units (Middle Triassic-Jurassic); 13- Greywackes,shales,volcaniclastics, the Rimava Formation (Permian); 14-Limestones, dolomites, the Turnaicum and Silicicum Units (Middle Triassic-Jurassic).

ples for this isotopic study (Fig. 7). Sedimentary carbonates are represented by limestones of the Carboniferous Zlatník Formation and the hydrothermal carbonates by magnesites, siderites and ankerites. According to b_0 values, measured in white micas by SASSI and VOZÁROVÁ (1987, 1992), the peak regional Variscan metamorphism was characterized by the temperatures ranging from 350 to 430 °C and the pressures between 2 and 2.5 kbar. The range of geothermal gradient has been inferred to have ranged from 40 to 45 °C/km. The Alpine regional tectono-metamorphic processes were marked by shearing deformations and by occassional formation of muscovite. Meanwhile, in the Ochtiná Formation - in the horizon hosting all economic deposits of the sparry magnesite - recrystallization of quartz and formation of radial chloritoide and kyanite, oriented oblique to Variscan mineral association, had taken place locally. No contact effects have been observed in the exocontact of the Alpine granite intrusion and the CM has been here converted into metaanthracite.

Meliaticum Unit

Two CM samples, collected from the drill hole DRŽ-1, which intersected the black shale horizons, were analysed. Black shales belong to the Jurassic Meliaticum Unit, exposed to diagenetic and/or anchizonal conditions during the Alpine metamorphic stage. The CM occurs in anthracitic form.

Methods

All isotopic analyses were performed on demineralized graphitic, subgraphitic or coaly materials The demineralization has been made by flotation and subsequent dilution of the residue in hot concentrated HF and HCl. The synthetic fluoro- or chloro-silicates have been removed by powdered

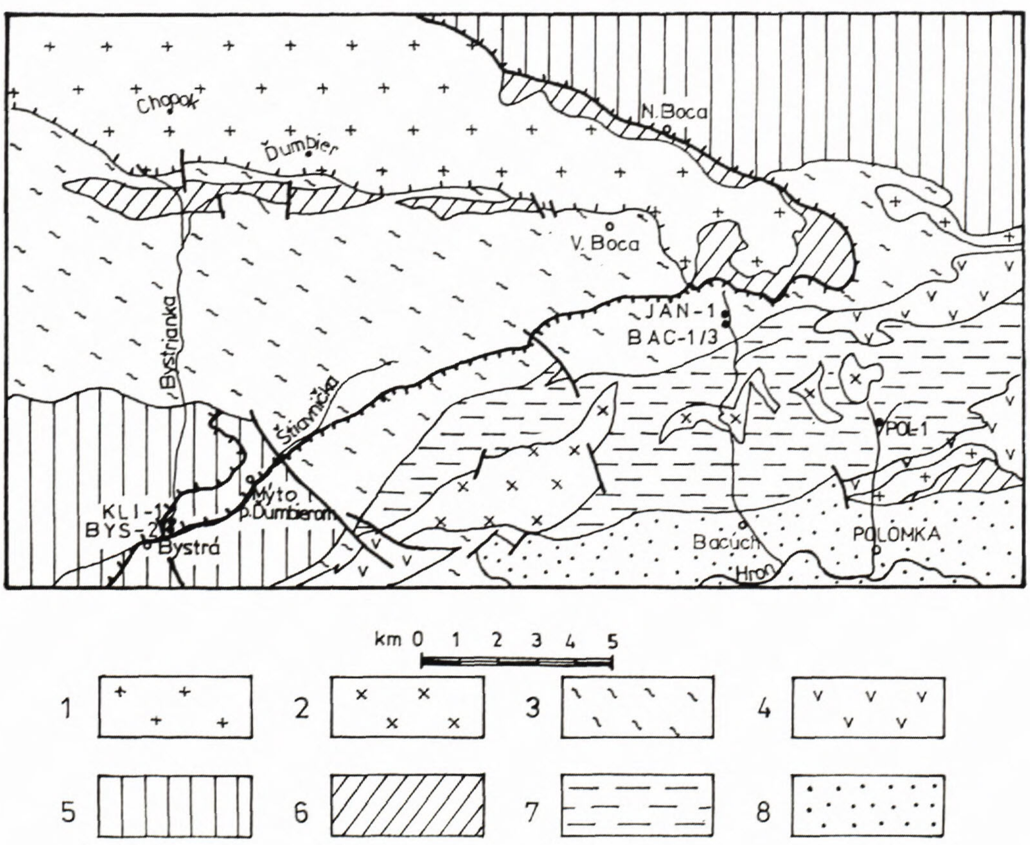


Fig. 6: Geologic sketch map of the Veporicum Unit, Nízke Tatry Mts. (after BIELY et al. 1992) with sample locations. Legend: 1-Granite, granodiorite (Variscan); 2-Granite porphyries and porphyrites (Variscan); 3-Orthogneisses, migmatites (Paleozoic-Pre-Cambrian?); 4-Amphibolites (Variscan); 5-Mesozoic rocks; 6-Triassic quartzites; 7-Paragneisses, schists, phyllites (Paleozoic); 8-Tertiary sediments

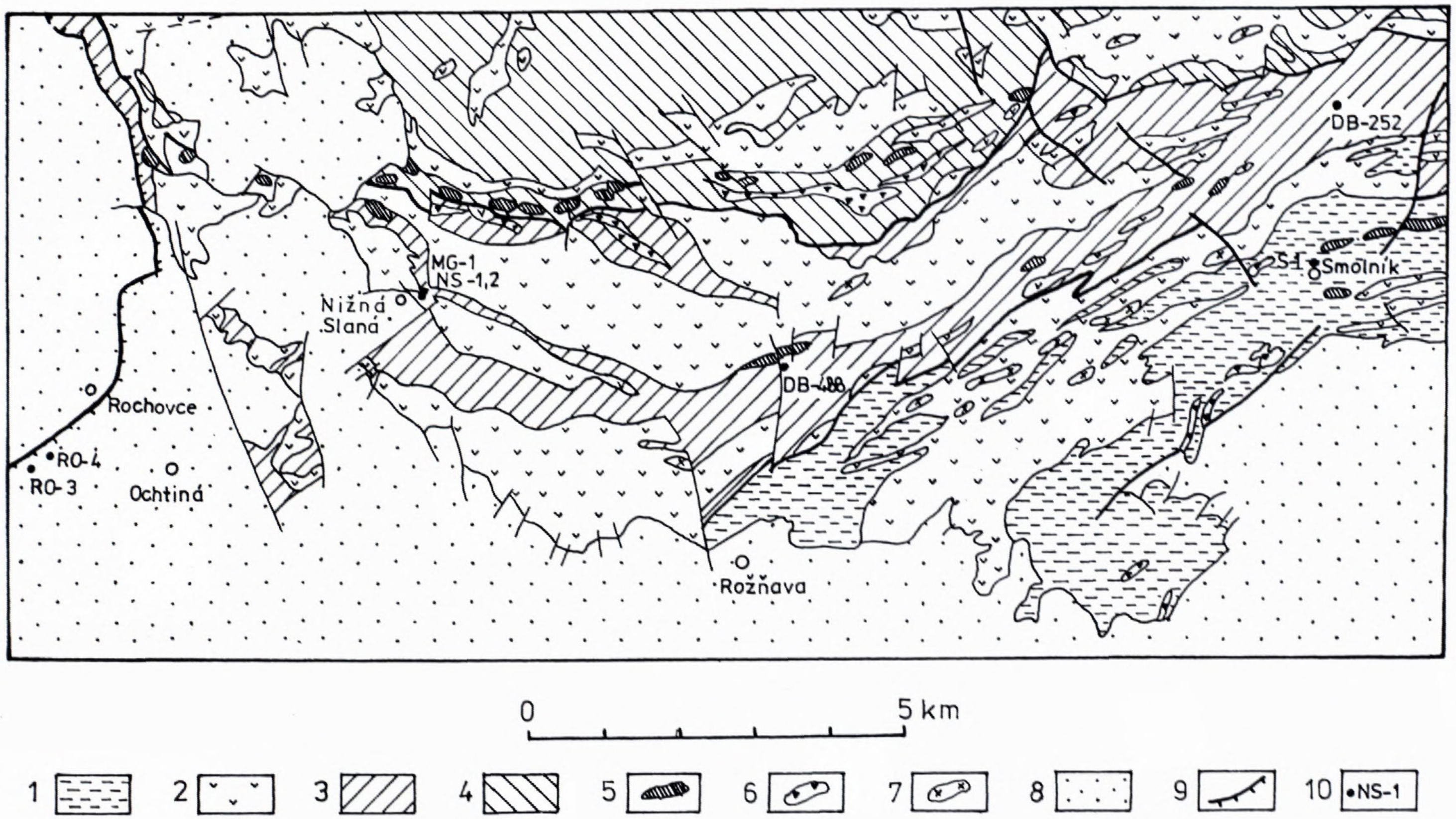


Fig. 7: Geologic sketch map of the southern part of Gemericum Unit (after SNOPKO *1974), with sample locations. Legend: 1-Clastic sediments, Upper Silurian-Middle Devonian; 2-metarhyolite tuffs and tuffites, Lower to Middle Silurian; 3-Shales and sandstones, Middle to Upper Silurian; 4- Shales and sandstones, Upper Cambrian to Lower Siluian; 5-Carbonates; 6-Lydites; 7-Quartz porphyries and keratophyres; 8-Late Paleozoic and younger units ; 9-Zone of contact between the Gemericum and Veporicum Units (Lubeník line); 10-sample location*

zinc and HCl and by multiple rinsing in hot distilled water. The concentration of carbon in the residues, measured by elemental analysis, was found to vary greatly from few per cent up to 99 per cent, depending mostly on the amount of CM in the host rock and the presence of resistant minerals, pyrite being the most common. The carbon samples were measured for $^{13}C/^{12}C$ composition using a Varian MAT 250 tripple collector mass-spectrometer, installed at the Department of Geology, University of Copenhagen. Analytical results were corrected for mass 46 contributions and recalculated to $\delta^{13}C$ values. The results are reported as per mil deviations from the PDB standard. The reproducibility measured as standard deviation on 10 standard preparations is better than 0.03 per mil on the δ-scale.

Discussion of isotope results

Tatricum Unit, Nízke Tatry Mts.

Most of the investigated carbon samples (40) came from Paleozoic carbonaceous units (CU) of the Nizke Tatry Mts., which crop out in the metamorphic terranes of the Tatricum or Veporicum Units. Among the five groups of CU, defined by MOLÁK et al. (1993), four were measured for isotopes on graphites. These are: 1. nebulites, 2. graphitic schists with Sb-Au mineralization, 3. problematics (metasediments?), and 4. schists of the "Klinisko" type. Furthermore, graphite also occurs in a newly defined lithotype: siderite-ankerite-micaceous phyllite (SAMP), described recently by Korikovsky and MOLÁK (1995). No measurements were made as yet on graphites found in the remaining fifth group, represented by phyllite of the Paučina Lehota type. Locations of samples submitted to isotopic study are shown, together with other samples containing graphitic and/or subgraphitic carbon, in Fig. 3.

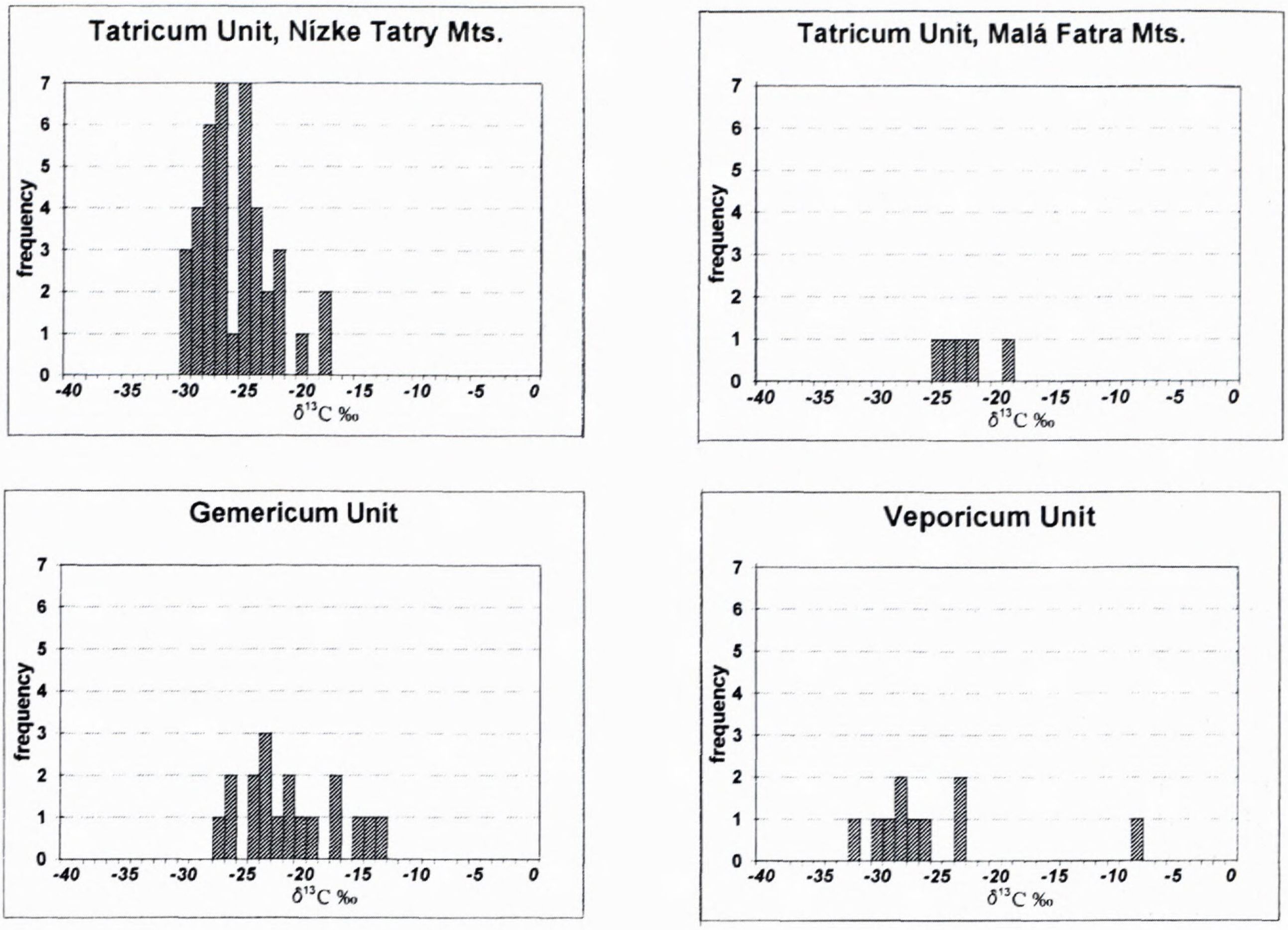
The frequency diagram (Fig.8a) for the samples from the Nízke Tatry Mts. shows that the majority of the $\delta^{13}C$-values range between -30‰ and -22‰. This confirms that (1) the carbon in the samples has an organic source and (2) that none, or only negligible re-equilibration with carbonate carbon took place after its deposition. The occurrence of slightly depleted carbon in some samples ($\delta^{13}C$ -values less than -30‰) may indicate an isotopically lighter precursor, possibly of carbohydrate nature, involved in formation of these CU. However, several black shales of Lower Paleozoic age have been reported to show similar strong depletion in ^{13}C (GALIMOV 1980, BUCHARDT et al. 1986, SCHIDLOWSKI 1986) and the ^{13}C-depleted composition of the Nízke Tatry samples can thus be consistent with suggested Early Paleozoic age of these rocks (MOLÁK et al. 1986 and 1989).

Relative enrichment in the heavy isotope ($\delta^{13}C$ - values around -20‰ or more) has been observed in some of the carbonate-free samples from the above mentioned groups 2 and 3, collected from the zones affected by hydrothermal alteration and shearing, and for some siderite-ankerite metasandstone and phyllite (SAMP) samples. However, the same carbonate minerals as in the SAMP, although in subordinate amounts, may also be present in the group 2 and 3 lithotypes, suggesting a degree of re-equilibration in these rocks as well.

The reported contents of Mg/Fe ± Ca carbonates in the SAMP of the Nízke Tatry Mts. are ~ 4 to 15 wt.% (rarely 40 wt.%) and the average content of graphitic carbon is 0.6 wt.%. Estimated metamorphic temperatures of the host rock did not exceed 300 °C (KORIKOVSKY-MOLÁK, 1995). As expected, the intensity of re-equilibration in a series of SAMP samples shows a linear relation with the carbonate content (Table 1). The progressive shift of $\delta^{13}C$ to more positive values should, in this case, be a function of carbon isotope exchange with the isotopically heavy CO_2, released from the carbonates during metamorphic decarbonation reactions. Decarbonation may commence in the lower greenschist facies and increases with increasing metamorphic grade (SCHIDLOWSKI, in JOHNS 1986). On the other hand, ^{13}C enrichment in the carbonate-free samples, collected from zones of hydrothermal alteration and shearing, should either be related to re-equilibration reactions with the heavy carbon in hydrothermal fluids, or to reactions with water to form ^{12}C enriched CO, thus leaving the remaining graphite relatively enriched in the heavy isotope ^{13}C. A mechanism, similar to the latter case, has been described by ANDREAE (1974) from the Arendal area of Norway. Our structural observations have shown that the propagation of important shear zones with migration of fluids occurred during the Variscan tectono-thermal activity.

Tatricum Unit, Malá Fatra Mts.

PULEC (1992) described graphite disseminated in the granitoids and crystalline schists in the Lúčna part of the Malá Fatra Mts. (Fig. 4). The $\delta^{13}C$-values (Fig. 8b) from 5 samples from this area indicate an organic precursor. Compared to the carbon isotope values from the Nízke Tatry Mts., these values are slightly enriched in ^{13}C. This shift is, in our opinion, associated with the effects of granitization and/or intense metamorphism, which caused a certain

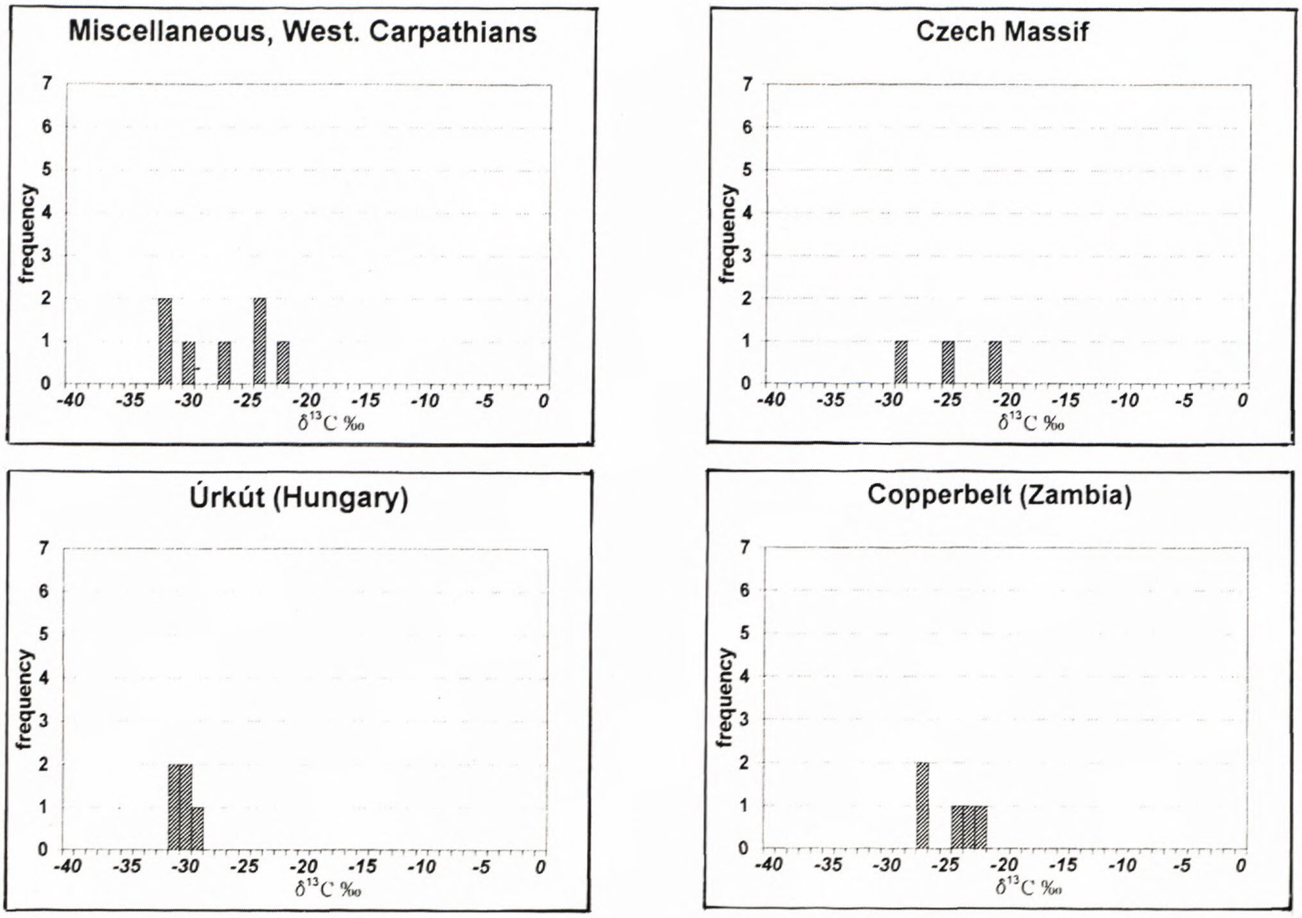


Figs. 8 a,b,c,d and 9 a,b,c,d: Histograms showing the results of isotope analyses.

degree of re-equilibration with juvenile gaseous carbon phase, perhaps in a CO_2 form. The degree of crystalline perfection of graphite is consistent with a deeper structural provenance of these graphite-bearing rocks. Although, this statement should be taken with caution as the number of evaluated samples is too small to allow for a more reliable explanation.

