SLOVAK GEOLOGICAL MAGAZINE

VOLUME 10 NO 4 ISSN 1335-096X

Geological Survey of Slovak Republic, Bratislava
Dionýz Štúr Publishers

4/2004

ISSN 1335-096X

SLOVAK GEOLOGICAL MAGAZINE

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

- **regional geology and geological maps**
- **lithology and stratigraphy**
- **petrology and mineralogy**
- **paleontology**
- **geochemistry and isotope geology**
- **geophysics and deep structure**
- **geology of deposits and metallogeny**
- **tectonics and structural geology**
- **hydrogeology and geothermal energy**
- **environmental geochemistry**
- **engineering geology and geotechnology**
- **geological factors of the environment**
- **petroarcheology**

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

Managing Editor: Gabriela Šipošová
Address of the publishers: Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovakia
Printed at: ALFAPRINT Martin
Price of single issue: USD12
Annual subscription ... the postage

SLOVAK GEOLOGICAL MAGAZINE

VOLUME 10 NO 4

ISSN 1335-096X

Geological Survey of Slovak Republic, Bratislava
Dionýz Štúr Publishers

4/2004

Slovak Geol. Mag., 10, 4 (2004), 241 – 262

Beňatina Klippe – lithostratigraphy, biostratigraphy, palaeontology of the Jurassic and Lower Cretaceous deposits (Pieniny Klippen Belt, Western Carpathians, Slovakia)

JÁN SCHLÖGL[1], MILOŠ RAKÚS[2], MICHAŁ KROBICKI[3], BRONISŁAW ANDRZEJ MATYJA[4], ANDRZEJ WIERZBOWSKI[4], ROMAN AUBRECHT[1], VILIAM SITÁR[1] and ŠTEFAN JÓZSA[1]

[1]Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina - G, SK-842 15 Bratislava, Slovakia, e-mail: schlogl@nic.fns.uniba.sk, aubrecht@nic.fns.uniba.sk
[2]Geological Survey of Slovak Republic, Mlynská dolina 1, SK-817 04 Bratislava, Slovakia, e-mail: rakus@gssr.sk
[3]University of Mining and Metallurgy, Department of Stratigraphy and Regional Geology, Al. Mickiewicza 30, PL-30-059 Kraków, Poland, e-mail: krobicki@geol.agh.edu.pl
[4]Institute of Geology, University of Warsaw, Al. Żwirki i Wigury 93, 02-089 Warszawa, Poland, e-mail: Matyja@uw.edu.pl; Andrzej.Wierzbowski@uw.edu.pl

Abstract. An abandoned quarry at Beňatina Klippe in the Pieniny Klippen Belt in eastern Slovakia shows the complete succession of Lower Jurassic to Upper Jurassic (Oxfordian) deposits well dated by ammonite faunas. The Lower Jurassic includes: sandstones and sandy marls (Dolný Mlyn Fm., ?Hettangian - Early Sinemurian), spotty limestones and marls (Allgäu Fm., Late Sinemurian – Late Domerian), glauconitic sandstones nad marlstones (Hôrka Fm. - new formation, Late Domerian), red marls (Hŕbok Marl Fm. – new formation, Toarcian). The Middle Jurassic part of the succession comprises thick crinoidal limestone formation (Aalenian - Bajocian) informally subdivided into three members: Member A - alternation of marly crinoidal limestones and grey marls, Member B - reddish crinoidal limestones, partly nodular, with intercalations of red nodular micritic limestones and cherts, Member C - greenish and grey crinoidal limestones with black cherts. These deposits are abruptly overlain along a marked ommission surface by pelagic ammonitico-rosso type limestones of the Czorsztyn Limestone Fm. (Late Bajocian – Oxfordian). The limestones are developed as filamentous microfacies of the latest Bajocian to early Bathonian age and followed by the *Globuligerina* microfacies yielding ammonites of Oxfordian age.

The Lower Cretaceous part of the succession corresponds to the Nižná Fm. It consists of various deposits such as crinoidal limestones, synsedimentary limestone breccia and marls containing abundant organodetrital material of the Urgonian shallow-water carbonate platform origin.

The succession of the Beňatina Klippe differs from typical successions of the Pieniny Klippen Basin. It may be interpreted either as a variety of the Czorsztyn Succession, and thus located in the northern part of the basin, or even as succession deposited at southern margin of the Pieniny Klippen Basin. Some ammonites of Early Jurassic to early Middle Jurassic so far poorly known from the West Carpathians are described in the palaeontological part of the paper. These include representatives of Lytoceratidae (*Alocolytoceras*), Arietitidae (*Coroniceras*), Hildoceratidae (*Frechiella*) and Graphoceratidae (*Ludwigia*, *Graphoceras*, *Brasilia*).

Key words: Jurassic, Western Carpathians, Pieniny Klippen Belt, Lower Cretaceous, ammonites

Introduction

Latest geological research in Eastern Slovakian part of the Pieniny Klippen Belt (PKB) brought new and important information on lithostratigraphic variability, paleontology and biostratigraphy of the Jurassic and Early Cretaceous deposits of this complex zone. The area of the PKB was affected by two tectonic phases which caused its breakage into separated "klippen", completely detached from their basement and from the neigbouring units as well. Therefore, the palaeogeographic reconstructions are based on the facies development of the individual klippen. Importance of the studied Beňatina Klippe lies in several levels. The locality represents one of the rare places with well preserved Liassic deposits. Moreover, some lithostratigraphic units in this klippe are new or show development different from that of the classic sections. The deposits exposed at Beňatina Klippe are rather highly fossiliferous, enabling their detailed biostratigraphic interpretation. In addition, the Middle Jurassic ammonite fauna occurring here shows a presence of some exotic South-Tethyan taxa, until now completely unknown from the Alpine-Carpathian areas (Schlögl & Rakús, in press).

The Beňatina Klippe belongs to the easternmost Slovak part of the Pieniny Klippen Belt (Fig. 1), situated on the NE edge of the Vihorlat Mountains, between the Diel Stratovolcano to the West and the Popriečny Stratovolcano to the East. These consist of young, Neogene volcanics which cover Jurassic-Cretaceous klippen of the PKB, except those in the vicinity of the villages Podhoroď and Beňatina. Almost all the deposits exposed in the klippen have been treated as belonging to the Czorsztyn Succession, with overall stratigraphic range in

Geological Survey of Slovak Republic, Dionýz Štúr Publisher, Bratislava 2004 ISSN 1335-96X