Veporicum Unit

The Veporicum Unit samples from both, the Jánov Grúň Complex and from the Early Paleozoic Klenovec and Ostrá Complexes have been included in a single diagram. The range of $\delta^{13}C$-values for the samples from the Veporicum Unit (Fig. 8c) does not differ significantly from that of the Tatricum samples (Fig. 8a, b). Consequently, the isotope composition of the precursor CM in both units should have been similar, although superimposed metamorphic processes would have been less intense in the Tatricum Unit. A single value that does not match the rest of the data (-8.66 ‰) originates from the southern Veporicum Klenovec Complex. It is a semigraphite found dispersed in a biotitic-albitic paragneiss. This rock was intersected by the borehole KS-1, east of the Klenovec village and the sample was collected from the depth of 154.6 m. This heavily ^{13}C enriched value was first considered to indicate an excessive equilibration with a "juvenile" carbon, or CO_2 with a carbonate precursor. However, the host rock contains neither carbonate, nor any signs of fluid passage, as indicated by the absence of tectonic disruption and alteration zones. The origin of this heavy carbon remains therefore enigmatic, although an alternative explanation could be considered that it was formed in a process of carbonate or carbon dioxide reduction. Similar mechanism has been described by SALOTTI et al. (1971). As a corollary to this observation we note that another semigraphite collected from the same drill hole and the same rock type from a depth of 237.5 m is depleted in heavy carbon (-30.99‰) despite the fact that it originates from a silicified and



Samples in Fig. 9 a: N-2 (3447 m) - Carboniferous anthracitic coal from the basement of the Paleogene flyscht; 52/75 and NEVIDZ- 1- Suchý and Malá Magura Mts.; DRŽ-1 drill hole, depths 90.5 m and 700.4 m; AUG-1 - Augustín adit, Malé Karpaty Mts.; JŠ-1 - coal trapped in an andesite sill.

chloritized zone and an enrichment in the heavy isotope should be therefore more likely.

Gemericum Unit

Comparing the results obtained for samples from the Gemericum Unit with those from the Tatricum and the Veporicum Units a shift towards less negative values can be noted (Fig. 8d). This shift is even more surprising considering the fact that the latter two units evolved within the deeper crustal levels, and having been exposed to more intense metamorphism, they should be enriched in the heavy isotope. However, the anthracite samples from the so called "Magnesite" Carboniferous (Ochtiná Formation) have yielded even more positive $\delta^{13}C$ values and represent, in fact, the most positive values from the entire set. Since the rock metamorphism of this unit is generally low, it could not contribute considerably to the equilibration with coexisting carbonates. Therefore, observed enrichment in ^{13}C should be attributed to either a different organic pedigree or to a different diagenetic pathway of the studied carbon. In other words, the difference in the isotopic composition of reduced carbon in the Gemericum rocks supports the view that the paleoenvironmental development of this unit has been exceptional in respect to other megablocks of the WC system.

Meliaticum Unit

The precursor of anthracite in the studied samples was organic matter. Since the carbonate bearing sample, collected from a shallower horizon, contains isotopically lighter carbon, compared to the carbonate-free sample taken from a deeper horizon (Table 1), no significant re-equilibration with the isotopically heavy carbon can be considered to have occurred here, and the variations in isotope composition can rather be attributed to a higher thermic gradient and more intense pyrolitic reactions than to the influence of carbonate carbon.

Foreign reference samples

Úrkút (Hungary)

Genetic aspects and stable carbon isotope composition of both, the ore-rich and the ore-poor, carbonates from the stratiform sedimentary manganese carbonate ore deposit of Úrkút, Hungary, has been discussed by POLGÁRI et al. (1991, 1992). The results have shown a negative linear correlation with the Mn contents and a negative exponential trend with the total organic carbon content. The authors argue that this mineralization was formed as a consequence of bacterially mediated diagenetic reactions that involved Mn reduction via one or two coupled reactions: the oxidation of organic matter with Mn oxyhydroxide reduction, or the oxidation of FeS produced as a byproduct of seawater sulfate reduction with Mn oxyhydroxide reduction.

Since no isotopic data for organic matter from Úrkút were available, we have analysed 5 samples (Table 1). Our results fall within the range of data for the Tethyan Lower Jurassic, reported by JENKYNS and CLAYTON (1986), but exhibit a more ^{13}C-depleted composition than the average found by these two authors (see Fig.9c).

Based on the present analytical results and previous data the following conclusion can be drawn :

- The Úrkút kerogen, depleted in the heavy carbon isotope, is likely of a bacterial (methanogenic?) derivation.
- Such light carbon could have been partially incorporated into the Mn-carbonates during diagenetic, bacterially mediated, mineralization processes.
- The Mn-richest ores are the most depleted in organic carbon, supporting an assumption that local organic matter has been involved in the mineralization processes.

Copperbelt, (Zambia)

SWEENEY et al. (1986) have undertaken stable isotope studies on sulfides and carbonates from the Konkola area. They observed a strong correlation between concentrations of copper and carbonate carbon. Dolomites from the Ore Shale exhibit δ^{13}C values ranging from -8.77 to -20.52 ‰ PDB, compatible with a partially organic source for the carbon. In contrast, dolomites from the footwall rocks are notably enriched in ^{13}C (-4.42 to -9.37 ‰ PDB), indicating an influence of marine-derived carbon. Neither in Sweeney's paper, nor elsewhere, were the stable isotope data for organic carbon reported. Altogether 5 samples of OC from various deposits were analysed in this study (Table 1, Fig. 9d).The observed isotopic ratios as well as the average δ^{13}C value are consistent with organic derivation of carbon, but a degree of equilibration with carbonate carbon is probable. This process was possibly based on the exchange with a gaseous phase, formed as a result of metamorphic and/or fluidization processes that also affected the carbonates. Such processes have obviously taken place simultaneously with the propagation of shear zones, as described recently by MOLÁK (1995) for several of the Copperbelt deposits, particularly those located within the Ore Shale Alignment. The inferred conditions of metamorphism (MOINE et al. 1986) should have corresponded to temperatures of 420 to 550 °C and pressures of 2 to 6.5 kbar. Such conditions are supported also by measurements of graphite crystallinity, with interlayer distances ranging from 3.36 to 3.37 Å. And this suggests the green schist to lowest part of the amphibolite facies metamorphism. The least negative values were found in two of the three measured Mufulira samples, which can be explained by their being exposed to the lowest degree of tectono-thermal effects. However, the third sample is at odds with this postulate. More data are required for further discussion.

Conclusions

Western Carpathians

A review of our isotopic data (Table 1) indicates that the majority of graphites or graphitoids in sedimentary and metamorphic rocks from the Western Carpathians are depleted in the heavy carbon isotope and presumably had sedimentary organic matter as a progenitor. However, some display a shift to ^{13}C enrichment that may have either resulted from a reaction with water, or from re-equilibration reactions with the heavy carbon isotope, both imported to the system in magmatic, metamorphic or hydrothermal fluids. One extremely ^{13}C enriched sample could have formed via reduction of carbonate or carbon dioxide.

The differences in δ^{13}C values between the Tatricum and Veporicum Units are only minor, consistent with the low degree of metamorphism of their host rocks and suggesting a limited degree of re-equilibration events. The intensity of re-equilibration in carbonate bearing rocks, which were exposed to identical metamorphic conditions, seems to be controlled by relative amount of carbonates in the host rock.

Slightly heavier carbon in the samples from the Gemericum Unit (Table 2) may indicate somewhat different sedimentary/diagenetic conditions and/or a different type of original OM. The latter case would be compatible with a presumption that this unit evolved under different paleoenvironmental conditions, compared to the other major units of the WC system.

Table 2 Average $\delta^{13}C$ values for reduced carbons

Unit/sample Mountain	$\delta^{13}C$ ‰	n
Tatricum Unit - (Nízke Tatry Mts,)	-26.21	40
(Malá Fatra Mts.)	-23.02	5
(Suchý & Malá Magura Mts.)	-32.57	2
Gemericum Unit	-25.25	7
"Magnesite" Carboniferous	-15.59	5
N. Gemericum (Rochovce)	-21.57	5
Veporicum Unit	-27.91	9
Meliaticum Unit (?)	-26.15	2
Foreign samples:		
Zambia		
Copperbelt (Precambrian)	-25.13	5
Hungary		
Mn shales Úrkút (Toarcian)	-30.73	5

The fact that several samples collected from the Tatricum and Veporicum Units contain unusually light carbon suggests to the presence of a very light organic precursor on one hand and to the absence of any re-equilibration, on the other. The most negative values ($\delta^{13}C$ less than -32 ‰) have been found in the samples from the Suchý and Malá Magura Mts. (Table 1, Fig. 9d) as well as in a sample from the Veporicum part of the Nízke Tatry Mts. Their original $\delta^{13}C$-values should have been around -35 ‰, but due to the pyrolitic reactions they should have lost some of their light carbon isotope and became relatively heavier. In general, such extremely negative values are known to occur in Precambrian graphites of bacterial or algal provenance (SCHIDLOWSKI 1986) and this may have been the case also for our samples. While the Precambrian rocks have not yet been documented in the WC, several datings of resistant minerals in metamorphic rocks indicate an import of Precambrian material. Despite its softness, graphite is also a resistent mineral in the geological environment and can be envisaged as a carrier of paleoenvironmetal and/or biological record. We therefore propose that several graphites and subgraphitic matter in Paleozoic sediments or metasediments could have been resedimented from an earlier Precambrian (or older Lower Paleozoic) metamorphic precursor.

Foreign reference examples

Úrkút

The mechanism of bacterially mediated large scale involvement of the OM in the mineralization process and formation of the Mn ores at Úrkút merits further study. Our limited findings support the generally accepted models of Mn mineralization.

Zambian Copperbelt

Our isotopic results support the presumed existence of re-equilibration processes brougt about by the isotopic exchange reactions with the heavy "juvenile" carbon, or with the remobilized carbon derived from carbonate host rocks. These processes were probably associated with the Pan-African metamorphic and tectono-deformational stages that were superimposed on the Copperbelt orebodies. Although the synsedimentary, syndiagenetic model for the Copperbelt orebodies is still applicable in view of many geologists (e.g. FLEISCHER et al. 1976, UNRUG, 1988, GARLICK, 1989), recent observation of shearing structures within the Ore Shale Alignment and the Domes Region as well as the chemical and mineralogical evidence for a broad presence of mineralized fluids in the shearing systems support the epigenetic aspects in the formation of Cu/Co deposits. This finding could be of importance for potential traditional and nontraditional types of Cu/Co mineralization in the Zambian Copperbelt and in the surrounding regions.

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SLOVAK GEOLOGICAL MAGAZINE

Experimental test of the isotope equilibrium criterion in the case of limestone samples selected for paleotemperature measurements

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Abstract. Results of experiments carried out to test the isotope equilibrium criterion of reliable oxygen isotope paleothermometry, are presented, and some practical proposals are given. Approximate geological dating by the use of time-temperature correlation is also considered.

Key words: paleothermometry, oxygen isotope temperatures, temperature - age correlation.

Introduction

In a previous paper (KECSKÉS - CORNIDES, 1992) we have considered the possibility of obtaining at least approximate age data in the case of limestone deposits taking into account the correlation found between the oxygen isotope ratio (usually given by the customary $\delta^{18}O$ data) measured for a great number of marine limestone types and the age of these samples. There is a definite decrease of the ^{18}O content with increasing age. Such a correlation is reasonable since the oxygen isotope ratio in question may often be used as a paleothermometer and, on the other hand, the temperature changes with time (age). These two relationships involve an indirect third one. This $\delta^{18}O$ - age correlation in favourable cases may provide age data estimations, sequences in time, etc., which are quite useful if no reliable data are available.

For instance, if an investigation on the formation and geological history of limestone caves is to be carried out (in our case that of the stalactite caves in the region Liptov, Slovakia) it is of primary interest to obtain chronological information too. The most direct and therefore the conventional method of geological dating is based on the decay of radioactive isotopes. Unfortunately however, the concentration of these isotopes in the stalactites is quite often very low, and this results in high uncertainty of the age data.

A reasonable choice is offered by the fact that we need both the carbon and the oxygen isotopic ratio of the calcite in the samples taken from the stalactites. The $^{13}C/^{12}C$ data usually present information on the origin of the carbon (e.g. organic, metamorphic, magmatic) while $^{18}O/^{16}O$ data provide the most sensitive and accurate paleoclimatic indicator, if properly used. Accordingly, oxygen isotope data will be at our disposal anyhow, and may be used also to try to figure out the chronology of the formation of caves to be investigated.

Thus, we have two reasons to use properly the oxygen isotope method of geochemistry. The measurement of the $^{18}O/^{16}O$ ratio does not pose any problem in view of the present-day high performance mass spectrometers.

The basic problem is presented by the recognition that a strict condition limits the use of the stalactites, calcite material for paleotemperature measurement: the calcite must had to be deposited in isotopic equilibrium with the water of its solution, i.e. with the ground-water that had been seeping into the cave from above. Obviously, it is a crucial requirement to posses a reliable and sufficiently sensitive method to apply this "equilibrium fractionated deposition" criterion.

Previous theoretical work

More than 20 years ago a paper was published by (HENDY, 1971) in which the isotope geochemistry of speleothems (a common term for both stalactites and stalagmites) is dealt with excellently. Taking into account all processes which lead to the precipitation of calcium carbonate to form speleothems, a detailed theoretical treatment is given to the isotope fractionation of the general process, in the case of both carbon and oxygen. As an important result the above criterion was formulated and also the principle of (the method of) its application was given: "Where the calcite has been deposited on a speleothem in isotopic equilibrium with the ground water, a variation in the $\delta^{18}O$ of the calcite would only occur if there had been a variation in climate, and thus these speleothems may be used as paleoclimatic indicators. Speleothems which exhibit a straight-line relationship between variations in $\delta^{18}O$ and variations in $\delta^{13}C$ should be regarded with suspicion

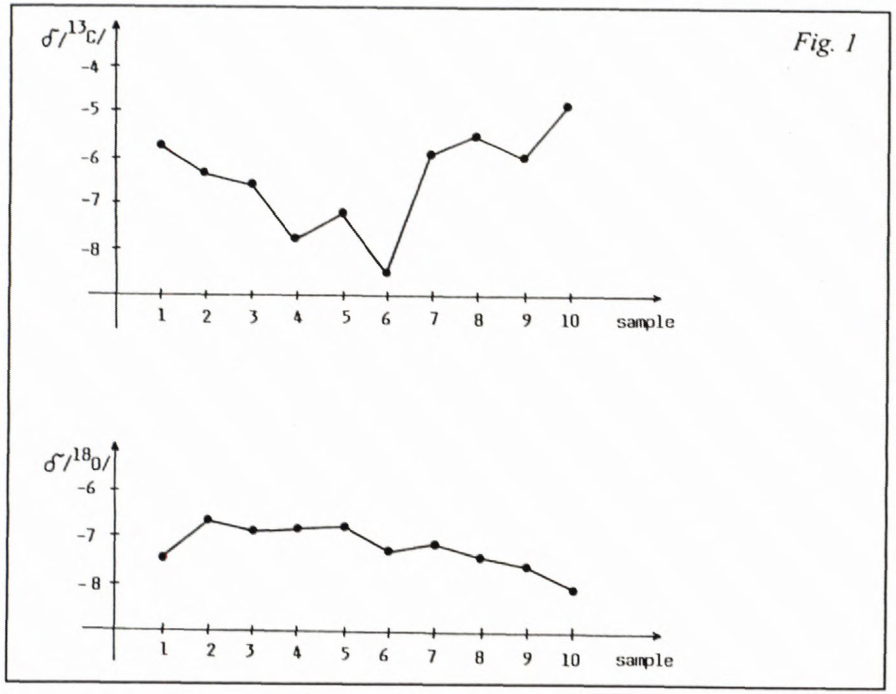


Fig. 1

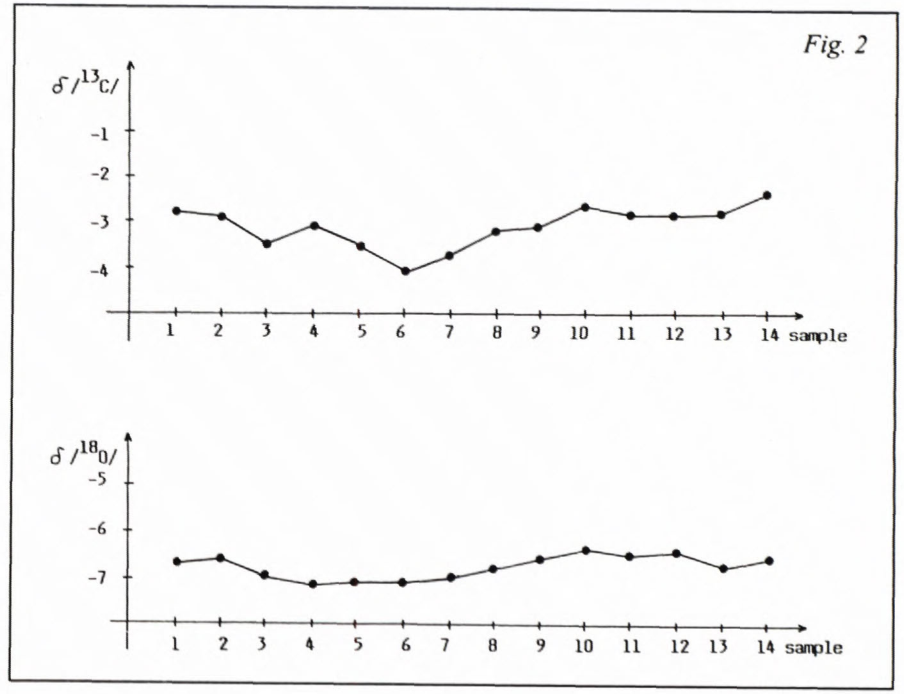


Fig. 2

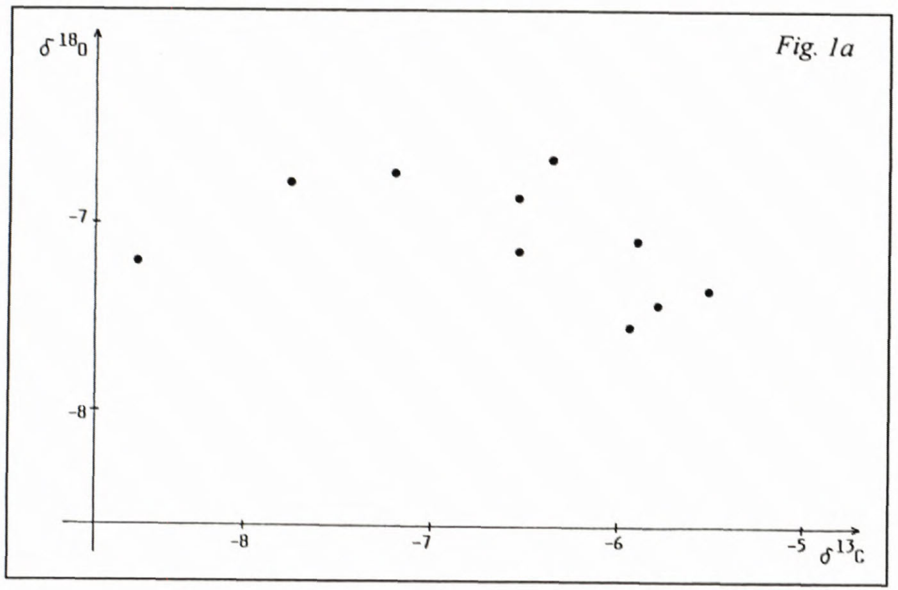


Fig. 1a

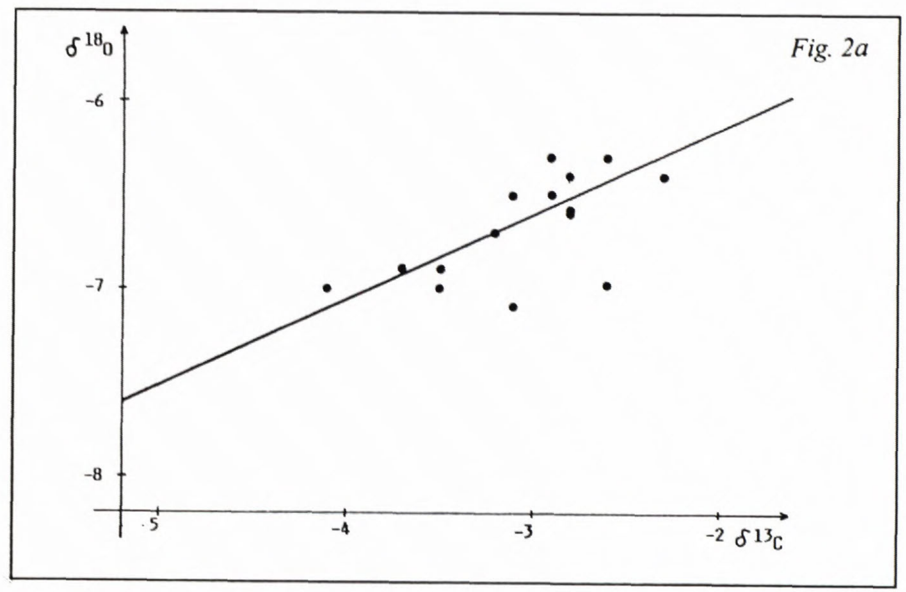


Fig. 2a

since it is likely that this was caused by kinetic isotopic fractionations and it is thus likely that the calcite was not in ^{18}O equilibrium with the water from which it was precipitated."

Experimental

Our present work was intended to carry out experimental test of the criterion proposed by Hendy to obtain information on its practical application, including reliability and sensitivity.

Three sets of calcite samples were chosen for this investigation representing three different kinds of localities, much dissimilar environmental conditions and, therefore, quite different possibilities for isotopic equilibrium:

No.1.set /10 samples/: a remote and deep-seated part of the famous stalactite cave of Demänova/Liptov, Slovakia/.

No. 2. set /14 samples/: a part of a small limestone cave near to the entrance (Liptov, Slovakia).