Slovak Geol. Mag., 10, 4 (2004), 241 – 262

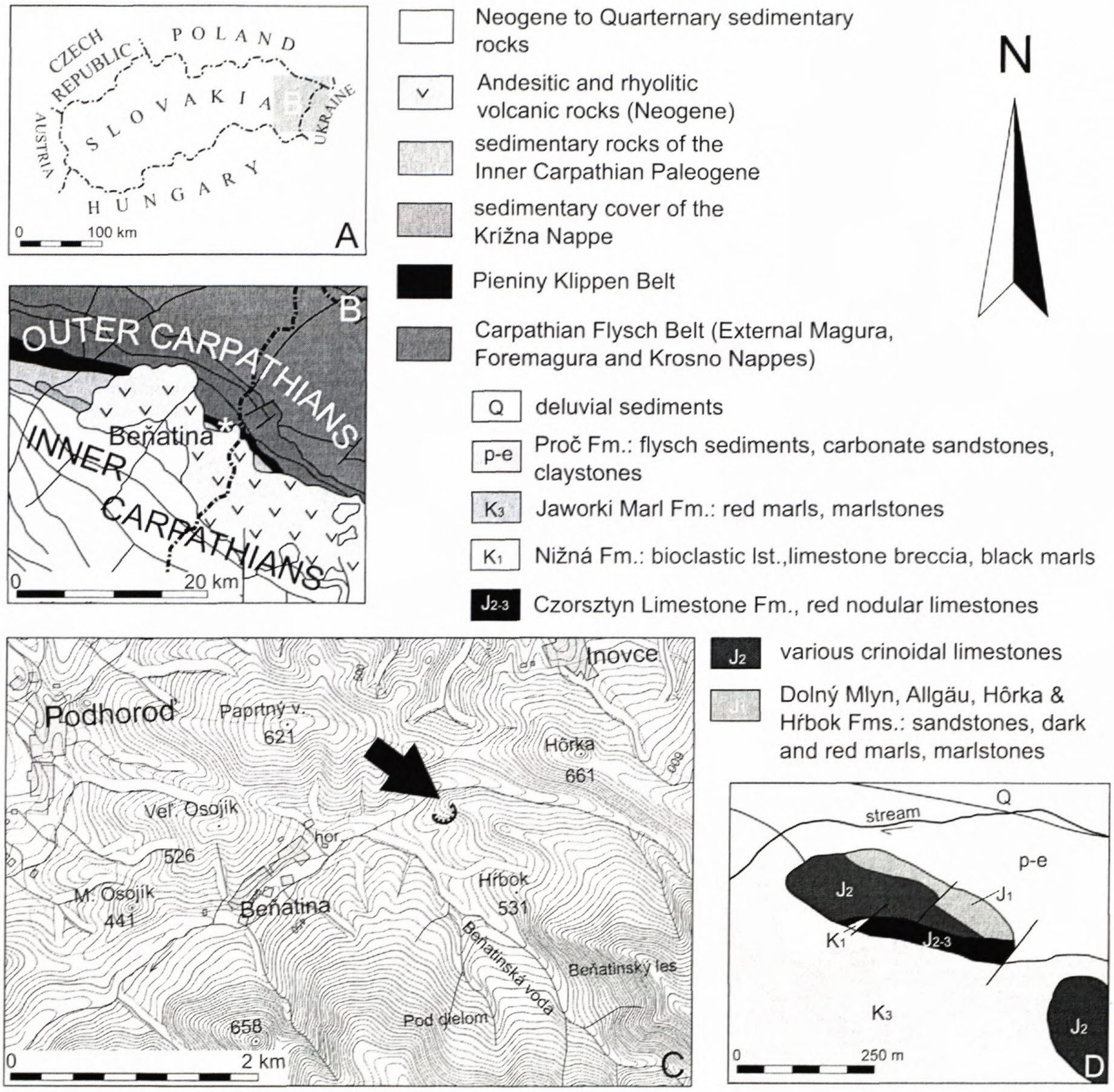


Fig. 1. Geographical and geological setting of the Beňatina klippe. A, C. Geographical position of the area of study (the quarry is arrowed). B. Geological sketch map of the eastern part of PKB and adjacent areas. D. Simplified geological map of the Beňatina klippe (after the manuscript of M. R.).

the studied area from the Hettangian to the Late Maastrichtian (Rakús & Potfaj, 1997). Three sections have been studied by the present authors in the Jurassic part of the succession in the quarry worked of the Beňatina Klippe: one in the northeastern part of the quarry (Fig. 2, denoted here as Section I, see also Figs 4.1-2), another in the western part of the quarry (Fig. 2, denoted as Section II), and the third in the southeastern part (Fig. 2, denoted as Section III). Moreover the Lower Cretaceous deposits were studied in the southwestern part of the quarry (Fig. 3 and Fig. 6.1, denoted as Section IV), but their relation to the deposits from Sections I-III is somewhat unclear.

Lithostratigraphic succession at the Beňatina quarry

Dolný Mlyn Formation

This formation was formerly well exposed in the upper northeastern part of the quarry (Fig. 4.1-2); recently, this face of the quarry is mostly obscured. Sandstones with thin intercalations of greenish marls prevail in the lower part of the formation. At the base there is 3 to 5 metres thick complex of light grey (brown on weathered surfaces) thin-bedded (layers to 10 cm), fine-grained sandstones and greenish sandy marls (Fig. 2). Sandstone "concretions" with limonitic crusts occur in thicker layers. Towards the top, the sandstones become more calcareous. They are commonly rich in opaque Fe cement. The sand grains are mostly represented by quartz, with very rare glauconitic grains, biotite scales and tiny echinoderm ossicles (Fig. 5.1). The sand is of nearly uniform size and very well sorted. The grains are subangular to angular. The opaque cement obviously migrated through the pore spaces subparallel with bedding and omitting more lithified parts of the sandstone. Locally, tiny elongated voids filled with chalcedony occur in the sediment.

The lower "sandstone" part is succeeded by dark-grey marls and marly limestones with coquina layers.

These are essentially represented by oysters (*Liogryphaea* layer, see section I). A 20 cm thick dark grey bioclastic limestone bed, lying directly below this coquina, yielded bivalves, gastropods, indeterminable fragments of arietitid ammonites and small clusters of serpulid tubes. A 20 cm thick dark grey marly limestone, lying above the *Liogryphaea* coquina, yielded a rich brachiopod fauna. It is bioturbated wackestone with irregular distribution of allochems. The matrix is partly recrystallized to peculiar microsparite with needle-shaped calcite crystals. These fibrous crystals locally perpendicularly overgrow some allochems. The allochems are represented by bivalve and brachiopod shell debris, agglutinated foraminifers *Ophthalmidium* sp., nodosariid foraminifers, less commonly - ostracods, echinoid spines and rarely - thin serpulid tubes. The sediment commonly contains framboids and seams of pyrite. Pyrite also locally infills the foraminiferal tests.

The upper part of the Dolný Mlyn Formation consists of a few metres thick complex of dark grey to black, more or less calcareous, slightly sandy marls with 10 to 35 cm thick layers of spotty marly limestones occuring mainly in its uppermost part (Fig. 2). These wackestones are rich in echinoderm ossicles, ostracods, fragments of juvenile bivalves, spicules, nodosariid foraminifers and plant fragments. Syngenetic pyrite is common, sometimes filling up the internal parts of ammonites.

Ammonite fauna was collected from the marly limestone beds from the uppermost part of the formation. It consists of arietitid taxa, such as *Coroniceras lyra* Hyatt or *C.* (*Paracoroniceras*) cf. *charlesi* Donovan and numerous *Arnioceras* sp. and *Arnioceras semicostatum* (Young & Bird) (*Arnioceras* are ex situ). Because of tectonics, the overall thickness of the formation cannot be measured.

Allgäu Formation

The overlying part of the sequence shows light-grey marly, sometimes spotty limestones alternating with grey-bluish to grey marls, called Allgäu Formation. Its overall thickness is not measurable, the uncovered part attains 14 metres. In the NE part of the quarry the formation is probably tectonicaly reduced (Fig. 2). Upper part of this formation is also visible at the entrance to the quarry, in its western part (Section II).

Macroscopic observations show that the sediment is spotted, i.e. bioturbated. This is not visible in the thin-sections. It is biomicrite, packstone with tiny detritus of mostly indeterminable allochems, which are mainly represented by sponge spicules, nodosariid foraminifers, echinoderm ossicles and tests of ostracods. Silty quartz admixture is present, too. Locally, seams and clusters of pyrite occur in the sediment.

Formation yielded numerous belemnite guards and ammonites: *Partschiceras* cf. *striatocostatum* (Meneghini), ?*Juraphyllites* sp., *Androgynoceras* sp., ?*Liparoceras* sp., *Pleuroceras* cf. *solare* (Phillips), *Pleuroceras* cf. *spinatum* (Bruguière), as well as badly preserved dactylioceratids such as ?*Reynesoceras* sp. and *Dactylioceras* sp. (cf. *D.* (*Orthodactylites*) *mirabilis* Fucini).

Hôrka Formation, new lithostratigraphic unit

Thin complex of greenish glauconitic sandstones, dark grey to greenish sandy-crinoidal limestones and glauconitic marlstones with intercalations of dark-green marls occurs between the underlying Allgaü Fm. and the overlying Hŕbok Marl Fm. (Fig. 2, Fig. 4.1-3). From the microfacies point of view they are biomicrites, wackestones to packstones with commonly occurring echinoderm ossicles, detritus of various bivalves (including thin-shelled "filaments"), ostracods, rare echinoid spines and nodosariid foraminifers. The rocks show the presence of the pressure seams with concentrated clay minerals and newly formed short fibrous calcite in the pressure shadows. Some layers (e.g. uppermost layer) are rich in juvenile ammonites. Ammonite shells are commonly geopetally filled. In some instances, these infillings do not correspond to each other which indicates some reworking of the sediment.

At the upper surfaces of the highest two beds there were found numerous Fe-oncoids and pyrite framboids, indicating stronger condensation and/or stratigraphic hiatus.

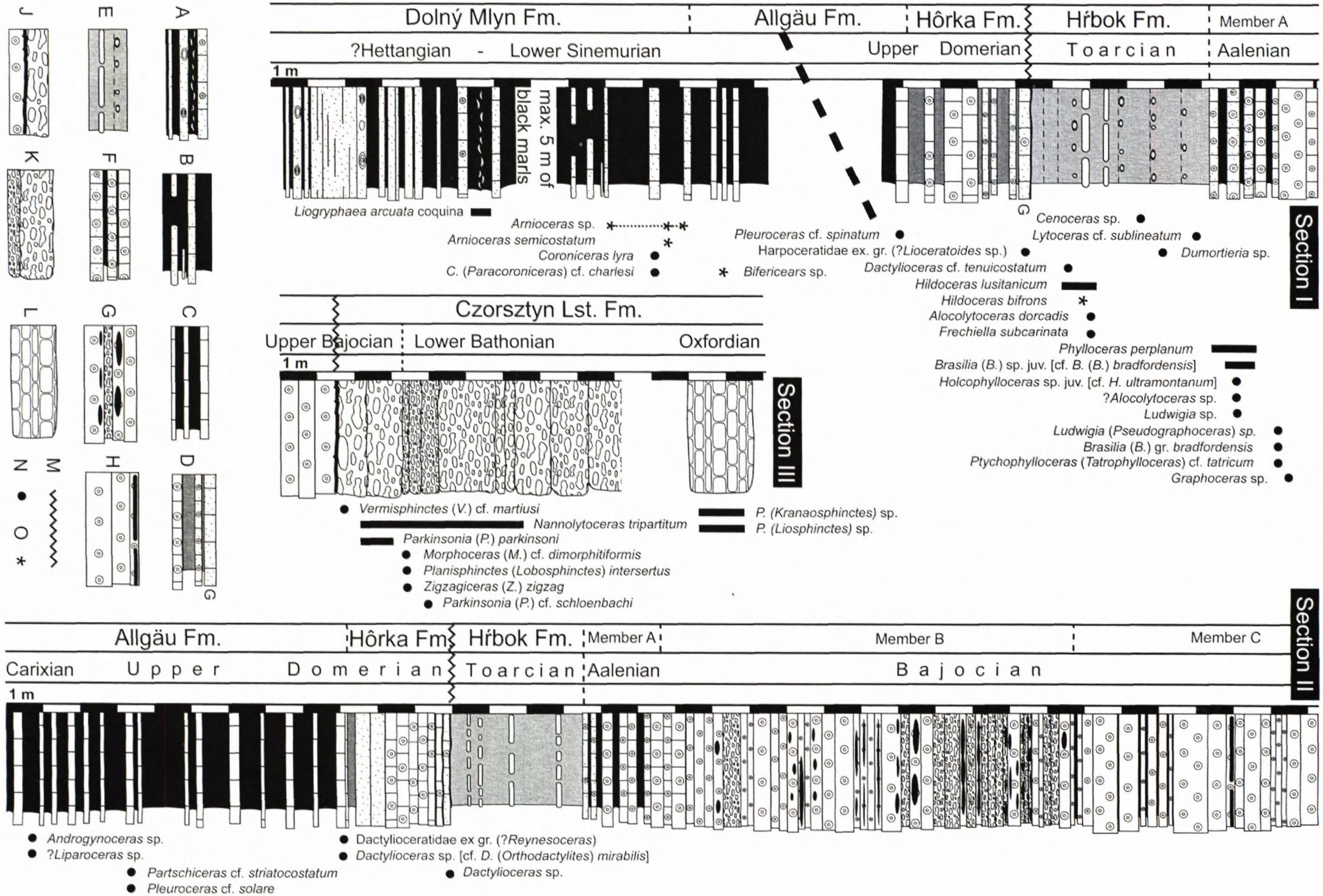
The formation yielded poor ammonite fauna including *Dactylioceras* sp. (cf. (*Orthdactylites*) *mirabilis* Fucini) and badly preserved fragment of an harpoceratid ammonite (*Lioceratoides*).

We introduce the name Hôrka Formation for this new lithological unit. The name is inferred from the hill Hôrka in the close neighbourhood of the Beňatina quarry (Fig. 1C). The overall thickness of the formation is 3.2 m in the section I. and 2.5 m in the section II.

Hŕbok Marl Formation, new lithostratigraphic unit

This striking new unit consists of red, locally laminated marls with aligned small concretions and rare thin intercalations of sandy marlstones up to 4 cm in thickness (Fig. 2). They represent biomicrites, wackestone to packstones (Fig. 5.3-8). Thin-shelled bivalves (*Bositra* sp.) dominate among the allochems (Fig. 5.5); moreover, there occur calcified sponge spicules, echinoderm ossicles, ostracodes, nodosariid foraminifers, *Lenticulina* sp., *Spirillina* sp., as well as the juvenile gastropods and fragments of the brachiopod shells. The allochems are often impregnated by Fe-Mn opaque minerals. A thin marlstone layer with abundant small ammonites has been observed in the lowermost part of the section (Fig. 5.8).

Some layers in the middle and upper part of the formation contain numerous small concretions (up to 3-4 cm in diameter) with Fe-Mn encrustations (Fig. 5.6). Round intraclasts of lithified sediment impregnated by Fe-Mn oxides form core of these concretions. Their impregnation is irregular; being more expressed at the margins, where the intraclasts are coated by thin microbial stromatolites. Inside the intraclast, the Fe-Mn impregnation is shown by irregular concentric seams. The sediment itself is represented by "filament" packstone to wackestone. Along with "filaments" (thin shells of *Bositra* sp.), the sediment contains common *Lenticulina* sp.,



Dolný Mlyn Fm.
Allgäu Fm.
Hôrka Fm.
Hŕbok Fm.
Member A
?Hettangian - Lower Sinemurian
Upper Domerian
Toarcian
Aalenian
1 m
max. 5 m of black marls
Liogryphaea arcuata coquina
Arnioceras sp.
Arnioceras semicostatum
Coroniceras lyra
C. (Paracoroniceras) cf. charlesi
Bifericears sp.
Pleuroceras cf. spinatum
Harpoceratidae ex. gr. (?Lioceratoides sp.)
Dactylioceras cf. tenuicostatum
Hildoceras lusitanicum
Hildoceras bifrons
Alocolytoceras dorcadis
Frechiella subcarinata
Cenoceras sp.
Lytoceras cf. sublineatum
Dumortieria sp.
Phylloceras perplanum
Brasilia (B.) sp. juv. [cf. B. (B.) bradfordensis]
Holcophylloceras sp. juv. [cf. H. ultramontanum]
?Alocolytoceras sp.
Ludwigia sp.
Ludwigia (Pseudographoceras) sp.
Brasilia (B.) gr. bradfordensis
Ptychophylloceras (Tatrophylloceras) cf. tatricum
Graphoceras sp.
Section I
Czorsztyn Lst. Fm.
Upper Bajocian
Lower Bathonian
Oxfordian
1 m
Section III
Vermisphinctes (V.) cf. martiusi
Nannolytoceras tripartitum
Parkinsonia (P.) parkinsoni
Morphoceras (M.) cf. dimorphitiformis
Planisphinctes (Lobosphinctes) intersertus
Zigzagiceras (Z.) zigzag
Parkinsonia (P.) cf. schloenbachi
P. (Kranaosphinctes) sp.
P. (Liosphinctes) sp.
A
B
C
D
E
F
G
H
J
K
L
M
N
G
Allgäu Fm.
Hôrka Fm.
Hŕbok Fm.
Member A
Member B
Member C
Section II
Carixian
Upper Domerian
Toarcian
Aalenian
Bajocian
1 m
Androgynoceras sp.
?Liparoceras sp.
Partschiceras cf. striatocostatum
Pleuroceras cf. solare
Dactylioceratidae ex gr. (?Reynesoceras)
Dactylioceras sp. [cf. D. (Orthodactylites) mirabilis]
Dactylioceras sp.

nodosariid foraminifers, shells of ostracods and rare echinoderm ossicles.