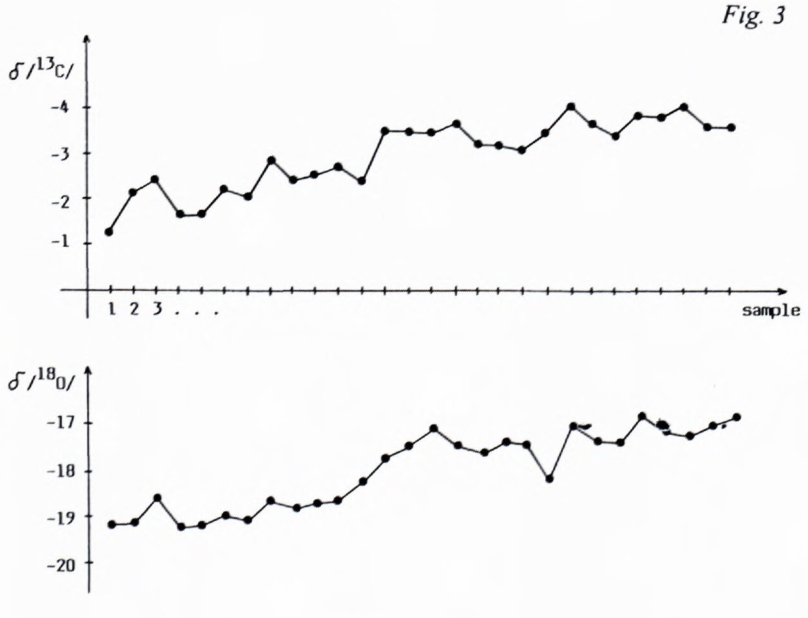
No. 3. set (28 samples): open-air limestone sediment, deposited from the water of a brook containing dissolved calcium carbonate. The individual samples of these sets provide time-sequences of calcite specimens (one for each set) offering the possibility of studying the relationship between the variations of $\delta^{18}O$ and $\delta^{13}C$, respectively, under different conditions of the three localities. The calcite samples have been obtained from the stalactite specimens by boring out material along the symmetry axis i. e. in the direction of growing, at 0,5 cm distances. In the case of the open-air sediments the samples were collected also at equal distances in the direction of the flow of the water from which the precipitation occurred. The isotope ratio measurements have been carried out (after applying the usual sample chemistry with phosphoric acid saturated to 100 per cent) using magnetic sector type isotope mass spectrometers with double collector system for gaseous samples, within the framework of interlaboratory cooperations (see acknowledgements). All mass spectrometers used have been manufactured by the same Finnigan MAT (Bremen) company and all are members of the same family of isotope mass spectrometers differing only in the degree of reproducibility, all being better than 0.1 % which is satisfactory for the investigation of correlation. The results related to the PDB standard are presented in Fig.1. to Fig.3.

Discussion and Conclusions

As suggested by Fig. 1., no straight-line relationship (correlation) may exist between the oxygen and carbon isotope data in the case of the No. 1. set of samples. On the other hand, for the samples of the sets No.2. and No.3. such correlation can be predicted. These relationships can even be better visualized by the $\delta^{13}C$ - $\delta^{18}O$ diagrams shown in Fig.1a. to Fig.3a.

Our findings can be presented also in a more quantitative way by the use of statistical mathematics. We have calculated the correlation coefficient ρ (ro) for the relationship of the oxygen and carbon isotope data in the case of all three sets of samples.

Fig. 3



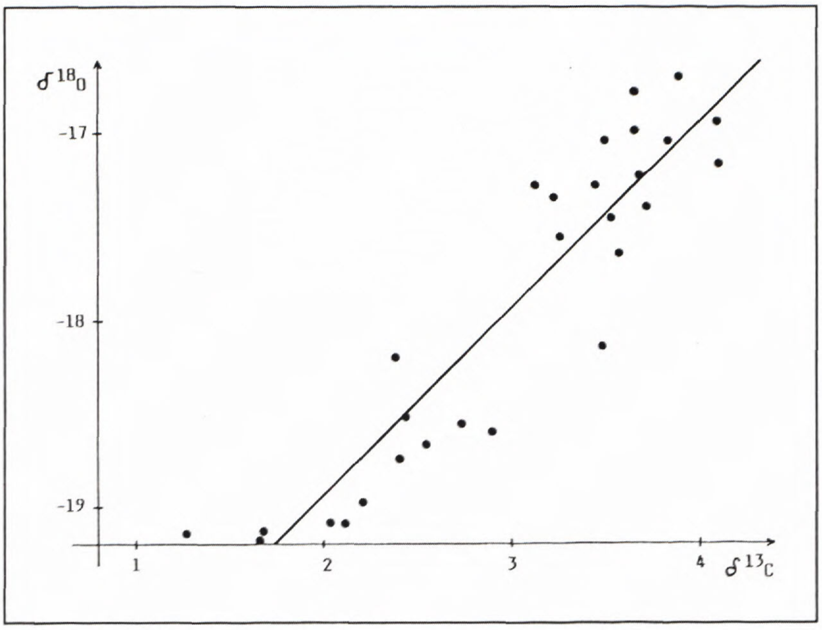


Fig. 3b

For the No.1. set ρ = -0,593 was obtained, i.e. a rather low absolute value. For this reason no linear relationship may exist in this case and therefore - according to the isotopic equilibrium criterion - the samples of the No.1. set can be used for paleotemperature measurements, as we had hoped.

On the other hand, in the case of the sets No.2. and No.3. the rather high ρ = 0,79 value, and the very high ρ = 0,925 value have been obtained, respectively, which indicate strong linear correlation. This is demonstreted by the two straight lines drawn in Fig. 2a. and Fig. 3a., the position of which was calculated using the least sqares method. Accordingly, the samples of the No.2. and No.3. sets are unsuitable for paleothermometry, as it was expected.

As conclusions we may point out that:

a/ The isotope equilibrium criterion as proposed by Hendy is a useful tool to obtain reasonable reliability of the oxygen isotope paleothermometry.

b/ For testing experiments, the measurement of a greater number of samples is to be used: 25-30, or more.

c/ An absolute value of the correlation coefficient less than 0,4 may guarantee an acceptable reliability of the oxygen isotope temperature data.

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Tectonogenesis of the Orava Depression in the light of latest biostratigraphic investigations and organic matter alteration study

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Abstract: The Orava Depression and its continuation in southern Poland, the Nowy Targ Depression, originated after the Early Sarmatian. Before this period, in the present area of the Nowy Targ Depression an Oligocene-Middle Miocene marine basin had been situated in piggy-back position.

The Orava-Nowy Targ Depression was previously considered to be a retroarc basin, however, the burial history of the depression and its position in the Periklippen mobile zone point to pull-apart origin.

The coal seam cropping out at low water level in the Orava Dam near the village Ústie nad Priehradou belongs to humites of the brown coal stage of alteration. Predominant coal lithotypes are xylito-detritic and detrito-xylitic ones, with low ash content. The vitrinite reflectance R_o of 0.35-0.43% and the results of technological analyses allow to classify the coal with the metaphase of the brown coal.

Coal altered in this way must have been buried in a depth of approx. 1150 m. Later on, the depression rose and erosion removed a considerable part of the basin filling. The depression is rising at present at the rate of +0.5 mm/y, or between 0.0 and +0.5 mm/y.

Key words: Orava-Nowy Targ Depression, coal vitrinite reflectance, burial history, erosional removal, pull-apart basin

Introduction

The filling of the Orava Depression contains coal seams accompanied by coal clays. In the past, seams cropped out at the villages Hladovka, Čimhová, Liesek, Trstená, Ústie nad Oravou, Dolný Štefanov, Námestovo, Vavrečka, Bohov, Jelešna-Voda and Červený Potok. The coal was used by local people as fuel. The seams are numerous, but they have low thickness and they are small in area (ČECHOVIČ 1940). According to SENEŠ and TOMSKÝ (1953), in the southern part of the depression the frequency of seams is relatively great: in a borehole 184 m deep there were 12 seams, but only one of them had a thickness of 1.3 m. Later on, near the village Vavrečka, pits were made in which 1 and 1.3 m thick seams were found. The borehole prospection aimed at the determination of balance coal reserves carried out in 1958 ended without success (GAŠPARIK et al., in SLÁVIK et al., 1967). In 1988, near the village Ústie nad Priehradou, a coal seam about 0.8-1 m thick could be studied and sampled.

Basic features of the geological setting of the Orava Depression

The Orava Depression is lying predominantly on the Magura flysch unit of the Outer Western Carpathians. Its southern part is lying on the Klippen Belt and the Central Carpathian Paleogene. The Magura Nappe consists of silico-clastic flysch formations. The uppermost members of the Magura Nappe are usually formed of the Magura Formation (Upper Eocene) and the Malcov Formation (uppermost Eocene-Oligocene). On the southern margin of the Nowy Targ Depression, on the Polish territory, younger formations have been described above the Malcov Formation: the Waksmund Formation of flysch character (Oligocene-Lower Miocene), the Stará Bystrica Formation, also of flysch nature, the Kopaczysko Formation of flyschoid character and the predominantly claystone Pasiek Formation. The age of the last three formations is Middle Miocene, the youngest sediments are of Upper Badenian to Lower Sarmatian age (CIEZSKOWSKI 1992). Upper Oligocene and Miocene formations formed after the folding of the Magura Basin in the Oligocene, in a piggy-back type of basin, on the back of the Magura Nappe. Later they were folded and incorporated into the Magura Nappe (CIEZSKOWSKY l.c.). They thus do not form a

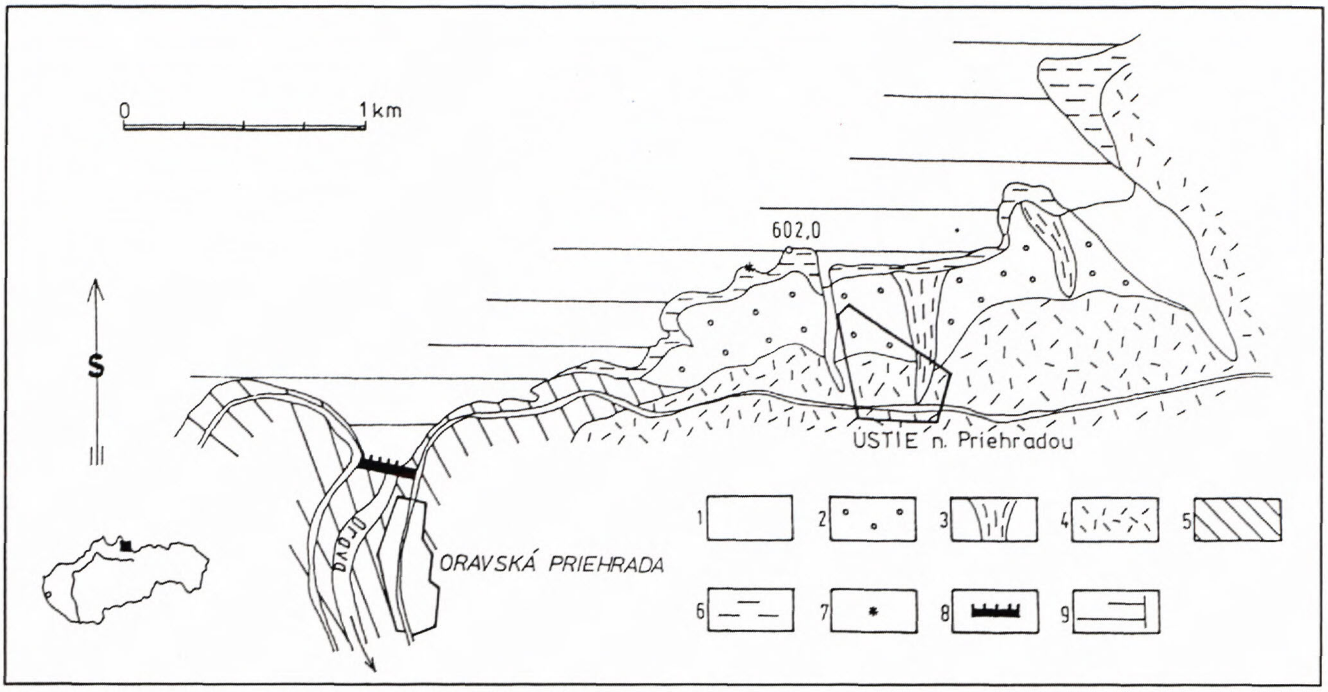


Fig. 1 Schematic geological map of the surroundings of the sampled coal occurrence near Ústie nad Priehradou
1 - proluvial sediments, 2 - fluvial sandy gravels and sands, 3 - alluvial cones, 4 - slope loams, 5 - Paleogene of the Magura Nappe, 6 - sandy clays and sands, Sarmatian in age, 7 - sampling location of coal, 8 - dam wall, 9 - dam lake water

part of the Orava-Nowy Targ Depression filling, but they are a part of its basement.

ROTH et a. (1963) thought that the formation of the depression was connected with a flexure bending of the crust which occurred in the Sarmatian, as the result of folding and back-thrusting of the Magura Nappe and, let us add, also of tectonic incorporation of the Oligocene-Miocene filling of the marine piggy-back basin into this nappe. From this point of view, the Orava Depression may be regarded as a retroarc basin. Another opinion on the genesis of the depression has been expressed by POSPÍŠIL (1990), who assumed that the depression formed on a mobile belt of the Periklippen zone by the pull-apart mechanism. The steep curves of sediment burial history during the Middle and Late Sarmatian and during the Pannonian (Fig. 7) are characteristic of the beginning of a horizontal displacement and for the subsidence in pull-apart type basins, which supports the opinion on the pull-apart mechanism of the basin opening. From the above it follows that the depression and its filling must be younger than the Lower Sarmatian, or that the depression filling is Sarmatian or younger. Opinions on the older age of the lower part of the filling must be in this sense corrected. Considerations on the presence of Lower Miocene and Badenian sediments in the depression (WATYCHA 1976, OSZAST and STUCHLIK in BIRKENMAJER 1978) originated probably as the result of insufficiently elaborated biostratigraphy of freshwater sediments, while marine sediments, which should certainly provide more suitable faunistic material for biostratigraphy, are missing in the basin filling.

Lithology

Sediments of the basin filling are lying discordantly on pre-Middle Sarmatian rocks. On the base of the basin filling there are coarse-clastic and pelitic sediments. Coarse clastics with their petrographic content are copying the basement. Maximum estimated thickness of basal beds is 250 m. At the margins of the depression they consist of medium-grained sands and fine gravels, the material of which came from the Paleogene basement. Towards the middle of the depression they disappear or they form irregular lenses among pelites (PULEC 1974).

The main part of the basin filling are grey monotonous clays and silts with variable content of the sandy admixture, or with sand layers. There are also present coal seams and layers of coal clays (NAGY in GROSS et al. 1993). Bentonite and acid tuff layers are rare. Above the grey clays there are lying grey rusty-brown-yellow spotted clays with sandy admixture. The thickness of the whole pelitic complex, according to the borehole OH-1 near the village Hladovka, exceeds 400 m (PULEC 1976). The estimated maximum thickness is approx. 500 m (NAGY l.c.). Towards the west the thickness of the formation decreases and near Vavrečka it is not greater than 10-20 m.

Above the clay formation there is lying a formation of polymict gravels containing material of the High Tatra provenance, together with sandstones of the Sub-Tatric unit of the Central Carpathian Paleogene. According to WATYCHA (1976), they are sediments of the Czarny Dunajec river, which, due to the uplift of the Gubala-Bukovina mountain range in the eastern part of the Orava-Nowy Targ Depression, was flowing into the Orava river.

In the grey clay of the main basin filling there were found ostracods: *Candona compressa* and representatives of the genus *Ilyocypris*, indicating Sarmatian to Pannonian age of the sediments (BRESTENSKÁ in PULEC 1976). WOZNY (1976) identified in the freshwater and land mollusc community the following species: *Xerophila sóosi* GAÁL, *Pisidium steinheimense* GOTTSSCHICK, *Clausilla* af. *grandis* KLEIN, confirming the Sarmatian to Upper Miocene age of the sediments.

According to fauna found in the borehole OH-1 above the clay formation, namely the gastropods *Steklovia koehnei* SCHLICKU-STRAUCH and the genus *Oxychylus* sp., ONDREJIČKOVÁ (in PULEC 1976) assumed Pliocene age of the upper part of the basin filling. She compared these sediments to the Pliocene of the Alpine fore-deep, the Rhine graben and the Vienna Basin, where they are considered to be Dacian.

The basin filling is slightly tectonically affected. It is not folded as the basement and the surroundings of the depression. Faults in the basin filling are interpreted on the basis of a gravity model. The more important ones have east-west direction and they participate in the asymmetric structure of the depression. Faults with greater throw restrict the depression in the north, i.e. in Poland. The southern margin of the depression is flatter, modelled by faults with lesser throw (POSPÍŠIL 1990).

Photo 1 General view of the coal seam exposed due to bank erosion near Ústie nad Priehradou

Photo 2 Detail of a coal seam with sample locations (ordered from Sample 1 at the base to Sample 4 at the cap)

Coal sedimentation and coal seams in the Orava Depression

The layers of coal clays and coal seams start to appear already in the lower part of the basin filling. They reached maximum extension and greatest thickness in the pelite formation. In Pliocene they are more rare.

In the Sarmatian sedimentation took place in freshwater environment with abundant influx from the surrounding rivers. In a closed space the depression degraded and numerous swamps formed here. The sedimentation environment and a favourable climate provided the conditions for the formation of coal clays and coal seams, creating in the basin filling lenses and irregular seams.

In the Orava Depression coal seams were best exposed in 1988, when the water was let out of the dam at Ústie nad Priehradou (Photo 1). The outcrop ceased to exist due to adjustments to the banks of the dam lake. The coal seam is 1 m thick, but small in area, as in the immediate underlier there is already the Magura unit flysch.

The underlying grey clays exposed in the thickness of 1.5 m are passing into black-grey to black coal clays 0.5 m thick, which in turn pass into a coal seam. Above the coal there are lying grey, brown-spotted clays. Their contact with the seam is sharp, indicating sudden ending of conditions favourable for coal sedimentation and rapid burial of the coal seam.

The coal is in the lower, 20 cm thick layer considerably contamined by clays with Fe oxides (Photo 2). Higher up there is a 40 cm thick layer in which black, 5-7 cm thick coal intercalations alternate with coal permeated with Fe oxides. It is cohesionless and fractured. Above there is a 5-6 cm thick layer of grey clays with carbonised plant debris separating a 40 cm layer of compact shiny black coal. Fe oxides occur here only on the surface of fractures.

From the leaf impressions found in the near surroundings of the locality, KNOBLOCH (1968) determined three plant communities:

a) Community with representatives of the genus *Glyptostrobus* and *Myrica*, giving rise to the coal seam

b) Very hydrophilous, even swamp community with *Byttneriophyllum tiliaefolium* and *Alnus* sp.

c) Community of a mesophyllious forest with predominant beech *(Fagus* cf. *grandifolia* foss.) and plane-trees (*Platanus platanifolia*).

The above author presented the opinion that these communities are of Sarmatian age, not excluding their older or even younger age. To the same conclusion came also SITÁR (in PULEC 1976) who, on the basis of the occurrence of *Platanus aceroides* GREPP in the borehole OH-1, compared sediments of the Orava Depression to Late Miocene filling of the Turiec Depression.

Coal-petrographic characterisation of coal from Ústie nad Priehradou and its carbonisation

Occurrences of coal seams in the Orava Depression were known already in the past, however, their more detailed characterisation, with the exception of chemical-technological analyses presented by GAŠPARÍK et al. in SLÁVIK et al. (1967), has not been mentioned in literature.

Therefore, coal from Ústie nad Priehradou was subject of coal-petrographic study, chemical-technological tests were carried out and special attention was given to the carbonisation degree using the study of vitrinite reflectance. Sampling location is shown in Fig. 1 and Photo 1. As in Slovakia same problems are studied at several coal deposits and first results are available (PETRÍK 1994), the carbonisation degree of coal from Orava could be compared with coal of the Handlová-Nováky Formation in the Hornonitrianska Basin.

Coal in Ústie nad Priehradou belongs to humites of the brown coal stage, belonging mainly to xylito-detritic and detrito-xylitic lithotypes, with relatively low ash contents.

From the micro-petrographic point of view, the most frequent maceral group is huminite represented by the sub-group of humodetrinite with the macerals denzinite and attrinite, and the sub-group of humotelinite with the macerals ullminite and textinite. The humokolinite sub-group is relatively abundantly represented by gelinite. The inertinite group has not been found in the coal.

We based the determination of carbonisation degree on the fact that light reflectance is the basic indicator which, in contrast to other determinations like carbon content (C^{daf}) in combustible matter, volatile combustible (V^{daf}) and combustion heat (Q_s^{daf}), is not dependent on the maceral composition. It is determined on microscopic objects in natural state, which have not been, prior to the measurement, thermally or chemically attacked. The measurement is carried out on macerals the behaviour of which in the carbonisation process is known and which have a low mineral ash matter content. It is based on the fact that the carbonisation degree is irreversible. Thus, it characterises the highest temperature which the coal, or dispersed organic matter (MOD) reached in its geological history.

The study of organic matter carbonisation provides basic information on the geothermal history of sedimentary basins and gives thus valuable information for the understanding of tectonogenesis and tectonic effects in the basin. It affects in a decisive way the evaluation of the carbohydrate potential and prognoses of occurrences and deposits of natural carbohydrates in the basin.

The measurement conditions at micro-photometric determination of light reflectance of coal were as follows:

- microscope MPV Leitz-Wetzlar
- wave length of monochromatic light - 546 nm+4nm
- refractive index of the oil immersion - 1.516-1.518
- reflectance standard: Glasprizma - Ro=1.24%
- magnification: 500x

The results of the measurement are summarised in histograms with the basic characteristics (Figs. 2 to 5). From the histograms it follows that mean reflectance in the measured samples varies in the range from 0.35 to 0.43%.

The boundary between black and brown coal from the point of view of carbonisation degree is vitrinite reflectance of about 0.5%. From this it follows that the coal studied may be ranged with ortho- to meta-phase of the brown coal stage of alteration. The results of coal reflectance measurement are consistent with the chemical-technological analyses (Tab. 1). This follows especially from the high values of coal combustion heat in original and dehydrated state varying from 15.86 to 21.93 MJ/kg (original samples), or from 18.17 to 24.98 MJ/kg (dehydrated samples), and from the values of caloricity varying from 14.75 to 20.75 MJ/kg (original samples), or from 17.26 to 23.98 MJ/kg (dehydrated samples).

In Slovakia, practically all coal belongs, as far as carbonisation is concerned, to the brown-coal stage of alteration, with the exception of the Upper Carboniferous meta-anthracite at Veľká Tŕňa (PETRÍK et al., 1990, PETRÍK 1992). The Horná Nitra Depression, the filling of which contains the Handlová-Nováky coal-bearing formation, went through a complicated neotectonic development. The coal seams of the deposits Handlová, Cígeľ, Nováky represent the whole brow-coal stage - hemiphase, orthophase and metaphase. The carbonisation is increasing from the Nováky deposit towards the deposit Cígeľ and the highest degree of carbonisa tion is at the Handlová deposit. The reflectograms (Fig. 6) show that coal of the Orava Depression may be compared on the basis of alteration degree with the Handlová coal, or even with coal from the deposit Cígeľ.

Geothermal and geotectonic history of the Orava Depression

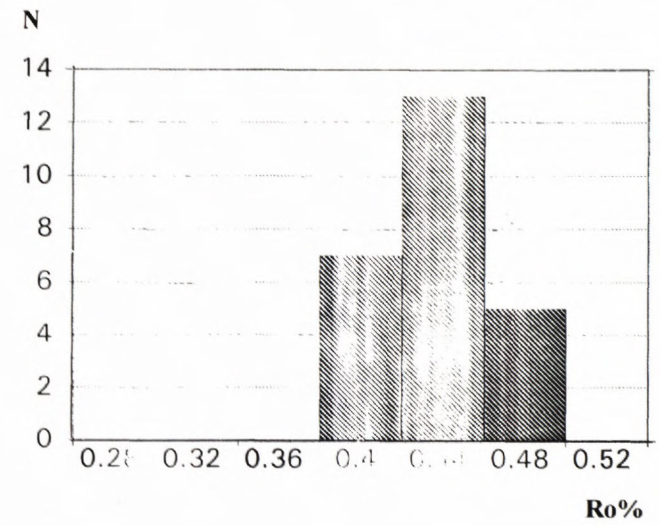
The Orava Depression, as mentioned above in detail, is relatively young. It formed after folding

Table 1 Chemical-technological analyses of coal from Ústie nad Priehradou (Orava Depression)

Determination	Unit	Original sample	Dehydrated sample	Combustible
Sample 1				
water	%	13.47		
ash	%	8.60	9.94	
combustible	%	77.93	90.06	
combustion heat	MJ/kg	20.94	24.20	26.87
caloricity	MJ/kg	19.76	23.22	25.78
volatile combustible	%	41.25	17.67	52.93
sulphur total	%	2.15	2.49	
Sample 2				
water	%	13.10		
ash	%	6.06	6.97	
combustible	%	80.84	93.03	
combustion heat	MJ/kg	21.71	24.98	26.85
caloricity	MJ/kg	20.52	23.98	25.78
volatile combustible	%	42.07	48.41	52.04
sulphur total	%	1.62	1.86	
Sample 3				
water	%	12.07		
ash	%	6.17	7.35	
combustible	%	81.46	92.64	
combustion heat	MJ/kg	21.93	24.94	26.92
caloricity	MJ/kg	20.75	23.93	25.83
volatile combustible	%	43.26	49.20	53.11
sulphur total	%	3.03	3.45	
Sample 4				
water	%	12.27		
ash	%	15.08	17.28	
combustible	%	72.20	82.72	
combustion heat	MJ/kg	15.86	18.17	21.96
caloricity	MJ/kg	14.75	17.26	20.86
volatile combustible	%	39.72	45.51	55.02
sulphur total	%	8.28	9.49	

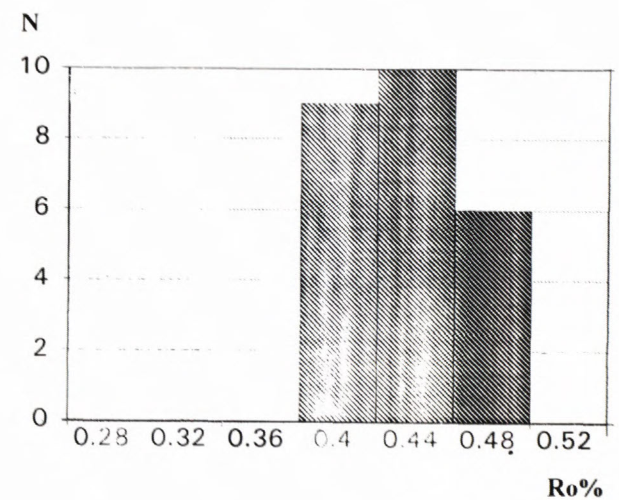
Sample No	Range of Ro values in %	Number of date	Relative frequency
1.	0.24 - 0. 28	0	0
	0.28 - 0.32	0	0
	0.32 - 0.36	0	0
	0.36 - 0. 40	7	28
	0.40 - 0. 44	13	52
	0.44 - 0.48	5	20
		0	0
	number of measurements	25	
	middle reflectivity	0,43	
	standard deviation	0.02	

Fig. 2 Reflectograme



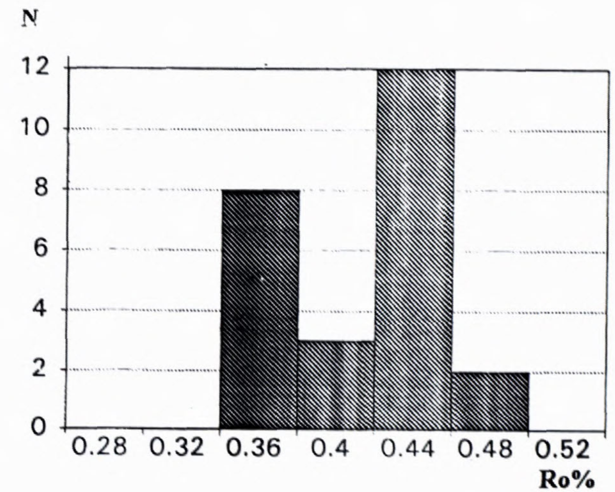
Sample No	Range of Ro values in %	Number of date	Relative frequency
2.	0.24 - 0. 28	0	0
	0.28 - 0.32	0	0
	0.32 - 0.36	0	0
	0.36 - 0. 40	9	36
	0.40 - 0. 44	10	40
	0.44 - 0.48	6	24
		0	0
	number of measurements	25	
	middle reflectivity	0,39	
	standard deviation	0.03	

Fig. 3 Reflectograme



Sample No	Range of Ro values in %	Number of date	Relative frequency
	0.24 - 0. 28	0	0
	0.28 - 0.32	0	0
	0.32 - 0.36	8	32
3.	0.36 - 0. 40	3	12
	0.40 - 0. 44	12	48
	0.44 - 0.48	2	8
		0	0
	number of measurements	25	
	middle reflectivity	0,35	
	standard deviation	0.04	

Fig. 4 Reflectograme



Sample No	Range of Ro values in %	Number of date	Relative frequency
	0.24 - 0. 28	4	16
	0.28 - 0.32	1	4
	0.32 - 0.36	3	12
1.	0.36 - 0. 40	13	52
	0.40 - 0. 44	4	16
	0.44 - 0.48	0	0
		0	0
	number of measurements	25	
	middle reflectivity	0,38	
	standard deviation	0.05	

Fig. 5 Reflectograme

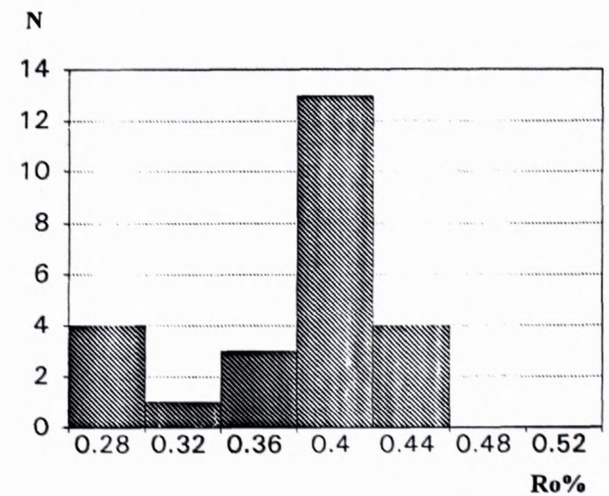


Fig. 2-5 Reflectograms of vitrine reflectance (R_o) of coal samples from Ústie nad Priehradou

processes in the Sarmatian. These processes led to the disappearance of the piggy-back type basin, which persisted from the end of the Oligocene to the Lower Sarmatian inclusive, on the back of the Magura Nappe. The Orava, or Orava-Nowy Targ Depression, formed probably as a pull-apart type

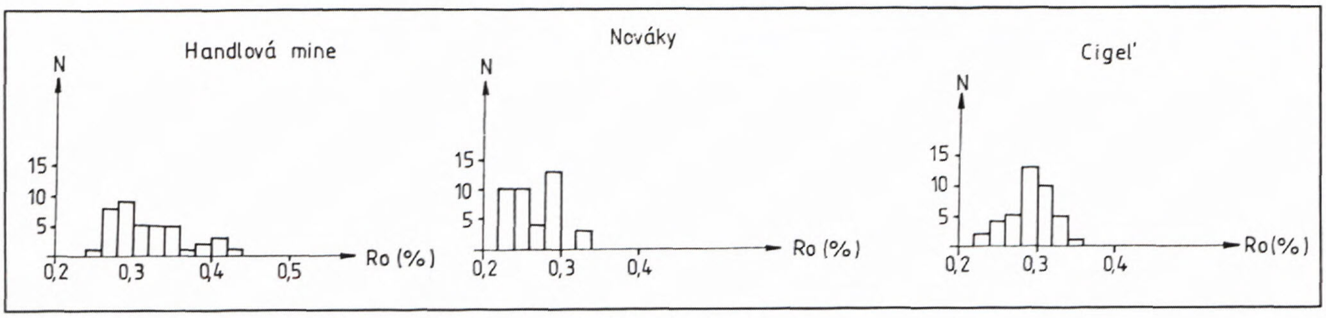


Fig. 6 Reflectograms of vitrine reflectance (R_o) of coal from the mines Handlová, Nováky and Cígel'

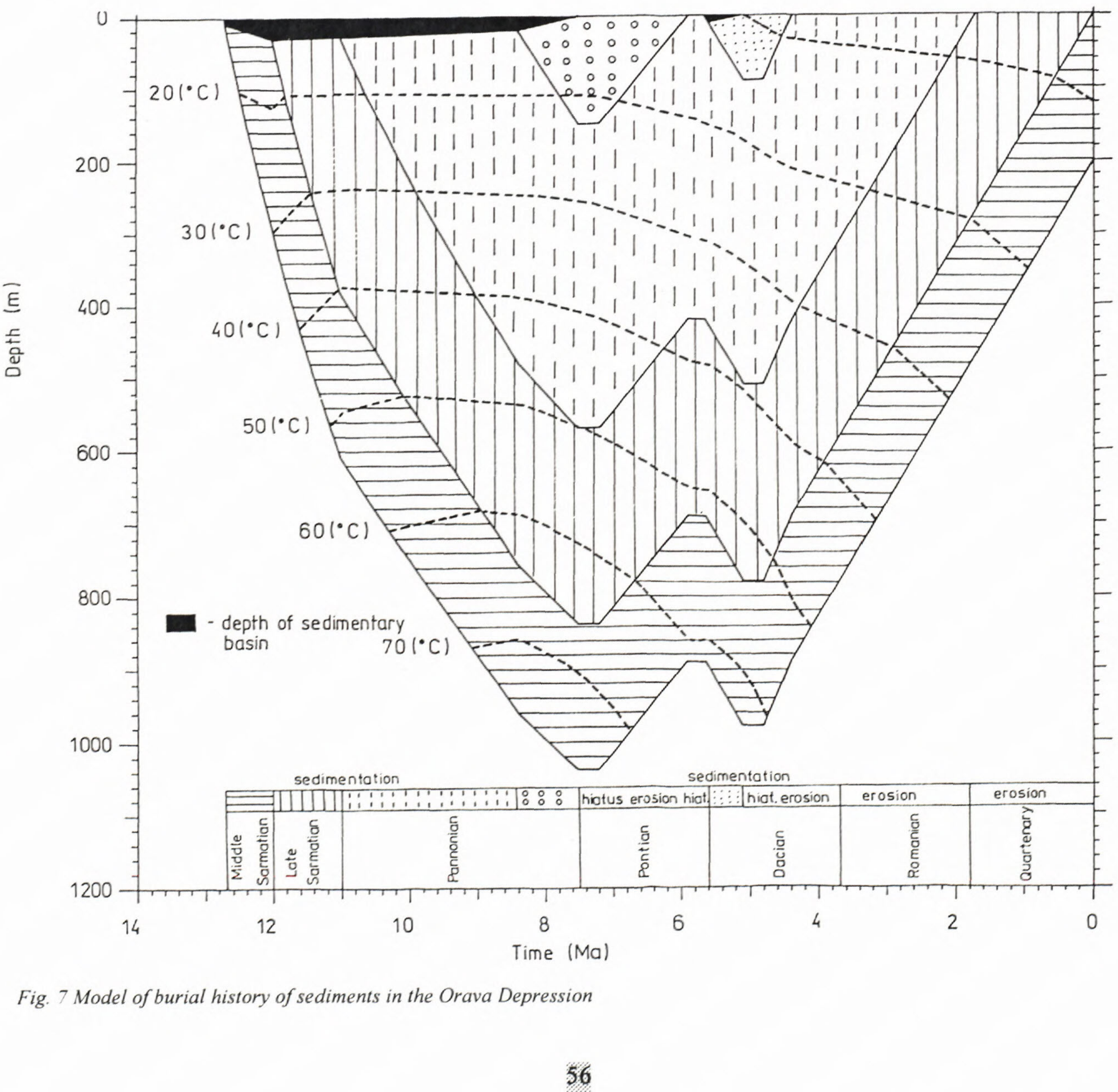


Fig. 7 Model of burial history of sediments in the Orava Depression

basin in the Late Sarmatian and it persisted to the Pliocene. The carbonisation degree of coal seams cropping out at present near Ústie nad Priehradou, with average vitrinite reflectance R_o 0.35 to 0.43%, is surprisingly high. In the depression there are absent any manifestations of local volcanism, i.e. there are no volcanic centres, or young intrusive magmatites which could provide heat for the given carbonisation degree of organic matter in the coal seams. The depression filling is not folded or metamorphosed, and so the carbonisation degree could not be caused by dynamometamorphic processes. The relatively high carbonisation degree of coal from Ústie nad Priehradou may be explained by the burial of the coal during the filling of the depression into a depth of approx. 1150 m (Fig. 7), where the temperature was sufficient for the coal to acquire the degree of thermal alteration which has been experimentally determined (Figs. 2-5), or calculated in the model (Fig. 8). Later on, maybe partly after the Miocene, but especially after the Pliocene, the depression must have been risen, its filling partly eroded so that coal in the surroundings of Ústie nad Priehradou reached the present surface

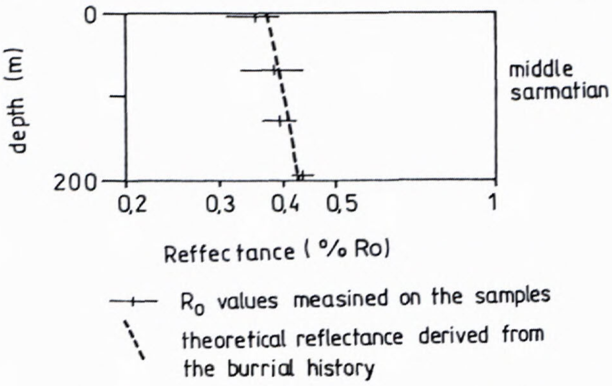


Fig. 8 Correlation of measured and modelled vitrinite reflectance values. The correlation indicates that the model of sediment burial history in the Orava Depression has been selected correctly.

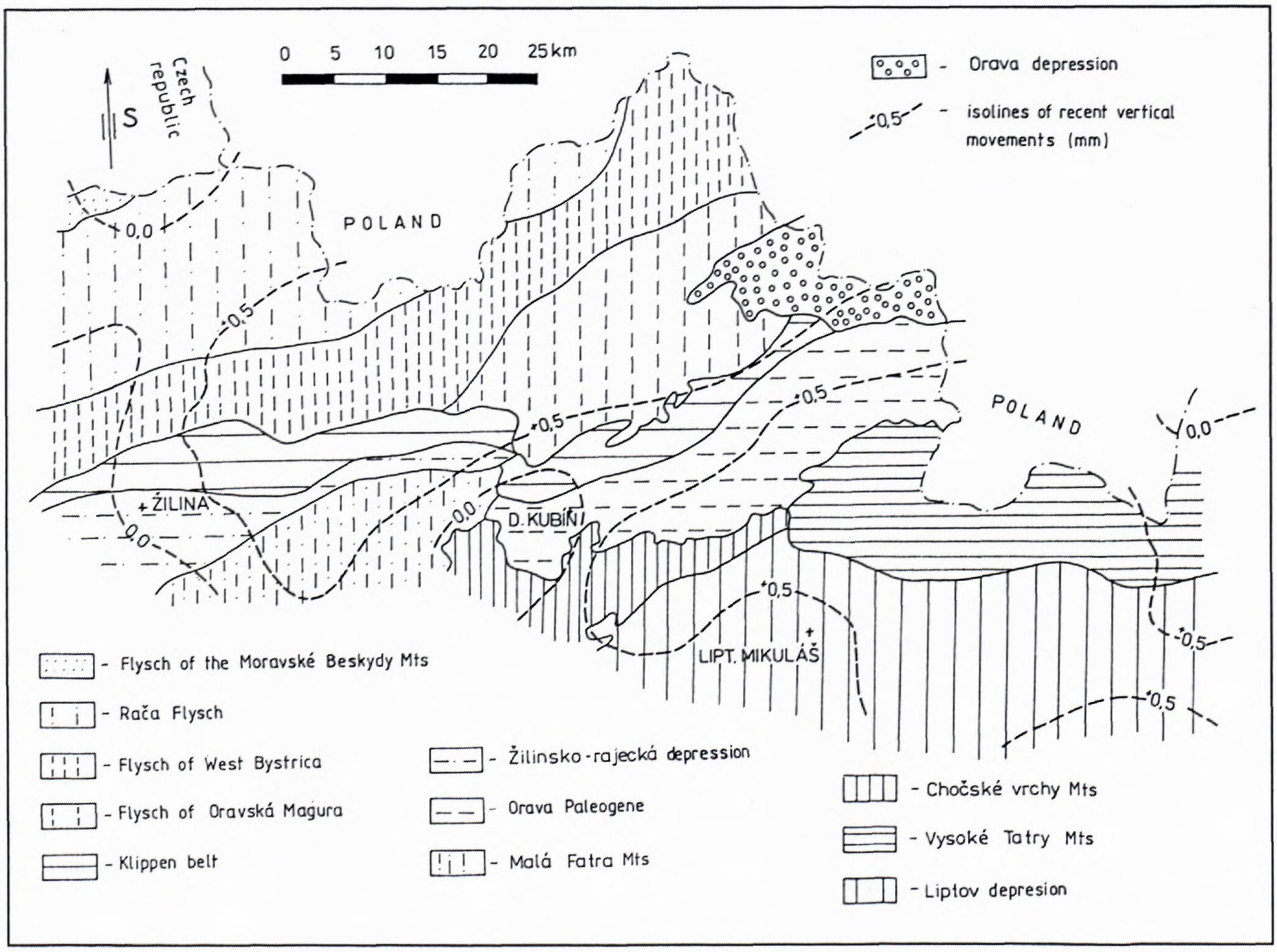


Fig. 9 Recent vertical movements in the area of the Orava Depression (after VANEK 1988)

of the depression. The rising the depression per sists to the present, which is indicated by measurements of recent vertical movements of the Western Carpathians. According to VANEK (1988) the major part of the Orava Depression is lying in an area which is rising at an average rate of + 0.5 mm/year, or a rate between 0.0 to +0.5 mm (Fig. 9).

Average rate of rising of the depression from the Dacian to the recent times (0.18 mm/year) calculated from the model is in accordance with recent vertical movements.

During the Dacian the depression lost the basin geodynamics, i.e. it ceased to subside and, on the contrary, it started to rise together with its geological surroundings. The geomorphologic form of the depression has been preserved not due to continuing subsidence, but due to the lithologic contrast between the soft, to erosion more prone sedimentary filling of the basin and the much harder rocks surrounding the depression.

Conclusions

The Orava Depression, and its continuation in Poland, i.e. the Nowy Targ Depression, formed after the Early Sarmatian. Before the formation of this depression, a piggy-back type basin reached into the area of the present Orava-Nowy Targ Depression, with marine sedimentation during the Oligocene to Middle Miocene (including Early Sarmatian). This basin ceased to exist due to folding causing an inversion of the basin and the incorporation of its filling into the Magura Nappe of the Outer Flysch Carpathians. The young Orava-Nowy Targ Depression formed, according to ROTH et al. (1963), due to a flexure caused by the load of the Magura Nappe during its back-thrusting with southern vergency. This thrusting affected also the Klippen Belt, which is overthrust on the Central Carpathians. The steepness of burial curves in the basin however indicates pull-apart mechanism of depression opening and it supports the opinion of POSPÍŠIL (1990) on the formation of the depression on the mobile belt of the Periklippen zone with horizontal movements.

The coal of the Orava Depression, namely from the surroundings of Ústie nad Priehradou, belongs to humites of the brown-coal stage of alteration, with predominant xylito-detritic and detrito-xylitic lithotypes, and relatively low ash contents. According to light reflectance of vitrinite and chemical-technological tests it may be ranged with the ortho- to metaphase of brown coal. It may be compared with coal from the deposits Handlová and Cígeľ in the Horná Nitra Depression.

Coal with such thermal alteration degree must have been buried in the process of basin filling. It reached the surface after the Pliocene, when the whole depression started to rise and erosion removed a substantial part of the original filling. The basin, due to lithologic contrast between the filling and the surrounding rocks, preserved its depression morphology in spite of the uplift continuing to the present.