The macrofossils include fairly common belemnite guards, and rather rare ammonites. The lower part of the Hŕbok Marl Formation yielded several fragmented dactylioceratid ammonites, whereas its middle part yielded *Alocolytoceras dorcadis* (Meneghini), *Frechiella subcarinata* (Young & Bird), *Hildoceras bifrons* (Bruguière) and *Hildoceras lusitanicum* Meister. Rare fragments of grammoceratid ammonites, *Lytoceras* cf. *sublineatum* (Oppel) and *Cenoceras* sp. were collected from the upper part of the formation.

We introduce the name Hŕbok Marl Formation for this new lithological unit. The name is derived from the hill Hŕbok in the close neighbourhood of the Beňatina quarry. The formation reaches 5 m in thickness in the section I, but it is only 3.6 m thick in the section II.

Formation of variable crinoidal limestones

The main part of the sequence is built by huge mass of crinoidal limestones (40 m at least). On the base of their variable lithology we have distinguished three different crinoidal complexes (members) within this formation, developing gradually one from another (Fig. 4.1,4,6).

The lower part (Member A) is represented by alternations of light grey marly crinoidal limestones and grey marls, rich in crinoidal ossicles. They develop gradually from the underlying deposits of the Hŕbok Marl Fm. (Fig. 4.1-2). Upward they continue as grey, locally always slightly marly crinoidal limestones. Abundant fauna of small phosphatized ammonites was found in the marly crinoidal limestone beds. The ammonites were probably reworked from the marly intercalations as suggested by theirs common presence within the marly intraclasts. Among the ammonites, *Phylloceras perplanum* Prinz, *Holcophylloceras* sp. juv. [cf. *H. ultramontanum* (Zittel)], ?*Alocolytoceras* sp., *Ludwigia* sp., *Brasilia* sp. juv. [cf. *B. (B.)* gr. *bradfordensis* (Buckman)], were recognized. Grey, always slightly marly crinoidal limestones and creamy (yellowish) crinoidal limestones from the upper part of the member are also rich in ammonites, essentially phylloceratids *Ptychophylloceras* (*Tatrophylloceras*) cf. *tatricum* (Pusch), and graphoceratids: *Ludwigia* (*Pseudographoceras*) sp., *Brasilia* (*Brasilia*) cf. *bradfordensis* (Buckman) and *Graphoceras* sp. In this part, fragments of coalified wood and one large (30 cm) fragment of black biotitic mica-schist were found.

From the microfacies point of view the deposits are sandy crinoidal biomicrites, packstones. The sandy admixture is mainly represented by angular quartz reaching up to pebble size. Other clasts belong to dolomites and siltstones. The bigger quartz grains show undulosity and polycrystallinity. Besides the crinoidal ossicles, nodosariid foraminifers, *Lenticulina* sp. and various sorts of bivalve and brachiopod shells, echinoid spines, bryozoans and various agglutinated foraminifers are present. The allochems are commonly bored, with the borings filled by Fe-Mn opaque minerals. These minerals also form clusters and seams within the sediment.

The middle part of the crinoidal limestone sequence (Member B) shows a great complexity, with alternation of different facies types (Fig. 2). Thick bedded reddish crinoidal packstones, with brown to dark red cherts, are typical for the lower 4 metres. Some beds are richer in clastic quartz. Reddish to greenish thick-bedded crinoidal packstones, with red cherts and intercalations of nodular limestone, follow in the next 6 metres (Fig. 4.5). Some beds are composite, with red micritic nodules in crinoidal matrix in the lower part of the layer and crinoidal packstone in its upper part. Except of some disarticulated brachiopods no macrofauna was found here. The crinoidal packstones are frequently silicified. The only preserved allochems are echinoderm ossicles, bivalves, brachiopods, foraminifers *Lenticulina* sp. and rare echinoid spines. Allochems are surrounded by chalcedony, locally with preserved remnants of the original intergranular micrite.

The upper part of the formation (Member C) is characterized by change of limestone colour from reddish to greenish and grey/greenish and absence of nodular or nodular/crinoidal layers and red cherts (Fig. 4.6). The limestones become coarser and thick-bedded (up to 1 m); the beds are frequently separated by thin layers of green marls or marlstones. They usually have a character of crinoidal packstones, but locally also of grainstones. Principal allochems as crinoidal particles are size-sorted. Filaments, juvenile gastropods and benthic foraminifers are common. Clastic admixture varies from 1 to 10%. It is dominated by quartz grains, abundant lithoclasts and rare glauconite grains. Dark grey to black stratiform cherts are present in the upper part of the member. Due to tectonics, the overall thickness of this sequence is not mesurable, but it is 30 metres thick at least. The sequence is capped by a thin Fe/Mn crust.

Czorsztyn Limestone Formation

Ammonitico Rosso deposits of the Czorsztyn Limestone Formation built almost the entire southern face of the quarry (Fig. 4.7). The formation was studied in detail by Rakús (1990a) and Schlögl (2002). The first 20 cm of the formation have a character of pseudonodular limestone, containing dispersed crinoidal detritus in nodules

Fig. 2. Jurassic of the Beňatina quarry. Section I. NE face of the quarry. Section II. Left side of the quarry entry. Section III. SE face of the quarry.

A. sandstones, crinoidal sandy limestones, dark shales with Liogryphaea arcuata coquina. B. dark marls with intercalations of dark-grey silty marlstones. C. dark to grey-greenish marls with marlstone layers. D. crinoidal marly limestones, sandstones with glauconite (G), greenish marls. E. red marls with marlstone layers and encrusted concretions. F. crinoidal marly limestones, dark-grey crinoidal marls. G. red crinoidal limestones with red cherts and nodular layers. H. cream to yellowish crinoidal limestones with black cherts. J. mineralized hardground between crinoidal and nodular limestones. K. red and grey nodular limestones. L. pseudonodular limestones. M. main omission surfaces and hard-grounds. N. fauna collected in situ. O. fauna collected ex situ.

and in surrounding matrix as well (crinoidal-filamentous wackestone and packstone). Coarse grains of quartz, traces of bioturbation and reworked ammonites occur near the base of the formation. Clastic admixture rapidly decreases upward. The ammonite casts are oriented parallel to the bedding. Ammonite fauna comes from the next 2 metres, including almost exclusively large specimens of *Parkinsonia* (*P.*) *parkinsoni* (Sowerby).

In the next 5 metres the limestones are richer in marly matrix, and the nodules are smaller (up to 5 cm). Mineralized intraclasts are common (intraclastic nodular facies, sensu Savary, 2000, Cecca et al., 2001). The ammonites are very abundant. In majority, they are fragmented with coroded upper sides and randomly placed in the beds.

The whole visible part of the formation consists of wackestones to packstones with "filamentous" microfacies and numerous mineralized intraclasts. Except the thin-shelled bivalves the allochems include calcified radiolarians, *Globochaete* sp., echinoderm ossicles and benthic foraminifers. Juvenile gastropods and sponge spicules appear locally in some beds.

Still younger deposits are preserved only as loose blocks in the floor of the quarry. These are pseudonodular limestones very poor in marly matrix. Nodules are large and irregular, composed of wackestones with *Globuligerina* microfacies. Only a few badly preserved fragments of perisphinctid ammonites were found here: *Perisphinctes* (*Kranaosphinctes*, *Liosphinctes*) spp.

Nižná Formation

These deposits form few metres thick sequence in the SW part of the quarry (Fig. 3, Fig. 6.1). The full thickness of the deposits remains unknown. The deposits are in tectonic contact with nodular limestones of the Czorsztyn Limestone Formation. This variable sequence consists of thin beds (up to 30 cm) of grey organodetrital (mostly echinoderm) limestones, black marls, grey siliceous limestones and limestones with laminated cherts. Two beds also contain silicified wood fragments (Fig. 6.3), locally mixed with chert debris. On the basis of the lithological variability, the formation can be subdivided into four units:

1. Creamy to grey, fine-grained crinoidal limestones with glauconite. These 150 cm thick thin-bedded limestones are free of lithoclasts or quartz admixture (Fig. 6.6). Locally, the limestones are laminated, sometimes silicified.

2. Coarse crinoidal limestone rich in lithoclasts of green, white and pink micritic limestones with some admixture of micritic clasts with glauconite and green micritic clasts with grey cherts. The lithoclasts are rounded, not sorted by size (Fig. 6.5,7). Some bigger lithoclasts are frequently bored (macroborings). The bed is 55 cm thick

3. Grey bedded limestones with cherts and wood fragments. They begin with 20 cm thick allodapic layer of beige, fine-grained limestone with hummocky cross-stratification. Next allodapic layer (30 cm thick) is separated by thin 5 cm thick black marl. This layer contains thin laminated cherts and coalified and silicified wood fragments (Fig. 6.3, Fig. 11). Next 30 cm thick crinoidal limestone layer shows an erosive base: it is laminated in the lower part but becoming massive and structureless towards the top; small lithoclasts and glauconite grains are common. Still higher layer, 5 to 8 cm thick, is the chert layer with wood fragments. Some wood fragments are 10-20 cm long and bear traces of *Teredo*-type borings filled with sediment (Fig. 6.4). The topmost layer of the unit consists of two parts: the lower part is represented by fine-grained, grey, massive crinoidal limestone, whereas the upper part consists of more fine-grained, indistinctly laminated crinoidal limestone with black cherts and dark grey bioturbated marls. .

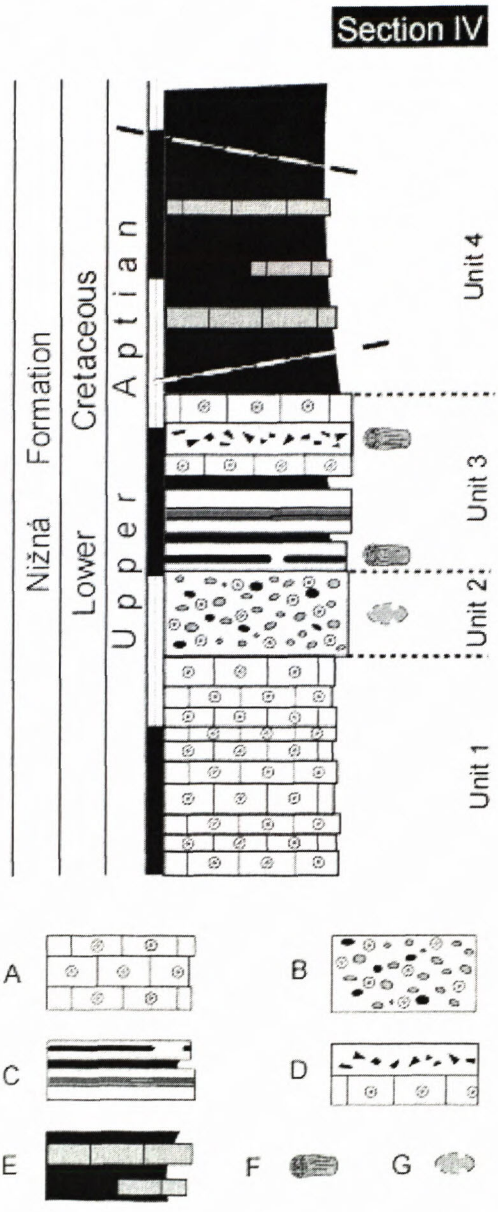


Fig. 3. Lower Cretaceous of the Beňatina quarry. Section IV. The toe of the SW face of the quarry.
A. creamy to grey crinoidal limestones. B. crinoidal limestone with numerous lithoclasts (breccia). C. grey biodetritic limestones with black cherts (locally laminated), black marls. D. grey detritic/crinoidal limestone with chert fragments. E. black marls with marly limestone layers and concretions. F. fossil wood fragments. G. lithoclasts with macroborings.

The limestones of the unit 3 have a character of biomicrites, packstones with skeletal detritus and various clasts. Some bioclasts point to shallow water origin of a part of detritus at least. The limestone contains numerous echinoderm ossicles (including complete crinoid calices), coralline algae, big orbitolinid foraminifers, thick layered tubes of serpulid worms, detritus of oyster-type shells, inoceramid shells, punctate brachiopods, bryozoans and agglutinated foraminifers. The intraclasts are mostly represented by marlstones, packstones with hedbergellid foraminifers or with rhaxa. Some clasts are phosphatized. The phosphatization prograded from inside, the outer parts of the clasts remained unchanged. One of the clasts is coated by thin phosphatic stromatolite, forming thus an initial oncoid. Along with hedbergellid foraminifers, the clasts contain agglutinated foraminifers, and prisms of inoceramid shells. There is also a large biosparitic clast with mostly indeterminable micritized allochems, agglutinated foraminifers, hedbergelids, fragments of bivalve shells and echinoderm ossicles. Some clasts with sponge rhaxa microfacies were observed too.

4. Bioturbated, black to dark green marls and marlstones (locally with pale laminae) with disturbed layers of dark limestones. In a pale laminae there are marls with dispersed larger allochems, e.g. echinoderm ossicles, detritus of oyster-type bivalves and agglutinated foraminifers. The laminae also contain silty quartz admixture, rare glauconite grains and intraclasts of organodetrital carbonates to marlstones (with coralline algae). The dark bioturbated marlstone contains tiny allochems, mostly indeterminable detritus of various skeletal organisms (Fig. 6.8). Only ostracod shells, poorly preserved hedbergellid foraminifers, rare phosphatic bone detritus, foraminifers *Lenticulina* sp. and agglutinated foraminifers could be determined. Like in the pale laminae, the sediment contains silty quartz admixture.

Biostratigraphy

Generally, the studied succession at Beňatina is sufficiently rich in macrofossils, enabling recognition of the chronostratigraphical ranges of the bulk of the lithostratigraphical units.

Dolný Mlyn Formation *(?Hettangian – Early Sinemurian)*

The lower, "sandstone" part of the formation has yielded a scarse biostratigraphicaly valuable macrofauna only. Rich brachiopod fauna collected from the marly limestone layer (directly above the oyster coquina, see Fig. 2, Section I) is represented mainly by *Callospiriferina haueri* (Suess) and *Liospiriferina* cf. *pichleri* (Neumayr), and by a few representatives of *Cirpa* aff. *planifrons* (Ormos) and *Calcirhynchia* cf. *fascicostata* (Uhlig). This fauna indicates early Liassic age of this dark grey limestones and suggests Hettangian or Early Sinemurian age as based mainly on biostratigraphical value of the first mentioned species known from the gresten facies of the Northern Calcareous Alps (e.g. Siblík, 1999). This taxon is very close to the most typical Early Jurassic Alpine spiriferinids – *Callospiriferina tumida* (Buch) and *Liospiriferina alpina* (Oppel) (Siblík, 1993, Dulai, 2003). A big undeterminable fragment of arietitid ammonite has been collected from the same bed indicating probably Early Sinemurian age. Moreover, the presence of coquina with *Liogryphaea arcuata* (Lamarck) confirms this datation, the stratigraphical range of the species being stated as Hettangian to Early Sinemurian.

On the other hand, rich ammonite fauna has been found in the upper, "marly" part of the formation. The topmost layers of the formation yield *Coroniceras lyra* Hyatt (Fig. 7.4, 8.3) and *C. (Paracoroniceras)* cf. *charlesi* Donovan (Fig. 8.2). They indicate the *A. semicostatum* Zone of the Early Sinemurian. Moreover, numerous *Arnioceras* sp. (Fig. 8.6) and *Arnioceras semicostatum* (Young & Bird) (Fig. 8.4) collected in the rubble, indicate the same stratigraphic interval.

Allgäu Formation *(Late Sinemurian – Pliensbachian)*

Ammonite fauna was collected mainly from the marly limestone beds. The oldest ammonite fauna originates from the rubble below the section I, including a small fragment of *Bifericeras* sp., a taxon characteristic of the Late Sinemurian *O. oxynotum* Zone. Very poorly preserved ammonites, including *Androgynoceras* sp. and ?*Liparoceras* sp. come from the lowermost exposed bed in the section II. These taxa are already indicative of the Carixian. Next fauna occurs approx. 3 m higher. It includes *Partschiceras* cf. *striatocostatum* (Meneghini) and, especially, *Pleuroceras* cf. *solare* (Phillips) (Fig. 9.4) that prove the Late Domerian age (*P. spinatum* Zone). The presence of *Pleuroceras* cf. *spinatum* (Bruguière) (Fig. 9.5) at the upper boundary of the formation indicates also the Late Domerian age. The latter form is associated with ?*Reynesoceras* sp. and with dactylioceratid ammonites *Dactylioceras* sp. (cf. *D.* (*Orthodactylites*) *mirabilis* Fucini). These *Dactylioceras* demonstrate dense ribbing with typical annulate ribs, a character shown by the earliest representantives of the genus. Their occurrence was recently stated in upper *P. spinatum* Zone of the Late Domerian (Rakús, 1995).