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Extension tectonics of the south-eastern margin of the Tribeč Mts.

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Abstract. The analysis of semi-brittle structures provided data for the recognition of two deformation stages: 1. Early Miocene brittle-ductile gravity gliding, related to the uplift of the crystalline core of the Tribeč Mts., and 2. Late Miocene normal brittle faulting controlling the deposition of the Komjatice depression filling.

Key words: Western Carpathians, Tribeč Mts., Miocene gravity tectonics, Komjatice depression

Introduction

The Tribeč Mts. forms a horst of NE-SW direction, divided cross-wise into the Zobor and Rázdiel parts. The southern Zobor part is formed of granitoid rocks and an imbricated Mesozoic envelope sequence. The geological structure of the Rázdiel part included granitoids, pre-Permian metamorphic rocks and a stratigraphically reduced envelope sequence with a markedly represented Permian basal formation, the Krížna and Choč Nappes (Fig. 1). The basic conception of the Tribeč Mts. geological structure has been shown in the geological map on the scale 1 : 50 000 (BIELY, 1974). The so far carried out geological investigations in the Tribeč Mts. were aimed mostly at the Rázdiel area, e.g. Kamenický (in Mahel' et al. 1967), KRIST (1971), IVANIČKA and HÓK (1992), IVANIČKA et al. (1992) and KRIST et al. (1992), HÓK et al. (1994).

The envelope sequence in the Zobor part is on the majority of the area represented only by quartzites of the Lower Triassic, which were in the past the subject of sedimentological investigation (HÓK, 1989). An exception are the occurrences of upper carbonate Mesozoic members north of Nitra and sporadic occurrences, e.g. in the are of Kostoľany pod Tribečom, Lefantovce, or Krnča. The envelope Mesozoic surrounds the granitoid core and the quartzites are modelling the characteristic positive relief, with rock walls situated on the side of the crystalline core.

During the basic geological mapping we could identify brittle-ductile deformation of the envelope Mesozoic, located in the surroundings of Kostoľany pod Tribečom.

Geological setting of the studied area and methods of investigation

The area of Kostoľany pod Tribečom is build of granitoid rocks of granodiorite to quartz diorite type. The base of the Mesozoic is formed of quartzites or quartz sandstones of the Lower Triassic. The granodiorites are at the boundary with quartzites affected by mylonitization. The foliation planes of mylonites are conform with the bedding of the Mesozoic rocks. Above the quartzites there are rudimentarily developed Lower Triassic chlorite-sericite sandy shales and Middle Triassic carbonates. South-west of Kostoľany pod Tribečom, above Middle Triassic limestones and dolomites, there are sporadically preserved Upper Triassic quartz sandstones and Liasic sand limestones.

On the bedding planes of the quartzites there is very well preserved slickensides, which has however not been observed in carbonate sequences. In both sequences we could sporadically observe mezoscopic folds of decimetre to meter dimensions. The fold axes are of NE-SW direction, they are open to isoclinal, with fold planes dropping to the north-west, or vertical.

The development of the Tribeč horst is related to the sedimentation of Neogene rocks and the development of the Komjatice depression, the sediments of which are lying along the margin of the mountain range. The sedimentation started in the Middle Badenian by marine transgression and lasted to the Pliocene, while the sedimentation environment was gradually becoming less saline already from the Lower Sarmatian (PRIECHODSKÁ, HARČÁR, 1988).

During the field investigations we concentrated on collecting available structural data, above all slickensides, joints and fold axes. Subsequently we evaluated the obtained data using usual methods of structural analysis (c.f. e.g. ANGELIER, 1994) and we processed the data in the form of diagrams (Fig. 2).

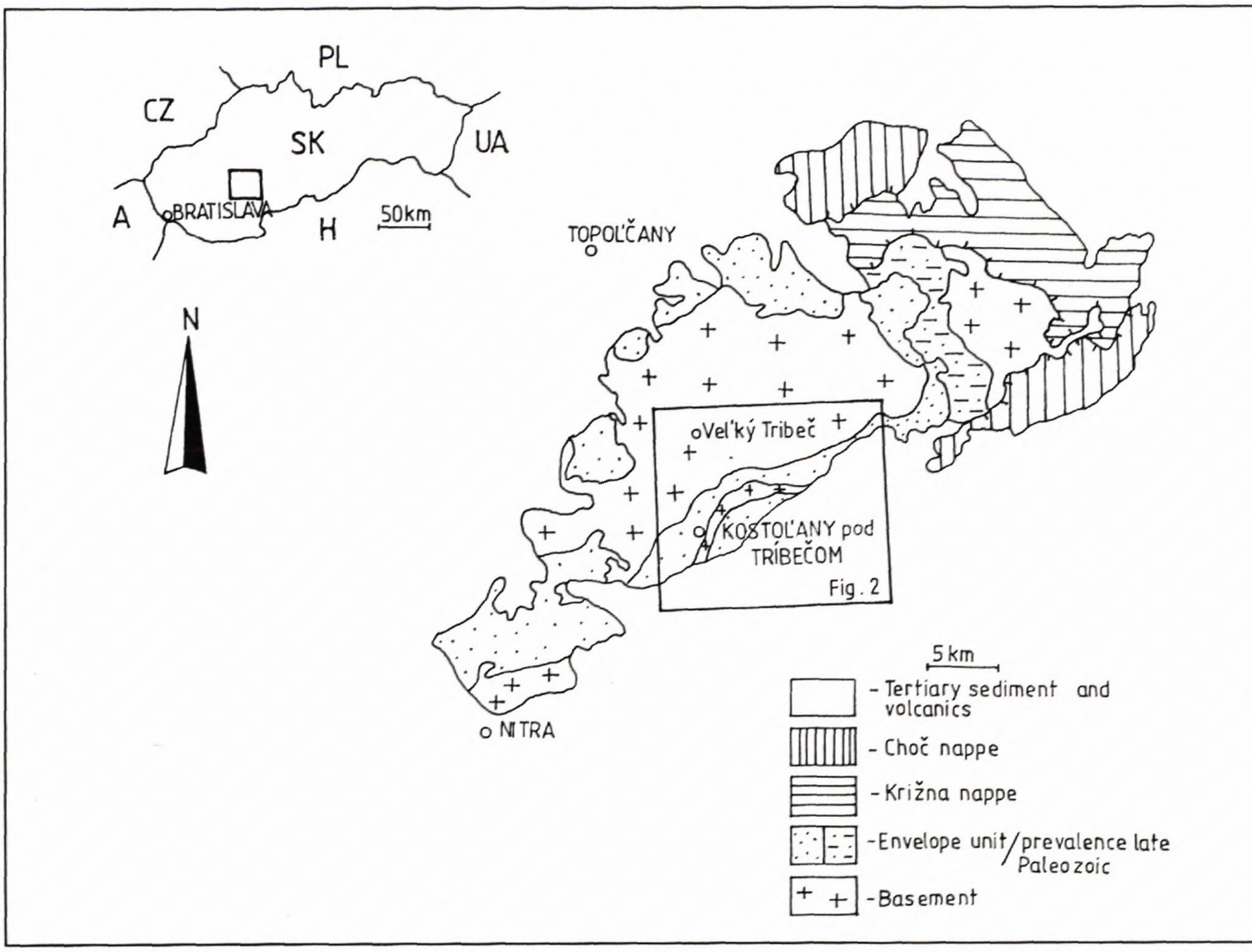

Fig. 1 Simplified geological map of the Tribeč Mts. (after HÓK and IVANIČKA, 1995) with the position of the studied area.

Interpretation of the results

The direction of slickensides striation on the bedding planes of Lower Triassic quartzites defines the direction of extension generally as south-east to south (Fig. 2). The displacement occurred on the bedding planes representing the primary inhomogeneity, which are conform to the foliation and the direction of transport in mylonites of granitoid rocks. The joints are younger than the slickensides and they form a sharply inclined, rectangular system generated in an extensional regime (HANCOCK, 1985, DUNNE-HANCOCK, 1994). The direction of the greatest extension is oriented generally consistently with the extension direction obtained by the analysis of slickensides.

Folds and slickensides formed in brittle-ductile conditions of deformation and we assume that they are related to the initial stages of the uplift of the mountain range which is, according to apatite FT age data (KOVÁČ et al., 1994), estimated at 28±1 Ma, i.e. the Early Miocene. In this time there were by this elevation generated low-angle normal listric faults along which the rocks gravitationally glided, while the bedding planes in the Mesozoic complexes served as primary inhomogeneity. The gravitational gliding caused folding of the whole complex into high-amplitude folds (Fig. 3). The folds formed in favourable conditions, e.g. at the contact of rocks with different rheologies (granitoids/quartzites, or quartzites/limestones) also on the meso-scale.

The brittle deformation stage is represented by joints conform in their direction with the system of Mojmírovce faults separating the mountain range from the Neogene filling of the Komjatice depression. The Komjatice depression reached the maximum of subsidence in the Pannonian. Investigation using boreholes (BIELA, 1978) confirmed that the sedimentation related to the Tribeč Mts. was controlled by the Mojmírovce fault system of NE-SW direction. We assume that the brittle deformation stage took place in the Late Miocene and that it is

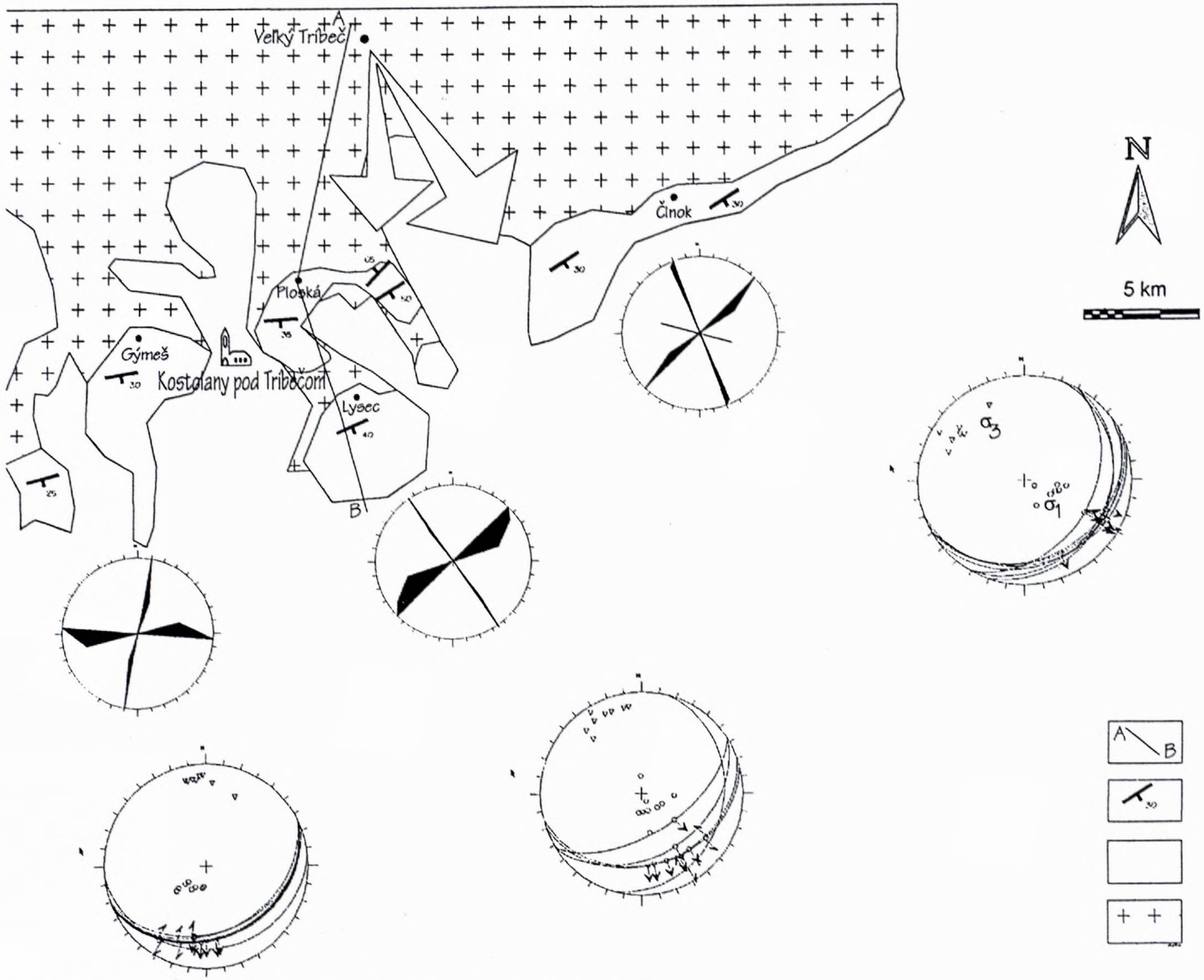

Fig.2 Simplified geological map of the SE part of the Tribeč Mts. (BIELY, 1974 - modified).
The diagrams of the Lambert lower hemisphere projection shows sets of joints directions (n = number of measurements) and projection of fault planes represented by great circles, the sense of displacement is indicated by black arows. Principal stress axis σ_1 - compression and σ_3 - extension are marked by small circles a triangles. Explanations : geological cross-section A - B, average dip direction of bedding, granitoids.

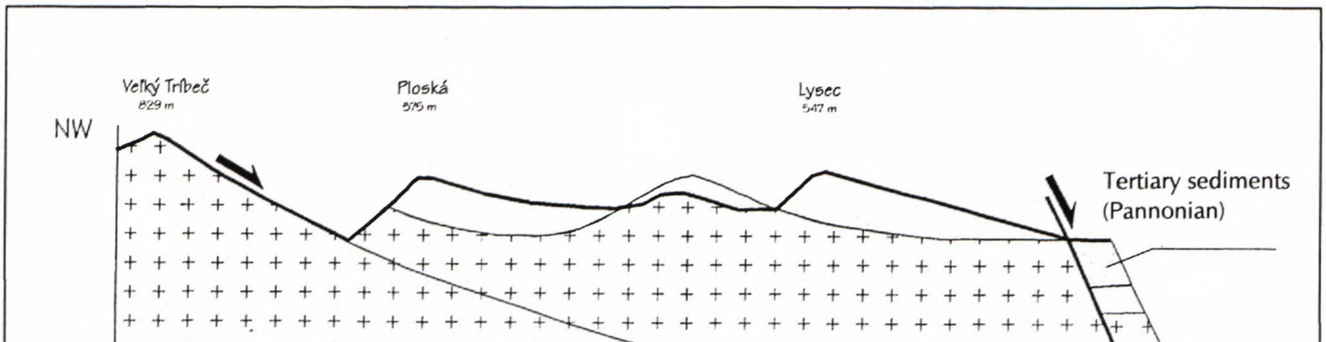

Fig. 3 Geological cross- section A - B (not to scale). Explanations see Fig. 2, with exception of the Tertiary sediments (Pannonian) on SE side of the section. The model of tectonic evolution 1) brittle - ductile extension (Oligocene - Miocene). 2) brittle extension (Pannonian).

related to the development of the Komjatice depression.

Conclusions

At the south-western margin of the Tribeč Mts., in the area of Kostoľany pod Tribečom, the deformation of the envelope sequence rocks of the Tribeč Mts. has been investigated. Two extension phases of NW-SE direction have been distinguished, related to the uplift of the granitoid core. The older phase has been dated as Middle Miocene. It is characterised by brittle-ductile structures which formed in the process of elevation of the mountain range and the formation of normal-slip listric faults. The brittle deformation phase took place in the Late Miocene and it affected the sedimentation in the north-eastern part of the Komjatice depression.

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Terranes of West Carpathians - North Pannonian Domain

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Abstract. The kinematic evolution of the West Carpathians arc system was affected in both Variscan and Alpine times. Fragments of newly formed Epi-Variscan crust were incorporated in the Paleoalpine West Carpathians units as evidenced by the repeating subduction, thrusting and transform fault processes. The Epi-Variscan crust gradually amalgamated by crustal thickening during Early to Late Carboniferous collision events, as overriding microplates (evidences of Tatra-Veporic Domain) of Eurasian affinity moved southwards.

The Lower Carboniferous flysch type basins originated in intrasutural embayment continuing in the Upper Carboniferous peripheral basin on the underthrusting plate (relics of Spiš Composite Terrane in Gemeric Domain) of African promontory.

The present West Carpathians have been divided into Outer West Carpathians and Central and Inner West Carpathians.

Crustal development of the Alpine Internides has been strongly influenced by the structural fabric of the Variscan collision orogeny. The Permian - Lower Triassic extension in the area of the former Variscan Externides (Gelnica Terrane in Gemeric Domain) results in continuing rifting in the Middle Triassic and opening of the large sedimentation area of the Meliata Ocean.

The main difference between distinguished structural zones of the West Carpathians is in age of main Alpine phases and intensity of deformational and metamorphic events. They are:

a) Inner West Carpathians - the HP/LT Late Jurassic events;

b) Central West Carpathians - the Lower/Middle Cretaceous;

c) Outer West Carpathians;

1) inner part - the Late Cretaceous/Lower Paleocene;

2) outer part - the Oligocene - Middle Miocene.

These kinematic stages represent the main phases of subduction -thrusting events followed by extension and uplift. Later deformation and emplacement to the present position were connected with Tertiary oblique collision of the West Carpathians - North Pannonian Block and North European platform.

Key words: West Carpathians, kinematic evolution, Variscan terranes, main Alpine deformational and metamorphic events

Introduction

This contribution summarizes the results of researches carried out within the framework of both, the IGCP Project No. 276 entitled: Paleozoic Geodynamic Domains and their Alpine Evolution in the Tethys (1986-1994) and the national project: Geodynamic Evolution of the West Carpathians (1991-1995). The objective of this analysis was to characterize Variscan terranes and to define their setting in the complicated Alpine structure of the West Carpathians.

The West Carpathian-Pannonian domain is characterized by the following development stages:

1. Pre-Alpine evolutionary stages - with predominant structural events from the Devonian/Early Carboniferous, to the Middle Carboniferous- Permian. Possible pre-Variscan evolutionary stages are included. These are preserved as fragments in the Alpine megaunits of the Inner and Central West Carpathians.

2. Pre-Middle-Cretaceous evolutionary stage - beginning of the compressional tectonic regime including the Late Jurassic subduction/accretion events in the Meliata oceanic domain as well as obduction of accretion prism sequences with HP/LT metamorphites.

3. Middle Cretaceous evolutionary stage - the northward migration of the orogenic contraction, revealed by the orogenic flysch sedimentation and successively closing of sedimentary basins from the Gemer-Bükk Domain through the Tatro-Veporic Domain. Shortening and origin of the north-vergent nappe system in the same manner.

4. Late Cretaceous to Paleocene evolutionary stage-comprises the closure of a supposed Penninic-related oceanic domain, origin of perisutural Senonian basin along the northern margin of the Tatric megaunit, the post-nappe Gosau sequences within the Inner West Carpathians.

5. Oligocene to Middle Miocene - northward prograding of the Flysch belt accretionary wedges of Carpathian orogeny, passing gradually into Neogene foredeep molasse depocenter; shortening and nappe

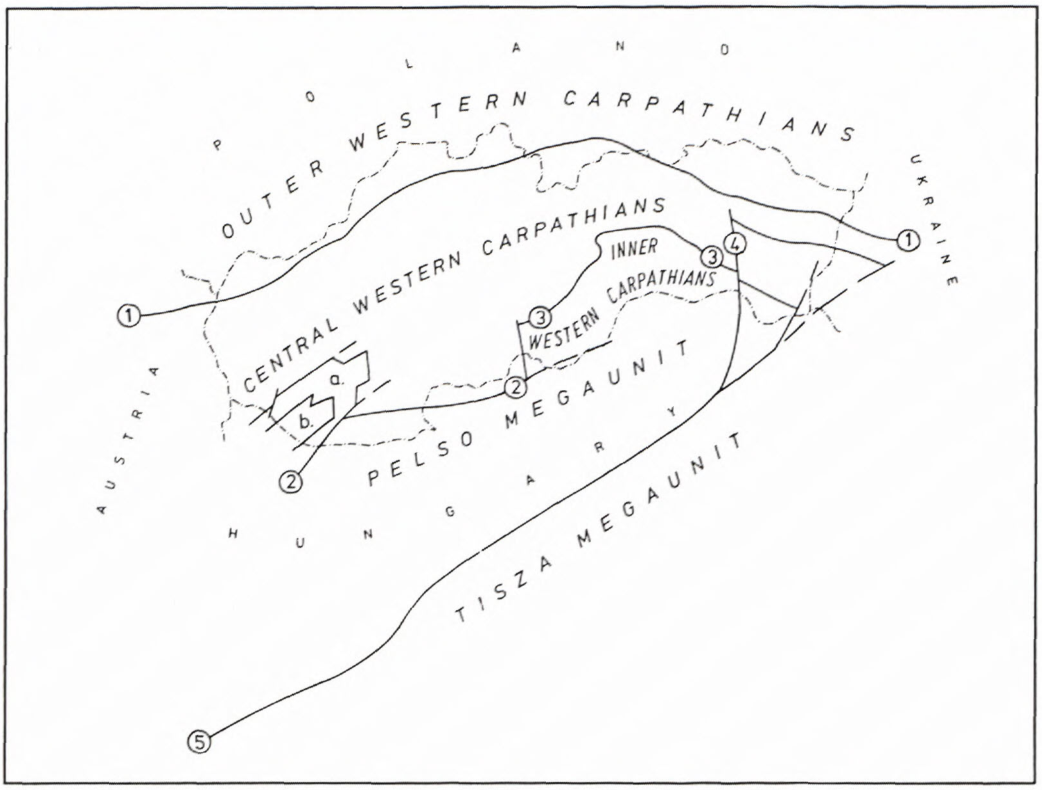

Fig. 1 Distribution of the main tectonic units of the West Carpathian - North Pannonian Domain
Legend: a) Upper Austroalpine Paleozoic, b) Southern Penninicum; 1 - Klippen Belt Lineament, 2 - Rába - Hurbanovo - Diosjenő fault zone, 3 - Lubeník - Margecany line, 4 - Hornád fault system, 5 - Mid-Hungarian Lineament

stacking within the Outer West Carpathians; origin of foreland Central Carpathian Paleogene flysch basin; gradual east-ward closing of Carpathian subduction zone; meanwhile, shearing and extensional tectonics predominated in the Central Inner and West Carpathians.