Hôrka Formation, new unit *(Late Domerian)*

Only uppermost beds yielded stratigraphicaly valuable ammonites. The co-occurrence of very badly preserved Harpoceratidae, probably representing genus *Lioceratoides* and the primitive first *Dactylioceras* with annulate ribs (Fig. 9.2), indicates Late Domerian age.

Hŕbok Marl Formation, new unit *(Toarcian)*

The ammonite fauna is not abundant but very significant, covering the whole Toarcian. The Early Toarcian age for the lower part of the Hŕbok Marl Formation is proved by occurrence of *Dactylioceras* cf. *tenuicostatum* (Young & Bird) (Fig. 9.1), the index fossil of the *D. tenuicostatum* Zone. Numerous *Hildoceras lusitanicum* Meister, associated with *Hildoceras bifrons* (Bruguière) (Fig. 9.6, 9.7), as well as a rare ammonite *Frechiella sub-*

Slovak Geol. Mag., 10, 4 (2004), 241 – 262

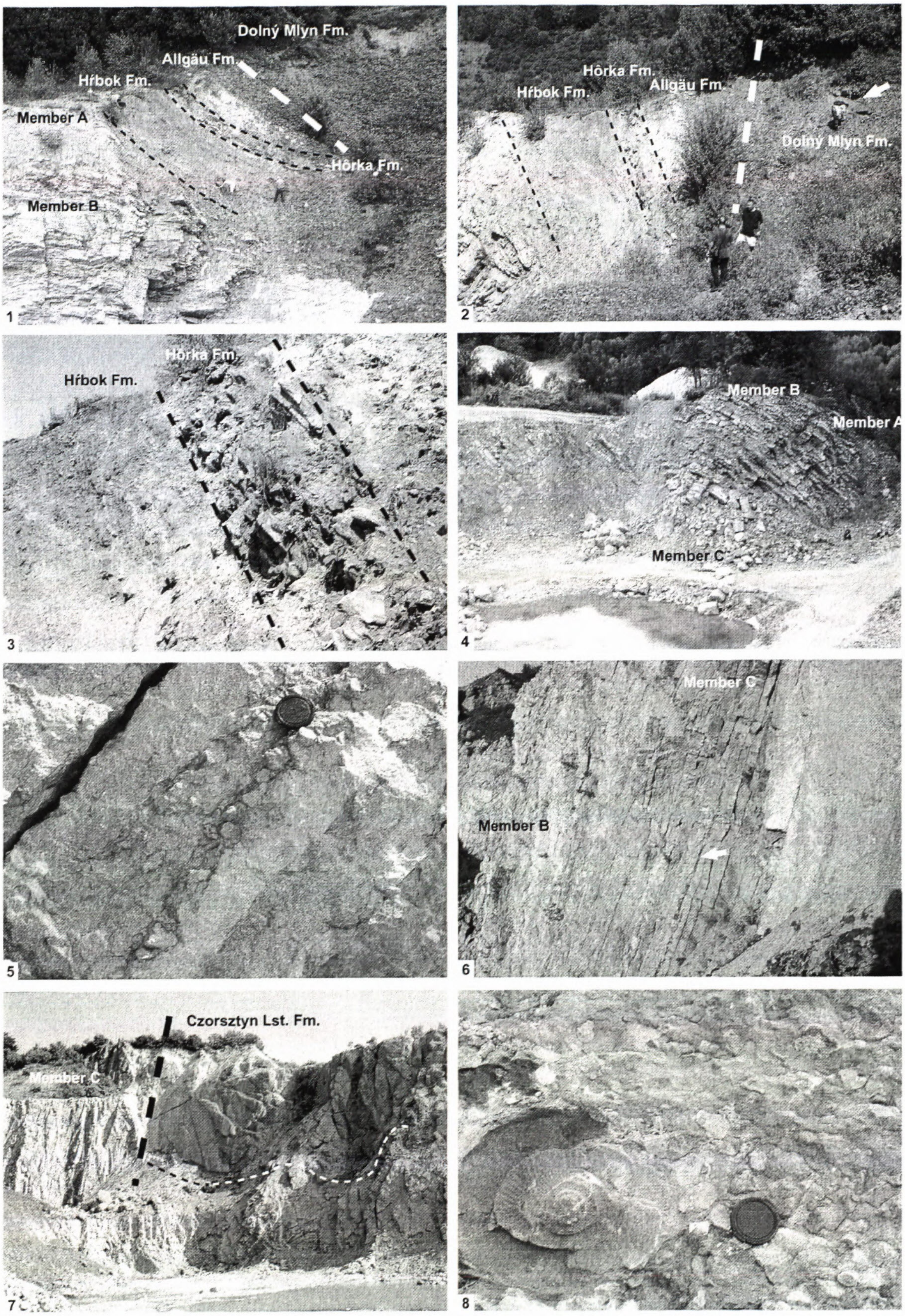


Fig. 4. 1-2. NE face of the quarry with the Liassic – Lower Dogger part of the section. 3. Detail of the boundary between Hôrka and Hŕbok Marl Fms. 4. Members A, B, C of the crinoidal limestone complex. 5. Detail of the reddish crinoidal limestone with red micritic nodules (Member B). 6. Upper part of the Member C, white to yellowish bedded crinoidal limestones with dark cherts (arrowed). 7. Tectonic (black line) and sedimentologic (black & white line) contact between member C and Czorsztyn Lst. Fm. 8. Detail of the Late Bajocian ammonitico rosso deposits of the Czorsztyn Lst. Fm.

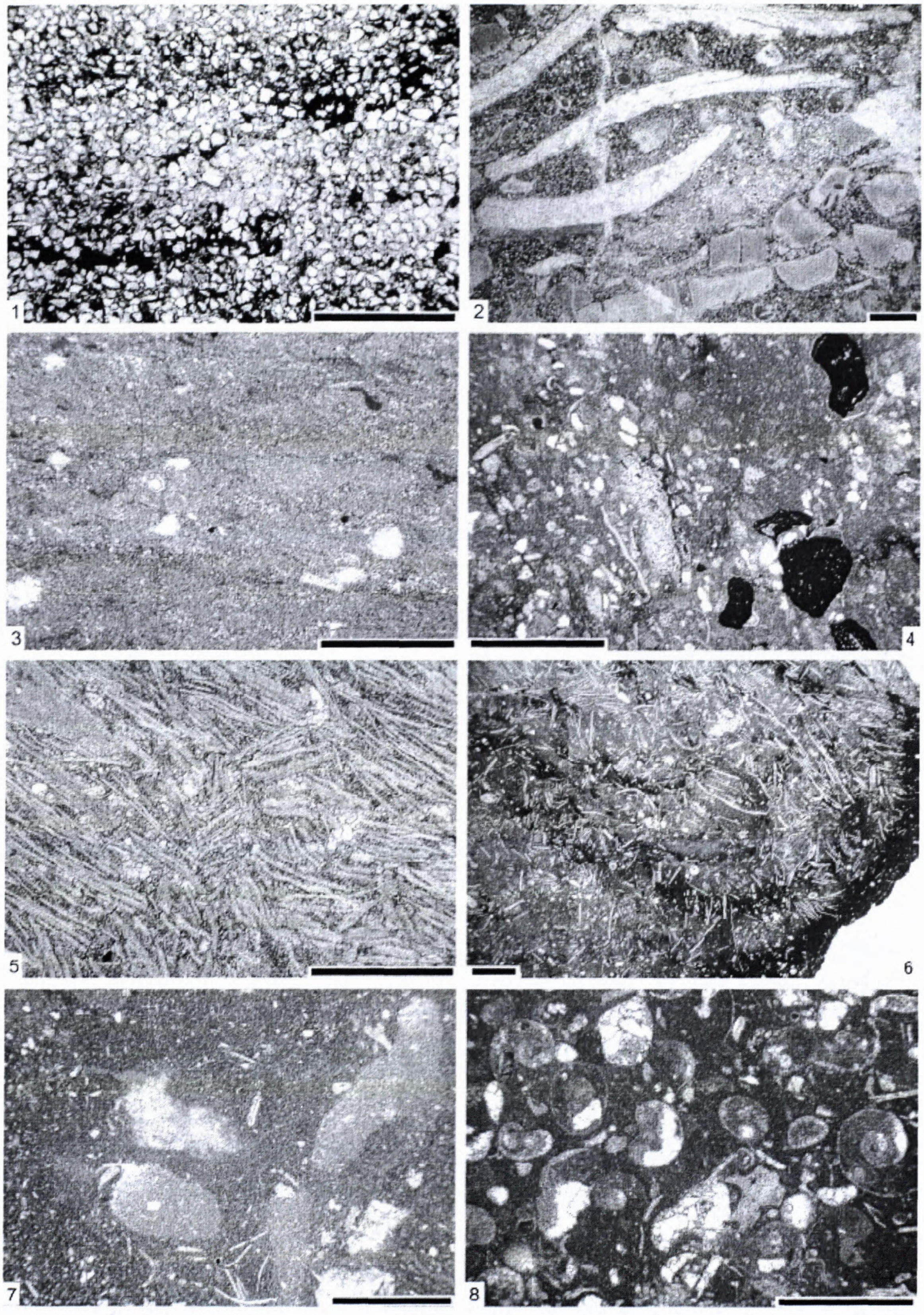


Fig. 5. 1. Dolný Mlyn Fm., sandstone with high portion of opaque cement in the intergranular space. 2. Dolný Mlyn Fm. (lowermost uncovered layer, Section I), crinoidal paskstone with large isolated crinoidal ossicles and numerous oyster fragments. 3-8. Hŕbok Marl Fm.: 3. Red marls. 4. Wackestones with numerous mineralized lithoclasts and high portion of quartz grains. 5. Bositra coquina. 6. Fe-oncoid with filamentous wackestone as a core, enveloped by thin microbial crust. 7. Red marls, heavily bioturbated. 8. Ammonite coquina, the base of the Hŕbok Marl Fm. (Scale bar = 1 mm)

Slovak Geol. Mag., 10, 4 (2004), 241 – 262

carinata (Yong & Bird) (Fig. 9.8), found in thin marlstone layers in the middle part of the formation prove the *H. bifrons* Zone of the Middle Toarcian. The occurrence of grammoceratid ammonites (*Dumortieria* sp.) in the upper part of the formation already suggest the Late Toarcian age. The uppermost layer of the red marls of the formation yields, moreover, *Lytoceras* cf. *sublineatum* (Oppel) (Fig. 8.1), the species frequently reported from the Middle–Late Toarcian (Schlegelmilch, 1976, Rulleau, 1998).

Crinoidal limestones
Member A *(Aalenian)*

There are two ammonite faunas recognised in this member. The lower, marly crinoidal limestones and crinoidal marls contain abundant small resedimented phosphatized ammonite casts. Phylloceratina highly prevail over Lytoceratina and Ammonitina, representing more than 90% of the whole fauna. The identified *Phylloceras perplanum* Prinz (Fig. 7.2), *Holcophylloceras* sp. juv. [cf. *H. ultramontanum* (Zittel)] (Fig. 7.3), *?Alocolytoceras* sp. have too wide stratigraphic ranges, and thus are of minor stratigraphic importance. On the other hand, *Ludwigia* sp. (Fig. 9.10, 9.12), and *Brasilia* (*Brasilia*) sp. juv. [cf. *Brasilia bradfordensis* (Buckman)] (Fig. 9.9) prove the *L. murchisonae* Zone of the Middle Aalenian.

The overlying grey, slightly marly crinoidal limestone beds yielded *Ptychophylloceras* (*Tatrophylloceras*) cf. *tatricum* (Pusch), *L.* (*Pseudographoceras*) sp. (Fig. 9.14), *Brasilia* sp. and *Brasilia* (*Brasilia*) cf. *bradfordensis* (Buckman) (Fig. 9.11). This fauna still indicates the *L. murchisonae* Zone. Poorly preserved fragments of *Graphoceras* sp. (Fig. 9.13) from the overlying beds of the creamy crinodal limestone (transitional part between the members A and B) already indicate the Late Aalenian *G. concavum* Zone.

Members B and C *(Bajocian)*

No ammonites are known from this part of the formation. The age of the members B and C can be estimated as the Early to upper Late Bajocian, on the base of the ages of the underlying and overlying deposits.

Czorsztyn Limestone Formation
(Late Bajocian – Oxfordian)

The basal 20 cm of the formation shows signs of resedimentation with reworked ammonite fauna containing big perisphinctid ammonites such as *Leptosphinctes* (*L.*) sp. and *Vermisphinctes* (*V.*) cf. *martiusi* (d'Orbigny). These are usually assigned to *G. garantiana* or lower *P. parkinsoni* Zone - the *P. acris* Subzone (cf. Galácz, 1980, Fernández-López, 1985). The lower part of the formation yields typical Late Bajocian fauna, including mainly *Parkinsonia* (*P.*) *parkinsoni* (Sowerby) (Fig. 10.4), the index species of the *P. parkinsoni* Zone. The Upper Bajocian part is approx. 2 metres thick. Very rich fauna collected from the overlying beds includes *Nannolytoceras tripartitum* (Raspail), *Planisphinctes* (*Planisphinctes*) *tenuissimus* (Siemiradzki), *Planisphinctes* (*Lobosphinctes*) *intersertus* Buckman (Fig. 10.1), *Morphoceras* (*M.*) cf. *dimorphitiformis* (Sandoval) (Fig. 10.2), *Pseudodimorphinites pinguis* (de Grossouvre) and *Zigzagiceras* (*Z.*) *zigzag* (d'Orbigny) (Fig. 10.3). It is typical of the *Z. zigzag* Zone (*M. parvum* Subzone) of the Early Bathonian. The species *Parkinsonia* (*Parkinsonia*) cf. *schloenbachi* Schlippe from still younger bed already suggests the *M. macrescens* Subzone of the *Z. zigzag* Zone. The overlying beds of the lower part of the formation exposed in the section in the quarry do not yield any stratigraphically important fauna.

The blocks of pseudonodular limestone found on the floor of the quarry yielded a few poorly preserved perisphinctid ammonites. These include *Perisphinctes* (*Kranaosphinctes*) sp., and *P.* (*Liosphinctes*) sp. indicative of the Middle Oxfordian.

Nižná Formation *(Late Aptian)*

The age of the formation can be determined on the base of the planktic foraminifers only. The occurrence of *Globigerinelloides algerianus* Cushmann & Ten Dam (Fig. 6.2), associated with *Blefusciana* cf. *infracretacea* (Glaessner), *Blefusciana aptiana* (Bartenstein) and also *Hedbergella* sp. prove the Late Aptian age of the black marls of the unit 4 (Fig. 3). Here the planktic forms are rare and constitute <5% of the total number of microfauna. This consists mostly of benthic foraminifers *Gyroidina* sp., *Lenticulina* sp., *Gavelinella* sp. (the most abundant), and others such as *Dentalina* sp., *Marginulinopsis* sp. and *Lagena* sp. as well as rare smooth ostracods.

The matrix of the limestone breccia (Unit 2 - see Fig. 3) is very poor in planktic foraminifers. On the contrary some clasts found here can be recognized as the foraminiferal packstones with dominant planktic foraminifers of the Late Aptian age which suggests short time difference between sedimentation of the deposits and their reworking.

Discussion

The section studied of the Beňatina quarry differs markedly from typical successions of the Pieniny Klippen Basin well recognised in central and western parts of the Pieniny Klippen Belt in Slovakia and Poland (see e.g. Andrusov, 1945; Birkenmajer, 1977; Mišík, 1997).

The lowest deposits exposed in the section are sandstones with intercalations of marls and *Gryphea* coquinas. They represent the Dolný Mlyn Formation and are of (?)Hettangian to Early Sinemurian age. Still younger are marls and limestones of Fleckenmergel/Fleckenkalk type corresponding to the Allgäu Formation and representing time interval from Late Sinemurian to Domerian. Very similar stratigraphic succession is known from the southwestern Ukrainian sections, at Priborzhavskoye and Perechin (Krobicki et al., 2003, and earlier papers cited therein).