6. Miocene to Pliocene evolutionary stage represents a concluding phase of the oblique collision with the North European plate in the eastern part of the Outer West Carpathians. At the same time, the transtensional/transpressional tectonic regimes predominated in the western part of the orogeny, but mainly in the Central and Inner West Carpathians.

The above characterization of the West Carpathian - Pannonian Domain has been mainly based on the knowledge of the Pre-Alpine and Paleo-Alpine structural levels.

WC/1. PIENINY TERRANE

This terrane comprises a very complicated system of Alpine N-vergent nappes, which reflect in the gradual intra-Cretaceous subduction and multistage collision events during the Cenozoic. The Pieniny Terrane is composed of:

1. Klippen Belt, which forms a complex of tectonic lenses of Jurassic - Lower Cretaceous, mostly pelagic radiolarites and carbonates, embedded in more plastic Upper Cretaceous - Lower Paleocene marly and flysch complexes.
2. Flysch Zone related to intra-Paleogene and Middle Miocene collision events.

TERRANE BOUNDARIES

The Pieniny Terrane is restricted by the Peri-Pieniny lineament in the south, separating it from the Tatro-Veporic Terrane. The northern boundary is formed by an overthrust plane of the Subsilesian Unit, which is thrust over the Carpathian Foredeep.

OVERSTEP SEQUENCES

1) Post-Alpine overstep sequences:

The post-nappe Gosau sediments were deposited in a perisutural compressional basin at the active northern Central West Carpathians margin (Wagreich & Marschalko, 1994). The Late Tertiary molassic sediments of the Carpathian Foredeep overstepped or the passive margin of the

North European Plate. Post-Savian sediments rest unconformable on different tectonic units of the Vienna Basin basement. The Vienna Basin basement is composed of the units of Pieniny terrane as well as main paleo-Alpine tectonic units of Tatro-Veporic terrane. Filling of the Vienna basin is variable (fresh water, brackish, marine) with maximum subsidence in the Karpatian-Badenian (VASS, 1982). Remnants of small intramontane depressions (Orava - Nový Targ Basin; Nowy Sacz Basin) overlapped either former suture-lineament (ONT B.) or Flysch Zone (Ns B.)

A. Variscan History

Present evidence of the existence of this basement are only pebbles in conglomerates of Upper Cretaceous and Paleogene flysch sequences (ANDRUSOV 1958, HAVLENA 1956, MIŠÍK & MARSCHALKO 1988, etc.). There were found pebbles of Permian red-bed sandstones and siltstones as well as fragments of Namurian A coal black shales and greywackes. Post-orogenic A-type trending magmatic suite of the Lower Permian age was determined from granitic pebbles (U/Pb zircon ages; UHER & PUSHKAREV 1994) of the Pieniny Klippen Belt.

Paragneisses of the Lower Paleozoic, lydites with Vendian spores (TIMOFEEV in KAMENICKÝ & KRÁL 1979) as well as Devonian and Visean limestones (MALÍK 1982) were described from the Cretaceous flysch conglomerates of the Pieniny Klippen Belt and external part of Flysch Belt.

In spite of the rare evidence about the nature of the Variscan and/or stage, the pebble compositions proved the Variscan eventually Pre-Variscan Eurasian provenance of the pre-Triassic pebble material (extra-alpidic crystalline basement).

B. Alpine History

Flysch Zone

Stratigraphy

The sedimentary area of the Flysch Zone was divided into several deep-water throughs, separated each other by submerged ridges. The deep-water, flysch sedimentary environment lasted from the Cretaceous to Eocene - Oligocene in the inner part of the Flysch Zone and from the Eocene to Lower Miocene in the outermost part. The only exception is the Magura group of nappes, in front of which there are also the Jurassic klippen. They are perhaps olistoliths and may represent elements of the Silesian cordillera rather than its primary basement (BIELY 1989).

The Flysch Zone forms the Tertiary accretionary wedge of the Carpathian orogeny, generally ranged into two groups: a) Silesian - Krosno (Moldavian) nappes in the north part; b) Magura group of nappes in the south (linked to the Rheno-Danubian flysch). Several thousand metres thick, mostly siliciclastic flysch sequences were detached from a strongly attenuated continental crust, according to some authors partly truly oceanic (BIRKENMAJER 1988, MAHEĽ 1989, OSZCZYPKO 1992), produced by Jurassic-Tertiary rifting.

Klippen Belt

Stratigraphy

The Klippen Belt represents a composite unit of strongly folded Jurassic and Cretaceous sedimentary series, which were supposedly underlain by continental crust to the north and probably by oceanic crust to the south.

It is assumed that the area of sedimentation of the Klippen Belt was formerly located on the southern margin of the labile North European shelf (RAKÚS et al. 1990). Evidence in favour of this assumption is only clastic detritus in younger sediments (ANDRUSOV 1958). In the Jurassic, extensional listric faults broke up this shelf into a horst (Czorstyn Zone) and a through (Kysuce - Pieniny Zone),related to oceanisation (BIRKENMAJER 1984), with maximum spreading in the Callovian. The opening of the oceanic domain (Vahicum after MAHEĽ 1981; Penninic ocean after RAKÚS et al. 1990) occurred along the Northern transform zone (RAKÚS et al. 1990) and was located between the Czorstyn Ridge to the north and Tatric-Carpathian (Apulian promotory) margin. Intra-Cretaceous S-directed subduction of this oceanic lithosphere gave rise to the ophiolite-bearing marginal thrust belt (MIŠÍK & MARSCHALKO 1988, BIRKENMAJER 1988). The origin of collision melange related to the Pieniny Exotic Ridge (ANDRUSOV 1958, MIŠÍK 1978 and many others) is supported by evidence within the Albian - Maastrichtian flysch conglomerates. The collision events were accompanied by high-pressure metamorphism (glaucophane-lawsonite facies) as well as Late Jurassic - Early Cretaceous island-arc volcanism and syn-collisional magmatism (evidence in exotic pebble materials and heavy minerals spectrum; MIŠÍK & SÝKORA 1981, ŠÍMOVÁ 1985, MARSCHALKO 1986, MIŠÍK & MARSCHALKO 1988, WINKLER & SLACZKA 1992, 1994).

Deformational and metamorphic events

The deformation of the Klippen Belt was multistage and very complicated. First of all, there is evidence of Early Cretaceous subduction related to closure of the Penninic Ocean. High-pressure metamorphism is inferred from pebbles of blueschist metabasalts (K/Ar 138-140 Ma; RYBÁR & KANTOR ex. MARSCHALKO 1986). From this time probably until the Paleocene, the inferred oceanic crust of the Penninic-Vahic domain was subduced southward below the North Tatric margin (MIŠÍK & MARSCHALKO 1986, BIRKENMAJER 1988, PLAŠIENKA 1995). Further deformations were connected with north-vergent Laramide nappe movements and Paleogene phases of folding and large transform movements, simultaneously with gradual closing of the Flysch Zone basins. Depocenters of residual flysch basins were shifted towards the platform foreland passing gradually into foredeep molasse sedimentation during the Neogene. The gradual eastward migration of Outer Carpathian subduction finally led to sinistral transtension and pull-apart opening of the Vienna basin.

Plutonic igneous intrusions

Evidence for syncollisional magmatic activity is provided only by clastic material derived from the Pieniny Exotic Ridge, which was found in the Klape, Kysuca - Pieniny and Manín Units. K/Ar radiometric data from granitoid pebbles proved Jurassic to Cretaceous age (K-Ar 140-90 Ma; KANTOR & RYBÁR 1978 ex MARSCHALKO 1986). This evidence is at variance with the new U-Pb zircon ages, which proved the Lower Permian A-type granitic suite from three occurrences of "exotic" pebbles of the Pieniny Klippen Belt. Barremian alkaline volcanism of the Flysch Zone producing a teschenite-picrite association is related to within-plate rifting processes (HOVORKA & SPIŠIAK 1989).

Time of docking

Time of docking of the Tatra-Veporic Terrane with the Penninic Ocean and with the southern margin of the North-European plate is indicated by termination of closing individual zones of the Klippen Belt sedimentation, gradually during the Late Cretaceous to Lower Paleocene.

WC/2. TATRO-VEPORIC TERRANE

The Tatro-Veporic Terrane contains pre-Gosau nappe units with distinct similarities in their lithostratigraphic and tectonometamorphic development during Variscan as well as Alpine orogenic events. Terranes of different geotectonic settings accreted du-ring the Paleozoic time to form a consolidated crust by the end of the Variscan orogenic cycle. Due to incomplete record, their definition must be considered preliminary. In the present tecto-nic pattern they are incorporated into the main Paleo-Alpine tec-tonic units of the Central Western Carpathians - Tatricum, North Veporicum/Fatricum (in the sense of PLAŠIENKA (1995), into the Fatric paleogeographic realm are placed also the Klape, Manín and related units), South Veporicum, Zemplinicum, as well as within rootless nappes - Hronicum. They contain the following structural levels:

1. Variscan Terranes.
2. Carboniferous-Permian overstep sequences.
3. Epiplatform Triassic formations prograding into extension-related setting in the Jurassic-Lower Cretaceuos.
4. Post-Alpine overstep sequences.

TERRANE BOUNDARIES

The Tatro-Veporic Terrane is separated by the Alpine thrust plane from the overlying North Gemeric Terrane. The northern boundary reaches the peri-Pieninic Lineament, which roughly borders the subvertical Klippen Belt. The Variscan nappe pile has been inverted during the Alpine orogeny.

OVERSTEP SEQUENCES

1. Post-Variscan overstep sequences:

The post-Variscan overstep sequences are generally volcano-terrigenous and continental. They cover their basement rocks with distinct stratigraphic unconformity. They are also separated from the overlying Lower Triassic formations by a stratigraphic hiatus and disconformity. Transpressional sedimentary basins (graben, pull apart basin) originated gradually in time and space, reflec-ting the process of post-suturing uplift and extension of an overthickened crust.

The Permian post-Variscan overstep sediments of the Tatra Terrane are continental (fluvial, lacustrine, alluvial fan, braided river, playas), with a dominant part of clastic detritus, reflecting provenance from an uplifted crystalline basement (VOZÁROVÁ & VOZÁR 1988, VOZÁROVÁ 1990).

Limno-fluvial coal-bearing cyclothemes dated as Lower Stephanian (NĚMEJC in BOUČEK & PŘIBYL 1959; SITÁR in PLANDEROVÁ et al. 1981) are a characteristic lithological member of the Byšta Susp. T. post-Variscan sequence. Intense synsedimentary tectonics was associated with calc-alkaline rhyolite-dacite volcanism.

The Upper Carboniferous-Permian overstep sequence of the Kohút Terrane is generally regressive, prograding from shallow-water (intracontinental lake or

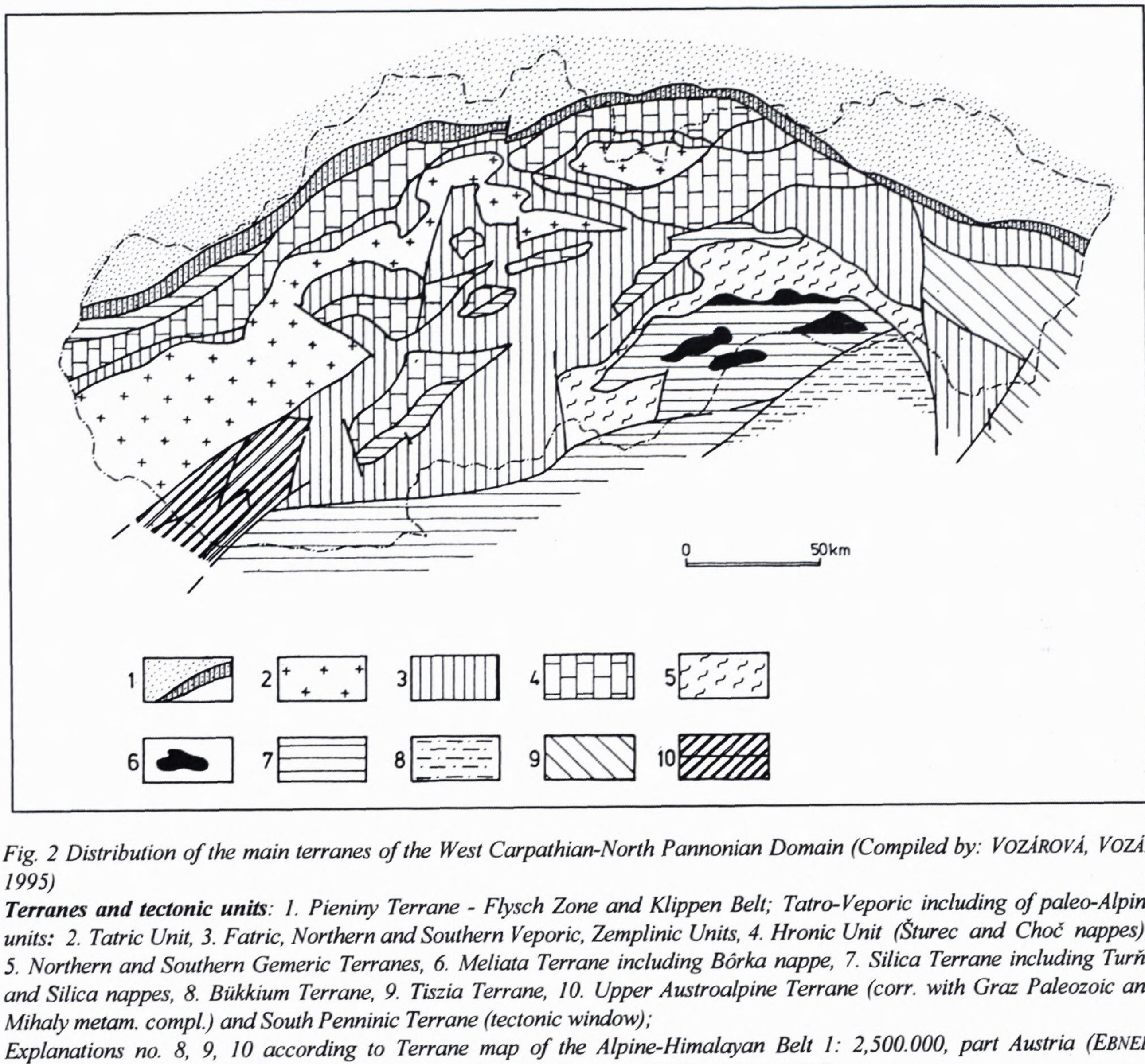

Fig. 2 Distribution of the main terranes of the West Carpathian-North Pannonian Domain (Compiled by: VOZÁROVÁ, VOZÁR 1995)

***Terranes and tectonic units**: 1. Pieniny Terrane - Flysch Zone and Klippen Belt; Tatro-Veporic including of paleo-Alpine units: 2. Tatric Unit, 3. Fatric, Northern and Southern Veporic, Zemplinic Units, 4. Hronic Unit (Šturec and Choč nappes), 5. Northern and Southern Gemeric Terranes, 6. Meliata Terrane including Bôrka nappe, 7. Silica Terrane including Turňa and Silica nappes, 8. Bükkium Terrane, 9. Tiszia Terrane, 10. Upper Austroalpine Terrane (corr. with Graz Paleozoic and Mihaly metam. compl.) and South Penninic Terrane (tectonic window);*

Explanations no. 8, 9, 10 according to Terrane map of the Alpine-Himalayan Belt 1: 2,500.000, part Austria (EBNER, NEUBAUER), Hungary (KOVÁCS et al.) presented at the XVth Congr. of CBGA, Athens 1995

paralic basin) to alluvial environment. Synsedimentary tectonic activity is reflected in large regressive cycles. Clastic detritus was derived from a cut magmatic arc. Palynological data proved Stephanian C-D to Lower Permian age (PLANDEROVÁ & VOZÁROVÁ 1982).

The Hronic Unit comprises an Upper Carboniferous - Permian thick continental clastic sequence (derived from the Ipoltica Susp. Terrane) with characteristic lava flows of continental tholeiitic basalts developed in rifting - related setting.

2. Post-Alpine overstep sequences:

The rare occurrences of Senonian sediments are evidently post-tectonic (mostly preserved in the western part of the area). They started as continental, lacustrine deposits and in a short time passed into marine environment. More widespread is the Lutetian transgression in the Central Carpathian Basin. The emergent Central Carpathian zones, with Variscan terranes and their overstep sequences as well as Mesozoic cover, were the source of clastic filling for this basin.

The last stage of post-Alpine overstep events was the sedi-mentation in Tertiary inter- and intramontane basins, evoked by disintegration of the back arc area within the newly formed Carpathian arc into partial blocks. The process was associated with a turn from dextral to sinistral transpression during the Lower Miocene, and was accompanied by antiklockwise

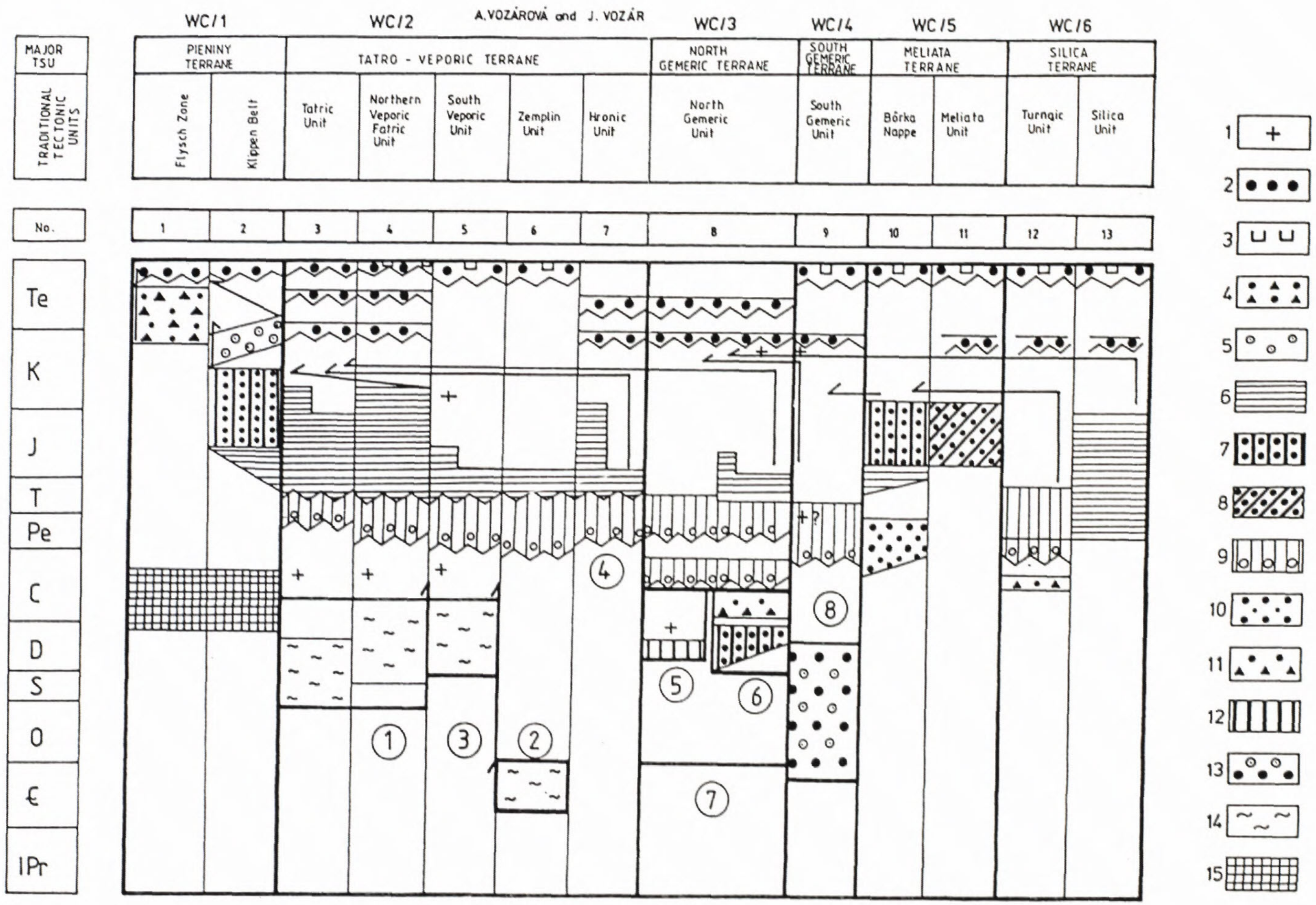

Fig. 3 West Carpathian - North Pannonian Domain

1 - Late, post-orogenic plutons S and I-S type, 2 - Post-Alpine overstep sequences, 3- Tertiary volcanics of Western Carpathian arc and back-arc area, 4 - Orogenic Flysch Belt formations, 5 - Deep-water and flysch-olistostroma Klippen Belt formations, 6 - Shalow-water and basinal facies related to Triassic/Jurassic extension regime, 7 - Complexes containing subduction related HP/LT metamorphics with to affinity oceanic crust, 8 - Subduction complexes (melanges, olistostroma), 9 - Late Variscan overstep sequences with passive continental margin formations in overlier, 10 - Rift-related sequences, 11 - Variscan flysch orogenic sequences, 12 - Lower crust island arc complexes with enclaves of subducted oceanic crust, 13 - Volcanogenic flysch with for-arc related setting, 14 - High grade metamorphic crust, two or more geodynamic settings (non differenciated), 15 - Extra-alpidic massifs of unknown geodynamic setting

Number for the Variscan Terranes - see text: *1. Tatra Terrane; 2. Byšta Suspected Terrane; 3. Kohút Terrane; 4. Ipoltica Suspected Terrane; 5. Klátov Terrane; 6. Rakovec Terrane; 7. Spiš Composite Terrane; 8. Gelnica Terrane.*

rotation of rigid basement blocks. Compression from the NE-SW to the NNW-SSE controlled sedimentation in the area of the Hornonitrianska kotlina Depression (HÓK at al. 1995) during the Late Pannonian to Quaternary. The transtensional tectonic activity culminated during the Badenian and Sarmatian, having been accompanied by intense andesite and rhyolite volcanism (NEMČOK & LEXA 1991). The Pliocene to Quaternary period is characterised by extensional overall uplift, with minor volcanic activity of alkali basalts. The origin of the Neogene basins was connected with two structural stages. The older (Early Miocene) originated as a part of a marine back arc basin, formed to the south of the Klippen Belt (connection with eastward migration of subduction of the Carpathians). During the Middle Miocene a mantle diapir caused heating and rifting of continental crust (Central Slovakia; Danube Lowland).

A. Variscan Terranes

Tatra Terrane (1)

Stratigraphy

The Tatra Terrane consists of medium- to high-grade paragneisses interlayered with calc-alkaline to tholeiitic basic and acid orthogneisses and migmatites (KORIKOVSKIJ et al. 1987 a,b; SPIŠIAK - PITOŇÁK 1990; JANÁK 1991; JANÁK et al. 1988; etc.) as well as of low-grade complexes (CAMBEL 1954; MIKO 1981; BAJANÍK et al. 1979; PUTIŠ 1983). Banded amphibolites are very specific. Sometimes they are associated with metaultrabasites. The latter are characterised by a primitive REE distribution and show some affinity either to the initial island-arc stage or to crustal fragments of oceanic affinity (SPIŠIAK - PITOŇÁK 1991). Relics of older HT/HP eclogite as well as granulite facies rocks were pointed out by HOVORKA - MÉRES (1989, 1990), VOZÁROVÁ (1993a).

Some low-pressure greenschist complexes (Jánov Grúň Complex and Predná Hoľa Complex: MIKO 1981, BAJANÍK et al. 1979) are in tectonic contact with the mentioned higher metamorphic complexes, reflecting thrusting during Late Variscan collision (this tectonic contact is fixed by the Permian overstep sequences). Both low-grade complexes comprise acid and basic volcanics and their volcanoclastics. This bimodal volcanic suite as well as the im-mature character of the clastics sediments (with grains of quartz, feldspars, clastic micas) support a possible continental intraplate (?) rifting origin of this sequences.

According to biostratigraphic data the low-grade metamorphosed complexes are mostly Silurian - Devonian and Middle - Upper Devonian in age (CAMBEL - ČORNÁ 1974, KLINEC et al. 1975, BAJANÍK et al. 1979, PLANDEROVÁ 1983, 1986). They represent sequences deposited most probably on a continental crust or on a transitional crust of an extension-related back-arc.

Byšta Suspected Terrane (2)

The crystalline rock complexes (Byšta Formation according to VOZÁROVÁ 1991) are correlated to the Tatra Terrane. Prevailing rocks are paragneisses, amphibolites and migmatites. Mineral assemblages indicate PT conditions of upper amphibolite facies (T = 650-680 °C, P = 4-5 kbar, VOZÁROVÁ 1991; 600-650 °C, 5,5-6,5 kbar, FARYAD 1995) associated with anatectic reworking of a part of the gneiss substrate. Data from boreholes realised on the territory of Hungary pointed to the presence of low-grade metamorphic rocks, the mutual relations of which were interpreted by PANTO (1965) as a tectonic - Late Variscan south-vergent thrust of higher-grade crystalline rocks on low-grade metamorphites. This opinion was confirmed by pebble material in Late Variscan conglomerates (VOZÁROVÁ & VOZÁR 1988) and by the fact that Carboniferous sequences cover both above mentioned complexes. Rb/Sr muscovite data from gneisses give 962-984 Ma (PANTO et al. 1967). These data require confirmation and are not sufficient for assuming Late Proterozoic age of metamorphism. Later overprint is suggested by K/Ar amphibole age - 307 Ma (LELKES-FELVÁRI & SASSI 1981).

Kohút Terrane (3)

Characteristic features of the KOHÚT Terrane are:

a) relics of a Lower Paleozoic/?Proterozoic basement, represented by acid- and basic gneisses of amphibolite facies and hybrid granitoids. These rocks are migmatitized and strongly diaphtorized (BEZÁK 1991);

b) Lower Paleozoic metamorphic complexes of upper green-schist/amphibolite facies whose mutual contacts are tectonic, while the main differences are in lithology;

c) a low-grade metamorphic complex containing magnesites, probably of ?Lower Carboniferous age;

d) distinct Alpine high-pressure reworking (VRÁNA 1964, MAZZOLI et al. 1992, MÉRES & HOVORKA 1992), which was associated with Alpine reheating connected with mildly alkaline granitoid intrusions and regional contact metamorphism (VOZÁROVÁ & KRIŠTÍN 1985, KORIKOVSKIJ et al. 1986, VOZÁROVÁ 1990a).

Protolith of some mica schists shows high-maturity and continental crust provenance (KOVÁČIK 1991, KORIKOVSKIJ et al. 1989, MÉRES & HOVORKA

1991). Bulk chemical composition and trace elements as well as REE patterns of orthogneisses indicate magmatic arc provenance (HOVORKA et al. 1987).

Ipoltica Suspected Terrane (4)

The existence of this terrane is suggested only by circum-stantial evidence, as for example the composition of Upper Car-boniferous - Permian overstep sediments, which were involved in the Hronic nappes. Due to Alpine nappe transport only slivers of strongly deformed granitoids were appear in the basal part of the Šturec Nappe. They were described as "segments a of squeezed out basement" (ANDRUSOV 1936; VOZÁROVÁ - VOZÁR 1979).

The mineral composition of sandstones as well as the kind of pebbles in the overstep sequences indicate their provenance in a continental magmatic arc with typical volcano-plutonic petrofacies (VOZÁROVÁ 1990). This continental magmatic arc was completely destroyed during the Alpine orogeny. It should be mentioned that the Ipoltica Suspected Terrane was probably of Variscan age.

Deformational and metamorphic events

Multistage development of deformational and metamorphic events has been recorded within crystalline complexes of the Tatra Terrane. Possible pre-Variscan or Early Variscan as well as Variscan metámorphism have been suggested (BEZÁK et al. 1992).

The earliest events were connected with granulite/eclogite facies metamorphism (700-750°C and 10-14 kbar, JANÁK et al. 1995; 675-770°C and 6-10 kbar, VOZÁROVÁ 1993), followed by amphibolite facies metamorphism. Further retrograde processes were connected with Late Variscan and Alpine shear metamorphism. Values between 380-301 Ma have been determined from paragneisses by means of Rb/Sr whole-rock and muscovite isochrons (BAGDASARYAN et al. 1983, BURCHART 1968). K/Ar hornblende ages of 554 and 882 Ma were obtained from gabbroamphibolites. U/Pb zircon ages from para-gneisses proved 581-551 Ma (CAMBEL et al. 1977).

Deformation and metamorphism (in the range of T= 500-560°C or 400-500°C at P=4-5 kbar) of the Lower Paleozoic complexes are connected with termination of Variscan orogeny. The youngest sediments are probably Lower Carboniferous in age and radiometric data (Rb/Sr whole rock age 319±5 Ma, CAMBEL et al. 1979) confirm syn- and late collision events.

Plutonic igneous rocks

There are a great volume of granitoid rocks of Devonian/Carboniferous age. Geochronological data are grouped on a time level: Rb/Sr isochron: 393 and/or 300 Ma; U/Pb zircon: 350 and 300 Ma; (CAMBEL et al. 1990). Magma differentiation ranged from leucocratic granite and granodiorite to tonalite. Several petrological criteria have been recently suggested for granitoid dis-crimination (BROSKA & GREGOR 1992, PETRÍK & BROSKA 1989, 1992, HOVORKA & PETRÍK 1992, KOHÚT 1992). Two petrological families could be thus distinguished: the first older (S-type) associated with metamorphism and anatexis, and the second younger initiated by rising of hot mafic magmas of mantle origin (I-type or mixed I-S type). Some indications of Permian magmatic activity point to WPG type (HOVORKA & PETRÍK 1992). Intrusion into the shear zone generated during Variscan collision-transpression is the most likely model for magma emplacement, as applied by KOHÚT & JANÁK (1995) for the Tatra granitoid pluton.

Time of docking

Time of docking of the KOHÚT and Ipoltica Terranes with the Tatra Terrane is indicated by the age of granitoid intrusions, which are considered to have formed as an immediate consequence of the docking event. It occurred probably during the Early Carboniferous.

B. Alpine History

The Late Variscan newly formed crust (Tatra Composite Terrane in the sense of VOZÁROVÁ & VOZÁR 1992) became an epiplatform area (together with the Austroalpine realm), with shallow-water sedimentation throughout the Triassic. Only exception is a differentiated type of the Upper Triassic in the Hronic Unit (a dolomite vs. Lunz facies). This area was gradually differentiated starting in the Middle Triassic and continuing mainly during Middle to Late Jurassic times, as a result of listric fault activity and active extension (RAKÚS et al. 1990). Sporadic occurrences of alkali basalt sills and lava flows within the Tatric and Krížna Nappe Mesozoic sequences proved an extensional, within-plate setting (HOVORKA et al. 1982). During the Upper Jurassic/Lower Cretaceous, abyssal environment prevailed, with some narrow zones of shallow-water sedimentation. Several sedimentary basins were created, later Fatric (Krížna) and to the north the Klape and Manín sedimentary areas.

Deformational and metamorphic events

The closing of the sedimentary basins and the connected overthrusting of Central Western Carpathian Nappes came to an end before the Late Turonian. The northward migration of orogenic contraction during the Cretaceous is revealed by the start and termination of orogenic flysch sedimentation: in the Hronic Valanginian-Hauterivian, in the Fatric Lower Albian - Lower Cenomanian, in the Tatric Middle to Late Albian - Lower Turonian, in the Klape Middle Albian - Middle Cenomanian. A distinct northvergent imbricate structure inside the mentioned units is characteristic as well as large synmetamorphic recumbent folds accompanied by ductile deformation. As concerns Alpine metamorphism, anchizone conditions have been recorded in Tatric as well as Zemplinic sequences (T = 210-270 °C; MILIČKA et al. 1991) and a transitional to epizone in North Veporic units (300-350 °C by means of illite crystallinity, PLAŠIENKA et al. 1989). These epizone conditions were accompanied by increasing intensity of strain and synmetamorphic ductile deformation. Rock complexes in front of nappes are nearly non-deformed.

The Mesozoic rock complexes of the South Veporic Unit under-went a relatively high grade of Alpine metamorphism, reaching conditions of medium/high pressure greenschist facies - determined by means of Ctd+Ky mineral compatibilities (VRÁNA 1964) and b_0 values of K-mica (MAZZOLI et al. 1992). The sediments were strongly ductile-deformed, contemporaneously with metamorphism and the first deformational stage - Eo-Alpine compression and an upthrust from SE to NW (MADARAS et al. 1995). Subsequent extension was connected with Cretaceous uplift (Ar/Ar muscovites data from blastomylonites give 84-94 Ma, MALUSKY et al. 1993). FT ages of apatites (89±10 and 53±7 Ma, KRÁL 1982) document multistage uplift and extension regime.

The emplacement of the Hronic nappes took place at near-sur-face level. The overthrust was accompanied only by brittle defor-mations. PT conditions of burial metamorphism correspond to dia-genesis (T in range of 100-150°C based on IC average values, ŠUCHA & EBERL 1992) in the greater part of the sequence. The pum-pellyite-prehnit assemblage proved anchizone conditions described near local shear zones (T around 200 °C, VRÁNA & VOZÁR 1969).

Plutonic igneous activity

Alpine heating is documented by regional contact metamorphism (VOZÁROVÁ & Krištín 1985; KORIKOVSKIJ et al.1986; VOZÁROVÁ 1990) only in the South Veporic Unit. K/Ar and Ar/Ar biotite ages from crystalline schists as well as Late Variscan meta-sediments give a range from 140 to 85 Ma (KANTOR 1960; KRÁL et al. 1995). Geochemical characteristics show affinity to calc-alcaline and alkaline, from normal to fractionated I/S type (HRAŠKO et al. 1995). Intrusion post-dated the Alpine regional metamorphism (VOZÁROVÁ 1990), connected with movement along shear zones in extensional regime.

Time of docking

The Lower-Middle Cretaceous time of docking the Tatro-Veporic and North Gemeric Terranes is indicated by the age of the youngest sediments within the rootless Hronic Unit as well as the Senonian overstep sequence.

WC/3. NORTH-GEMERIC TERRANE

The North-Gemeric Terrane is composed of:

1. Variscan Klatov and Rakovec Terranes which are inferred to have been amalgamated in the Upper Devonian/Carboniferous to form the Spiš Composite Terrane.
2. Upper Carboniferous-Permian shallow marine to continental overstep sequences.
3. Stable continental shelf-related Alpine sequences, with manifestation of rifting in the Upper Triassic-Jurassic.
4. Post-Alpine overstep sequences.

TERRANE BOUNDARIES

The North-Gemeric Terrane is restricted by Alpine thrusts in the hanging-, as well as in the footwall. Locally the northern boundaries are covered by post-Alpine overstep sequences. The Klátov Terrane is bounded by pre-Alpine thrust against the Rakovec Terrane.

OVERSTEP SEQUENCES

1. Post-Variscan overstep sequences:

The Upper Carboniferous sequences related to collision setting started in the Westphalian A by delta-fan, coarse-grained sediments, containing fragments of metamorphosed rocks from the Rakovec and Klatov Terranes. After initial rapid sedimentation the marine peripheral basin was deepened and fine-grained metasediments were associated with high-K tholeiitic basalts and their volcanoclastics. The final stage is documented by the subsequent paralic environment and interruption of sedimentation during the Stephanian.

Continental Permian sequences overstepped a slightly deformed filling of the Westphalian peripheral basin as well as the Rakovec and Klátov Terrane complexes. Coarse-clastic sediments derived from the collision belt are associated with bimodal basalt-rhyolite volcanism. The development of this basin was connected with the post-Variscan transpression stage.

2. Post-Alpine overstep sequences

There are preserved only as small relics of Upper Cretaceous coarse-grained marine sediments. More distinct are the Upper Paleocene-Eocene to Lower Oligocene clastic sediments which partly cover the northern Alpine thrust boundaries of the North-Gemeric Terrane.

1. Variscan Terranes

Klátov Terrane (5)

Stratigraphy

The Klátov T. represents a complex of amphibolite facies rocks of oceanic crust affinity, pre-Westphalian in age, as they were reworked within the Westphalian conglomerates (ROZLOŽNÍK 1965; VOZÁROVÁ 1973).

Radiometric data support the Variscan age of metamorphism (380-280 Ma, K/Ar: CAMBEL et al. 1980; 320-281 Ma, K/Ar: KANTOR et al. 1981). In addition, some data from amphibolites yielded 391-448 Ma (K/Ar: KANTOR 1980). Due to this wide variability of data, specific radiometric research should be attempted in order to ascertain the more precise age of the metamorphism.

The Klátov T. consists mostly of amphibolites accompanied by serpentinized spinel peridotites (only antigorite serpentinites and their hydrothermal - metasomatic derivates have been found), gneisses, rare marbles and Ca-silicate rocks (SPIŠIAK et al. 1985). The Klátov T. was penetrated by veins of plagiaplites. Fragments of these rocks are often found in Westphalian conglo-merates together with pebbles of tonalite and trondhjemite magmatites (VOZÁROVÁ 1973).

Ultramafic rocks and metabasalts of the Klátov T. are con-sidered to be a part of a dismembered ophiolite suite (HOVORKA & IVAN, 1985). Amphibolites are geochemically close to N-MORB basalts (IVAN 1992). The Klátov T. rock complexes represent an ancient subducted oceanic crust with fragments of lower crust of an island arc (VOZÁROVÁ 1993b; IVAN 1994). The finds of regressive overprinted eclogitic rocks (HOVORKA et al. 1994) allow to assume a previous high-pressure event.

Deformational and metamorphic events

The rocks complexes of the Klátov T. underwent metamorphism under higher-temperature amphibolite facies (T= 520-630 C , P= 4-6 MPa) and part of them even eclogite facies conditions, and subsequently, greenschist-facies retrograde alterations. The prograde as well as retrograde metamorphic stages are pre-Westphalian because both kinds of metamorphic mineral assemblages were determined in gneiss and amphibolites pebbles of the Westphalian conglomerates (VOZÁROVÁ 1993b).

The whole gneiss-amphibolite complex is overprinted by Alpine deformation and shear metamorphism reaching max. greenschist facies along the Alpine thrust and shear zone.

Plutonic igneous intrusions

Evidence of the presence of tholeiitic-series magmatites.

Rakovec Terrane (6)

Stratigraphy

The Rakovec T. consists of rock sequences of the Rakovec and Črmeľ Groups. The Rakovec Group is composed mainly of basic metavolcanoclastics, accompanied by tholeiitic basalts and small amounts of intermediary and acid volcanics. The bulk composition and REE contents of the Rakovec Group metabasalts suggest primary island arc tholeiites (BAJANÍK 1981) or E-MORB/OIT basalts (IVAN et al. 1992). Only small amounts of metapelites, fine-grained metasandstones and lenticular interlayers of carbonatic rocks or cherts occur here. The predominant tholeiitic metabasalts and metavolcanoclastics suggest for the Rakovec Gr. an ensimatic island arc setting, having originated probably on back-arc oceanic crust. The Rakovec Group is biostratigraphically undated. The pre-Westphalian age of the protoliths as well as of metamorphism is documented by the occurrence of pebbles in Westphalian conglomerates (VOZÁROVÁ 1973).

The Črmeľ Group was described as a sequence of alternating pelites, sandstones, basic volcanics and volcanoclastics, subsidiary acid volcanolastics, carbonates and lydites metamorphosed under low-grade conditions. The sequence has distinct sedimentary features of distal flysch. The Upper Tournaisian-Visean age is indicated by microflora (BAJANÍK et al. 1986). The predominant tholeiite, low-K metabasalts and the flysch-type sediments re-present probably the filling of a remnant basin (relics of marginal basin with ocean floor), which formed in the first stage of collision.

Deformational and metamorphic events

With regard to petrological data we may assume two Late Variscan metamorphic events: i) first, to the blueschist-facies transitional metamorphism (linked to subduction processes), which is documented by relics of Na-Ca amphiboles (HOVORKA et al. 1988) amidst actinolite crystals in metabasalts of the Rakovec Gr.; ii) second, corresponding to low-pressure greenschist facies conditions. It was estimated from analytical results based on b_0 geobarometry on K-white micas, which indicated a narrow thermal ran-ge of 350-370 °C at a relatively high metamorphic thermal gra-dient of approx. 40-45 °C/Km (SASSI & VOZÁROVÁ 1987, SASSI, R. & VOZÁROVÁ 1992).

Plutonic igneous intrusions

The Rakovec Terrane is pierced by small bodies of gabbrodiorite, gabbros and doleritic dykes, related to back-arc ophiolitic crust.

Time of docking

The docking of the Rakovec and the Klátov Terranes was pre-Carboniferous, connected probably to the Bretonian events as it is supported by the origin of the intrasuture Črmeľ flysch basin.

Spiš Composite Terrane (7)

The Klátov T. and Rakovec T. are inferred to have been amalgamated prior the Lower-Carboniferous (Bretonian events).

The Lower Carboniferous Ochtiná tectonostratigraphic unit was formerly described as an independent terrane (VOZÁROVÁ & VOZÁR 1992), due to its only tectonic contact to the hanging- and footwall. Coexistence with the Spiš Composite Terrane is documen-ted by affinity of the Ochtiná clastic material to the rock complexes of the Rakovec and Klátov Terranes.

The lower part of the Ochtiná tectonostratigraphic unit consists of flysch-like clastic sediments - metaconglomerates, metasandstones, metapelites, interlayered with basaltic metavolcanics and metavolcanoclastics. Deep-sea fans were derived from converging plate margins (intrasuture embayment) of a huge mass of detritus, among them pieces of oceanic and island arc crust. Slabs of ultramafic rocks indicated by antigorite serpentinites as well as granitoid detritus have been reported. The mechanism of their emplacement is connected with gravitational, mass flow sedimentary processes. The Tournaisian-Visean age of this part of the Ochtiná unit has been proved by microflora (BAJANÍK & PLANDEROVÁ 1985). The flysch sedimentation was gradually replaced by shallow-water, pelitic-carbonate facies of Upper Visean-Serpukhovian age (conodonts; KOZUR & MOCK & MOSTLER 1976).

Deformational and metamorphic events

The Lower Carboniferous sequences was deformed in the pre-Westphalian. The collision and crustal thickening processes gave rise to progressive regional low-pressure metamorphism of the Lower Carboniferous complexes but, on the other hand, the Rakovec sequences were mostly completely reworked under low-pressure conditions.

Time of docking

The docking of the Spiš Composite Terrane was the pre-Westphalian. During the continuing collision event the Lower Carbo-niferous flysch basins were closed. The initial stage of the perisutural basin began in the Westphalian A with coarse-clastic deposits of delta-fan type, associated in space with shallow-marine littoral and neritic environments. They cover the meta-morphosed complexes of the Spiš Composite Terrane with distinct unconformity. Termination of the existence of this basin, accompanied by its partial destruction, occurred during the Stephanian. The post-collision Permian sequences were adjusted by transform strike-slip movement and/or renewed rifting. They overlapped even weakly deformed and anchimetamorphosed sedimentary filling of the Westphalian peripheral basin.

2. Alpine History

During the Alpine cycle the Variscan Spiš Composite Terrane and its post-Variscan overstep sequences became a part of the passive continental margin. Direct provincial affinity to the North Gemeric Variscan basement seem to have, besides their overstep sequence, only the Lower Triassic evaporitic and shallow-marine clastic to carbonate formations. The Middle Triassic to Lower Jurassic (Stratená and Galmus Gr.), shallow-water sediments of epiplatform type are rather in tectonic position (part of the rootless Silica Nappe). However, it is more probable that this sequence is primary Mesozoic cover above the Spiš composite Terrane.

WC/4. SOUTH-GEMERIC TERRANE

The South-Gemeric Terrane contains the following structural levels:

1. Variscan Gelnica Terrane volcanogenic flysch sequences.
2. Upper Stephanian-Permian to Lower Triassic overstep sequences.
3. Post-Alpine overstep sequences.

TERRANE BOUNDARIES

The Gelnica Terrane is restricted by Alpine thrusts in the hanging - as well as in the footwall.

OVERSTEP SEQUENCES

1. Post-Variscan overstep sequence

Upper Stephanian-Permian to Lower Triassic volcano-sedimentary complexes characterized by a high content of mature mineralogical detritus related to transform/strike-slip setting. They reflect the initial stage of post-Variscan rifting. Filling relics of this basin are mostly represented by quartzose conglomerates and sandstones, associated with a lower amount of Ca-Alk rhyodacites and their volcanoclastics. They are resting with an unconformity on folded and metamorphosed Gelnica Terrane rocks. Sediments represent a continental, alluvial-lacustrine formation, which has a distinct cyclic structure and is passing upward into near-shore, lagoonal-sebkha facies. A characteristic feature is decreasing grain-size and also distinctly diminishing mineralogic maturity of sediments in the same direction.

2. Post-Alpine overstep sequences

They are represented by near-shore to continental Eocene-Oligocene sediments, relatively wide-spread Upper Miocene-Pliocene continental sediments and andesite volcanoclastics, as well as Pleistocene proluvial dirty gravels.

A. Variscan Terranes

Gelnica Terrane (8)

Stratigraphy

It consists of the Gelnica Group and the Štos Formation, latter formerly classified as a part of the North Gemeric Rakovec Group. Generally, the Gelnica Group consists of a thick flysch sequence comprising acid to intermediate volcanoclastics, with distinct features of turbidite currents and gravity mass flows (Ivanička et al. 1989). Dominant calc-alcaline volcanism was related to an active continental margin which testifies to rela-tively long-lasting subduction processes. Tholeiitic basalts with affinity to CAB, E- even N-MORB basalts occur subordinately as well (Bajaník 1981, Ivan 1992). The proximity of an active con-tinental margin is documented by a huge mass of chemically mature terrigenous sediments, mixed with continental margin arc-related rhyolite-dacite volcanoclastic material.

The relatively ?long-lasting subduction processes are proved by biostratigraphical data: according to palynomorphs and acri-tarchs the age of the Gelnica Group is Upper Cambrian - Lower Devonian (Ivanička et al. 1989, Snopková & Snopko 1979). U, Pb isotope data of zircons from metavolcanoclastics confirm a wide range of their ages: $^{207}Pb/^{206}Pb$: 392 - 577 Ma, $^{207}Pb/^{235}U$: 392 - 573 Ma, $^{206}Pb/^{238}U$: 391 - 497 Ma (Cambel et al. 1977, Ščerbak et al. 1988). A Proterozoic age of continental source is indicated by U/Pb zircon data from metasediments, ranging between 651 and 940 Ma (Cambel et al. 1977).

The Štós Frm. consists of a rhythmical sequence of metapelites and metasandstones with only scarce occurrences of small metabasalt bodies. In spite of its tectonic position above the uppermost part of the Gelnica Gr. complexes it comprises the same provenance types of detrital material as the previous one. The age of the Štós Frm. has not been biostratigraphically dated.

Data provided by distribution of flysch facies, petrofacial analysis of metasandstones, heavy mineral assemblages and zircon typology as well as bulk chemical composition and REE pattern of metavolcanics make it possible to interpret the Gelnica Terrane rock complexes as a forearc basin setting associated with an active continental margin.

Deformational and metamorphic event

The age of the Gelnica Terrane regional metamorphism has not been confirmed by radiometric dating. Geological evidence suggests a pre-Permian age as its fragments are found in the overlying continental molasse formation whose basal part was palynologically dated as Upper Stephanian-Autunian (Planderová 1980). These data do not rule out the possibility that the tectonometamorphic processes are of intra-Carboniferous, pre- or post-Westphalian age.

The grade of metamorphism reaches the lower part of low-pressure greenschist facies. Diffractometric muscovite b_0 values suggest a fairly narrow temperature range of 350-370 °C at a pressure of about 2-3 kbar. This signals a rather high geothermal gradient during the climax of metamorphism - 40°C/km (Sassi & Vozárová 1987, Mazzoli & Vozárová 1989). Early Paleozoic rocks of the Gelnica Terrane have been isoclinally folded with an axial planar cleavage.

Plutonic igneous intrusions

The Gelnica Terrane was intruded by leucocratic granite whose radiometric ages are very contrasting. Rb/Sr whole-rock ages give 346 Ma and 282-224 Ma and subordinately 159-144 Ma (KOVACH et al. 1986, CAMBEL et al. 1989). The only Alpine ages were proved by K/Ar muscovite - 141 Ma and K/Ar biotite - 132 and 97 Ma (KANTOR & RYBÁR 1979). According to petrological data it exhibits marks of syn-collision, S-type granitoids (HOVORKA & PETRÍK 1992). Rb/Sr whole-rocks ages are probably mixed and they reflect the age of protolith. A better understanding of the plutonic igneous activity in the Gelnica Terrane requires further geochronological radiometric research. Strong effort is necessary in order to cla-rify whether the age values belong to two magmatic events or not.

Time of docking

The Carboniferous-Permian time of docking of the Gelnica Terrane with the Spiš Composite Terrane has not been proved with satisfaction till now. The main reason is: - completely different the Late Variscan development in both areas; - insufficient radiometric dating of stitching granitoids, which are situated in the contact between them (Hnilec area). Further radiometric data are necessary to confirm or contradict the Variscan age of these stitching magmatites. Time of docking of the Gelnica Terrane with a more southern zone of Variscan range (Bükkium T.?) can be inferred from the break of sedimentation and absence of the Middle Carboniferous marine molasse. Most probably it could take place during the Moscovian.

B. Alpine History

The Mesozoic cover of the Variscan Gelnica Terrane is unknown due to its tectonic removal during the Alpine orogeny. Only Lower Triassic lagoonal-sabkha facies developed continuously from Permian "Verrucano" type sediments have been preserved.

Deformational and metamorphic events

The Alpine metamorphic history reached from the anchizone to lower greenschist facies, as ascertained from metamorphic mineral assemblages in the Permian and Lower Triassic sediments. Concerning the Alpine overprint of Variscan rock complexes, affected were mainly rocks along strike-slip faults, overthrusts and shear zones.

Plutonic igneous intrusions

The wide-spread intra-crustal shearing reflected collision events which took place in the Lower Cretaceous and caused most probably reheating or even a syn-collisional magmatic event (Rb/Sr whole rocks: 149-159 Ma, KOVACH et al. 1989, loc. Dlhá dolina valley, Podsúľová).

Time of docking

The time of docking of the Gelnica Terrane with the Szendrö-Bükk subunit is indicated by closing of the Meliata oceanic trough and succeeding crustal thrusting during the Upper Jurassic/Lower Cretaceous.

WC/5. MELIATA TERRANE

The Meliata Terrane can be described as a disrupted terrane, represented by HP/LT active continental and oceanic slivers, as well as by the thrust-outliers of the Middle/Upper Jurassic olistostromatic accretion prism sequences. All these units contain evidence of closing of the Meliata oceanic domain, following the Permian? - Middle Triassic rifting and opening of the Meliata ocean.

TERRANE BOUNDARIES

The Meliata Terrane is bounded by Alpine thrusts. It is sand wiched between the South-Gemeric (below) and the Silica (above) Terranes.

OVERSTEP SEQUENCES

The post-Alpine overstep sequences are represented by near-shore to continental Eocene-Oligocene sediments, as well as Upper Miocene-Pliocene sediments and volcanoclastics.

Bôrka Nappe

Stratigraphy

The most distinct features of the Bôrka Nappe rock complexes are: 1. Alpine high-pressure metamorphism which affected rocks of diferent stratigraphic horizons; 2. Presence of metabasalts with ophiolitic affinity; 3. Thrust outlier position above different parts of the South Gemeric Variscan basement or its Permian-Lower Triassic overstep sequence and below overthrust mass of the Silica and Turňa Nappes.

The Bôrka Nappe comprises a deformed complex of metasediments and metavolcanics with distinct foliation, crenulation cleavage and stretching lineation. The whole sequence consists of several lithostratigraphic units, each of which shows very specific lithological features (in MELLO et al. 1992). Phyllites, meta-sandstones, metaconglomerates with lesser amouts of metarhyo-lites and their metavolcanoclastics as well as thrust outliers composed predominantly of products of acid volcanism are supposed to be Permian in age. This assumption is supported by similarity of their lithologic composition to the authochtonous South Gemeric Permian deposits. The most characteristic lithostratigraphic unit of the Bôrka Nappe is the horizon of metabasalts and associated metavolcanoclastics which are gradually connected with white marbles in the underlier and rhythmic metapelites, metasandstones in the overlier. The stratigraphic range of this complex is assumed to be Upper Triassic-Lower Jurassic ? (without any biostratigraphic data). According to bulk chemical composition, trace element distribution as well as REE pattern, the Bôrka Nappe metabasalts show affinity to N-MORB, ocean floor and/or within-plate basalts.

Meliata Unit

Stratigraphy

The Meliata Unit on the territory of the Western Carpathians is known as: 1. blocks tectonically reworked into the basal melange of the Silica Nappe; 2. rootles thrust outliers of the Upper Jurassic olistostromatic sequences. They are tectonically overridden by the Silica and Turňa rock complexes.

The salinar melange consists of Lower Triassic marly shales with blocks of serpentinites (HOVORKA & ZLOCHA 1974; HOVORKA 1985). Their size ranges from 10 m to several 100 m or even km^2 below the Tertiary filling of the Košická nížina Lowland (PLANČÁR et al. 1977). The Middle/Upper Jurassic olisthostromatic formations contain fragments of Anisian platform carbonates, red Ladinian radiolarites (DUMITRICA & MELLO 1982) as well as fragments of oceanic basalts and deep-water sedimentary rocks. Single ?olistoliths are situated amidst Middle/Upper Jurassic black shales (MELLO et al. 1975; MOCK et al. 1993). In addition to oceanic basalt olistolite, a horizon of coarse-grained polymict breccias with redeposited rhyolitic clasts as well as acid volcanoclastic turbidites were described from the borehole BRU-1 (VOZÁROVÁ & VOZÁR 1992). Radiolarites from associated siliceous shales proved Callovian-Oxfordian *age (Eucyrtidellum unumaensis*, Yao 1979; ONDREJIČKOVÁ 1992). This acid volcanic detritus might be related to a hypothetic island arc, assumed by KOZUR (1991).

DEFORMATIONAL AND METAMORPHIC EVENTS

Incompletely preserved sequences of the Bôrka Nappe underwent high-pressure metamorphism due to subduction-accretion processes during the Upper Jurassic orogeny (REICHWALDER et al. 1995; FARYAD 1995; VOZÁROVÁ & MAZZOLI in prep.). The age of metamorphism has been proved by Ar/Ar method from fengite (155 Ma, MALUSKI et al. 1993; 150 - 165 Ma, FARYAD & HENJES-KUNST 1995). P-T conditions estimated for the peak of metamorphism are 400-450 °C, pressures 10-12 kbar, at metamorphic thermal gradient of approx. 10 °C/Km. The same pressure character has been confirmed by means of b cell dimension of muscovites (MAZZOLI et al. 1992). Slices of rock complexes with mineral assemblages corresponding to the transitional greenschist/blueschist facies have been also ascertained. Petrological analysis indicates P-T paths produced by crustal thickening model, in which, after early blueschist facies, metamorphism continued by fairly isobaric thermal relaxation and then rapid uplift.

Low temperature part of anchizone (250-300 °C), transitional low/medium pressure type is characteristic for rock complexes of the Meliaticum (ARKAI in ARKAI & KOVÁCS 1986). They reached a low stage of deformation, except for crushed zones. Rigid rocks, mainly basalts and coarse-grained breccias, do not show any signs of cleavage. The dark shales are plastic-deformed.

Time is docking

Time of docking of the South-Gemeric Terrane with the southern continental margin of the Meliata Ocean is determined on the basis of the age of high-pressure metamorphism related to Late Jurassic subduction-accretion events. The following was a subsequent uplift due to extension of an overthickened accretionary wedge (REICHWALDER et al. 1995).

Further history was connected with nappe emplacement during Middle Cretaceous events.

WC/6. SILICA TERRANE

The Silica Terrane represents fragments of disappeared continental block, originally situated to the south of the Meliata ocean. It is composed of thrust-outliers of the Middle Carboniferous flysch as well as rift-related Permian red-beds and evaporites, following by shalow-water carbonate deposition.

The shallow-water Middle Anisian carbonate ramp was disrupted with beginning of the opening of the Meliata oceanic domain. There were deposited shelf/slope and deep water facies, mainly in the Jurassic (DUMITRICA, MELLO 1982). In the Hungarian part (the Bodva Unit) are known acid volcanics, which seem to represented the volcanic arc developed above the Meliata subduction zone (KUBOVICS et al. 1990). Evidence about this volcanic activity was found also inside of the Upper Jurassic olistostrome of the Meliata Unit (borehole BRU-1; VOZÁROVÁ & VOZÁR 1992).

TERRANE BOUNDARIES

The Silica Terrane is separated by basal thrusts in the hanging-, as well as in the footwall.

OVERSTEP SEQUENCES

The Upper Cretaceous continental overstep sediments were described by MELLO & SNOPKOVÁ (1973). Redeposited Upper Cretaceous sporomorphs (SNOPKOVÁ in VASS et al. 1982) as well as pebbles of Upper Cretaceous carbonates were found in the Eocen-Oligocene conglomerates (VASS et al. 1994).

For further post-Alpine overstep sediments see Meliata Terrane.

Turňa Unit

Stratigraphy

On Slovak territory this unit contains:
1. Olistostrome, flysch sediments of Bashkirian age;
2. Continental to evaporitic Permian sequences;
3. Basin facies of marbles, calcareous slates, allodapic limestones and sandstones mostly of Middle to Upper Triassic age.

The Middle Carboniferous flysch sequence (borehole BRU-1, VOZÁROVÁ & VOZÁR 1992) contains a horizon of carbonate olisto-strome with conodont fauna corresponding to the Idiognathoides zone (EBNER et al. 1990). This lithostratigraphic unit (Turiec Form., VOZÁROVÁ 1992) was compared with South Alpine type Carboniferous flysch facies, as it is known from Szendrö and Karawanken - South Alpine mountain ranges. The coeval Western Carpathian Middle Carboniferous sediments represent the post-orogenic, marine molasse stage. The Permian continental red-bed deposits overlapped with unconformity the Middle Carboniferous flysch sediments. The Upper Permian - Lower Triassic horizon is characterised by evaporitic sedimentation, which had features of rifting processes (redeposited evaporite clasts, intraformational breccias). Sedimentation from the Middle-Late Anisian till the Late Norian took place in basinal conditions. Black shales with layers of allodapic limestones interrupted the carbonate sedimentation in the Carnian. Carbonates deposited after this event are rich in cherts (for more details see MELLO et al. 1992).

Deformational and metamorphic events

The Middle Carboniferous metasediments underwent low-pressure greenschist facies metamorphism. The geobarometric estimation based on b_0 values of muscovites proved the low-pressure of about 2-3 kbar at a temperature of max. 350-370 °C (MAZZOLI & VOZÁROVÁ 1989).

The Variscan age of metamorphism is assumed on the basis of phyllite fragments in the overlying Permian conglomerates. Distinct metamorphic foliation is cut by younger cleavage, the age of which is most probably Alpine. Parallely to this cleavage there crystallized columnar porphyroblast of chloritoids.

Based on IC-averages from Mesozoic rocks, P-T conditions of Alpine metamorphism correspond to the boundary of anchi- and epizone (T about 300°) at the transition between medium and higher pressure (ARKAI in ARKAI & KOVÁCS 1986).

Silica Unit

Stratigraphy

The non- or slightly metamorphosed Mesozoic sequence in the stratigraphic range of Lower Triassic to Lower Jurassic builds large karstic plateaus on the Slovak territory. According to MELLO (in BAJANÍK et al. 1983, in MELLO et al. 1992), the Lower Triassic is represented by variegated sandy-shaly sediments, yellow and grey carbonate shales and graywackes. In the Middle Triassic, mainly in the Anisian, epiplatform carbonates are predominant. During the Ladinian and mainly the Upper Triassic, rifting was replaced by sediments of an unstable shelf, alter-nating with zones of hemipelagic sedimentation (cherty lime-stones). Lower Jurassic sediments, preserved rudimentally only, are represented by Liassic-Doggerian spotty marls and in some places by red, pelagic limestones overlain by Callovian-Oxfordian radiolarites (DUMITRICA & MELLO 1982).

Deformational and metamorphic event

The Silica Unit is in upper plate position, mostly non-metamorphosed or reaching only diagenetic recrystallization. Based on C averages, the regional transformation of the Silica rock complexes corresponds only to medium- or late-diagenetic stages (temperatures did not reach 200°C).

The structure of the Silica Unit is formed by flat, mesoscale synclines and anticlines, with imbrications on their limb. These imbrications show northern vergency (HÓK et al. 1995). The emplacement of Silica Unit onto the Turňa Unit with the Middle Carboniferous flysch sequence as well as onto the obducted ophiolites of the Meliata Unit and the HP/LT Bôrka Nappe complexes took place in the Lower Cretaceous, subsequently to the closure of the Meliatic oceanic basin. Senonian karstic dolina filling with remnants of plants (MELLO & SNOPKOVÁ 1973) seems to date this emplacement.

Time of docking

The time of docking of the Silica Terrane with the Meliata Terrane is indicated by the age of the Senonian overstep sequence (MELLO & SNOPKOVÁ 1973).

Conclusion

In agreement with the concept and the objectives of the IGCP Project No. 276 "Paleozoic geodynamic domains and their alpidic evolution in the Tethys", the analysis of terrains of the Western Carpathian-Northern Pannonian territory has been focused to characterise the development during the Variscan stage.

As postulated in the IGCP 276 Project, a brief outline of the Mesozoic and Tertiary overstep sequences has been made in order to construct the map of Variscan terrains, observed in the Alpine structures. All the findings of both authors have been used to construct the map of the Variscan terrains at a scale 1:2, 500 000, part Western Carpathians, presented by EBNER et al. in 1995 at the XV. Congress of the CBGA in Athens.

The co-operation in the construction of the map allowed for a co-ordinated plotting of the geological boundaries, or links between the geological units across national boundaries, so that the units with dominant standing in Austria (southern Penninicum - Rechnitz, Upper Austroalpine U. - Graz-Paleozoicum), or in Hungary (Bükkium - Pelsómegaunit, or Tisza megaunit, with continuation into the Pre-Tertiary basement in the Eastern Slovakia) could be characterised in detail in the explanations, edited by the authors: Ebner, Neubauer (Eastern Alps), or Kovács et al. (Hungary). This is why we did not address these units in our study and we refer to the papers of the above mentioned authors.

The correlation of delineated dominant Western Carpathian units with the Eastern Alps suggests that:

- Flysch zone and the Klippen belt are well correlable with the corresponding units in the Alps, in particular, the Flysch zone of the Western Carpathians corresponds with the Northern Penninicum
- The Tatricum can be correlated with the Lower Austroalpine
- The Veporicum, including its nappe units, derived from this zone, correlates with the Middle Austroalpine Units.
- The Upper Austroalpine Units can be correlated with the Hronicum, Gemericum and Silicicum Units of the Western Carpathians.

A particular standing has the Meliaticum Unit, represented in the Eastern Alps by a complicated scaly zone, located in the footwall of theMesozoic of Upper Austroalpine Units. A more complex evidence concerning the Meliaticum Unit are available in Hungary, with a proven continuation into the Vardar Zone.

The units assigned to the innermost part of the Western Carpathians due to particularities in their development (the Silica and the Turňa Nappes), have been formed as north vergent nappe units and they can evidently be linked with the Bükkium Unit, in their root zones.

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STUDY OF GEOLOGY AT THE FACULTY OF NATURAL SCIENCES COMENIUS UNIVERSITY BRATISLAVA, SLOVAK REPUBLIC

Comenius University is the oldest and largest university in Slovakia. It follows the university tradition of the Academia Istropolitana, one of the oldest university in Central Europe, established in 1467.

The Faculty of Natural Sciences is the second largest faculty of Comenius University. It is divided into five sections: Biological section, Chemical section, Environmental section, Geographical section and Geological section.

GEOLOGICAL SECTION - DEPARTMENTS

- *Applied and Environmental Geophysics*
- *Engineering Geology*
- *Geology of Mineral Deposits*
- *Geology and Paleontology*
- *Hydrogeology*
- *Mineralogy and Petrology*
- *Institute of Geology*
- *Geochemistry (Environmental section)*

Studies in Geology comprise an initial three-year program leading to the Bachelor's degree in various majors, which may be followed by a two-year program of further study leading to a Master's degree. For most students, study takes five years and a Master's degree is a prerequisite for entry to the program of postgraduate study, which takes three to four years, and leads to a Doctor's degree. As a rule, courses are conducted in Slovak. However, several study programs, at all three levels, are offered in English.

The five-years study is at present provided in five basic study branches which are listed below subdivided into several specializations.

— GEOLOGY and MINERAL DEPOSITS
— GEOCHEMISTRY
— ENGINEERING GEOLOGY and HYDROGEOLOGY
— APPLIED and ENVIRONMENTAL GEOPHYSICS
— ENVIRONMENTAL GEOLOGY

The study of geological science provides an excellent basis for a professional career in any area of Geoscience, particularly in geological survey, geological exploration of metallic and non-metallic raw-materials, petroleum geology, hydrogeological exploration, engineering geology and civil engineering, water and environment management.

The Bachelor's and Master's program in Geology provides a strong background for those who intend to extend their studies (at the postgraduate level) in any geological specialization - either at Comenius University in Bratislava, or at other European or overseas universities.

The postgraduate level program at Comenius University consists, in part, of lectures, seminars and practical classes, but the emphasis is laid on tutorials and on project work under the guidance of an experienced supervisor. The Geology program makes it possible to select from the following branches of Geological Science:

- Geology and Paleontology
- Mineralogy, Petrology and Geochemistry
- Geology of Mineral Deposits
- Hydrogeology
- Engineering Geology
- Applied Geophysics

The Faculty of Natural Science is situated in campus in Mlynská dolina, a pleasant part of Bratislava, not far from the Danube. The campus consists of five Faculty buildings and student hostels, where about 80 % of students are housed. In campus, the Faculty provides full teaching facilities, together with a wealth of cultural, social and sport opportunities for students and staff. The Faculty enjoy a high degree of independence and autonomy, is chaired by Dean and governed by the Faculty Academic Senate.

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