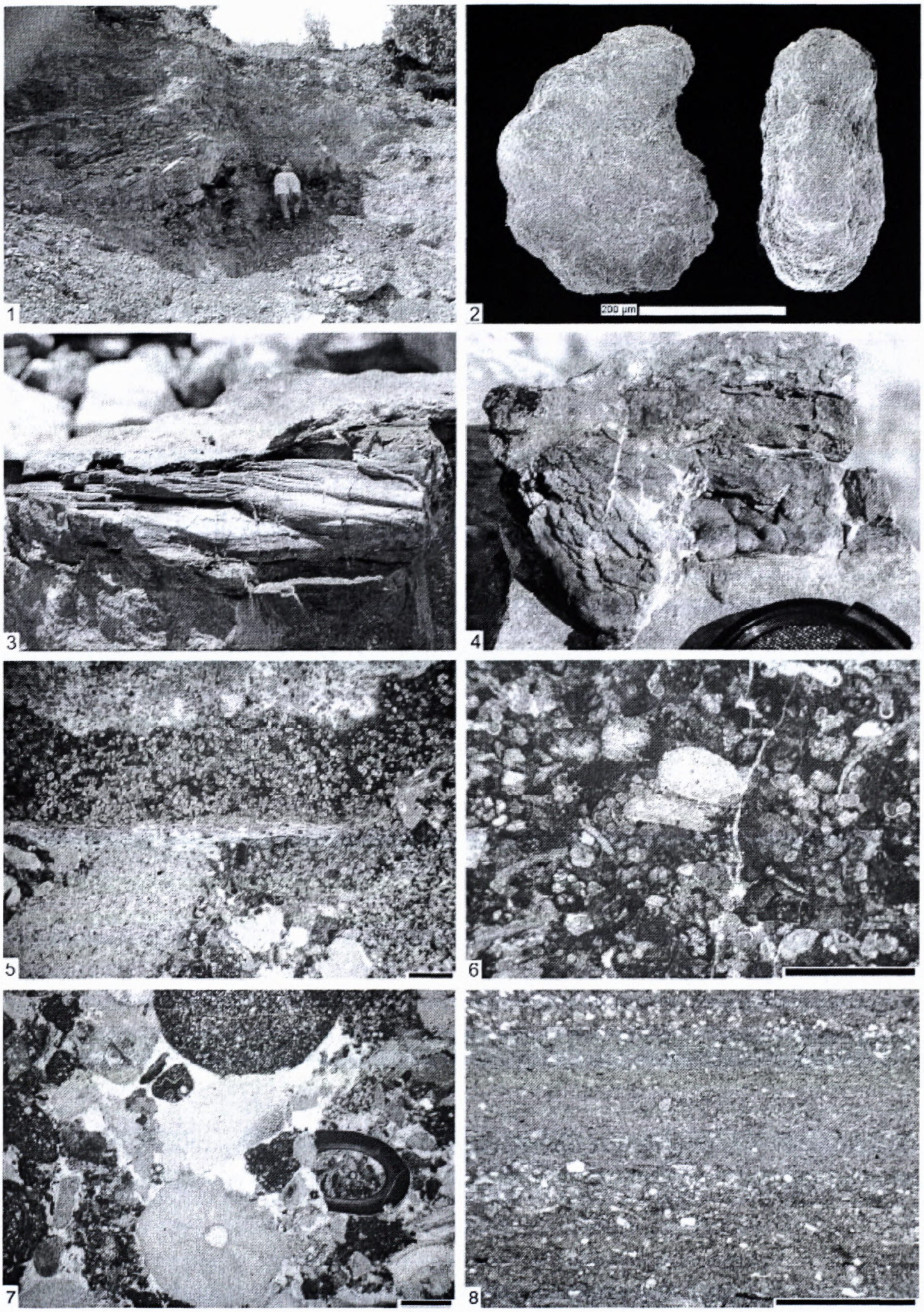


Fig. 6. 1-8. Nižná Unit: 1. Lower Cretaceous part of the Beňatina quarry. (backside of Michal Krobicki as a scale). 2. Globigerinelloides algerianus Cushman & Ten Dam, black marls of the Unit 4, Late Aptian. 3. Fossil wood fragment (approx. 15 cm long). 4. Teredo-like borings in the wood fragment. 5. Limestone breccia; the biggest clast (upper half of the picture) contains abundant planktic Late Aptian foraminifers. 6. wackestone with crinoidal particles, planktic foraminifers and bivalve fragments. 7. Limestone breccia consisting of rounded lithoclasts and large bioclasts (crinoid ossicles, serpulid tubes). 8. Laminated black shales. (Scale bars 5-8 = 1 mm)

The Lower Jurassic deposits corresponding to the discussed stratigraphical interval are generally poorly known in central and western parts of the Pieniny Klippen Belt. The Dolný Mlyn Formation has been known so far from a single section at the Dolný Mlyn quarry in western Slovakia (Rakús & Potfaj, 1997); the stratigraphical position of the spotty bituminous limestones and dark sandy marls representing there the upper part of the formation is documented (Hlôška, 1992) by occurrence of ammonite *Arnioceras mendax rariplicata* Fucini indicative of the Early Sinemurian. On the other hand, the deposits of the Allgäu Formation are known from not numerous sections in the Pieniny Klippen Belt in Poland and Slovakia where they yield ammonites of the Pliensbachian age (e.g. Andrusov, 1931; Birkenmajer & Myczyński, 1994; Rakús, 1995). These incomplete data make difficult the detailed recognition of the facies pattern in central and western part of the Pieniny Klippen Basin during Hettangian to Pliensbachian, and hence preclude closer palaeogeographical comparisons.

The stratigraphical interval at the turn from Lower to Middle Jurassic at the Beňatina quarry comprises three well marked lithological units. These include: green glauconitic sandstones, marls and sandy crinoidal limestones (Hôrka Formation, Late Domerian), red marls (Hŕbok Marl Fm., Toarcian), and marly crinoidal limestones and marls (Member A of crinoidal limestones, Aalenian). These units demonstrate small thicknesses, and other indications of slow sedimentation rate and/or synsedimentary erosion: presence of ferrugineous oncolites – directly below the Hŕbok Marl Fm., occurrence of intraclasts with thin microbial stromatolites and Fe-Mn encrustations – within the Hŕbok Marl Fm., rich admixture of clastic quartz grains, and presence of small phospatized ammonites in the clay lithoclasts – within crinoidal limestones of the member A. Similar lithology show deposits of uppermost Pliensbachian to Aalenian age in southwestern Ukrainian part of the Pieniny Klippen Belt at Priborzhavskoye and Perechin (see Krobicki et al., 2003). It is a development markedly different from coeval deposits of Toarcian to Aalenian age in central and western part of the Pieniny Klippen Belt in Slovakia and Poland. Here dominant are dark spotty limestones and marls (Krempachy Marl Formation) and dark marly shales with spherosiderite concretions (Skrzypny Shale Formation) well known from the Czorsztyn to the Kysuca/Branisko successions (see Birkenmajer, 1977).

A marked contrast between the two discussed areas was related possibly with uplift of the eastern segment of the Pieniny Klippen Basin already at the end of Lower Jurassic. Here, at Beňatina the sediments formed under anoxic-disoxic conditions (Dolný Mlyn Fm., Allgäu Fm.) were replaced at the turn of Pliensbachian and Toarcian by deposits formed in well oxygenated bottom conditions with clear signs of reworking of the sediment. The abrupt uplift, at the end of Lower Jurassic took place also in the area of North-Tatric Ridge south of the Pieniny Klippen Basin. It is distinguished as so called Devín Phase, marked by deep erosion, formation of extraclastic limestones, and an increasing contrast between the formation of partly anoxic sedimentation of the deposits of the Allgäu Fm., and appearance of well aerated "ammonitico-rosso" limestones of the Adnet Fm. (Plašienka, 2003). On the other hand, oxygen-depleted sedimentation continued during Toarcian and Aalenian in the bulk of central and western parts of the Pieniny Klippen Basin. It has been not earlier than during Early Bajocian when also in this area, the crinoidal limestones appeared what was related with uplift and formation of the Czorsztyn Swell (Ridge) (see Aubrecht et al., 1997).

The members B and C of the crinoidal limestones of the Beňatina sections show some similarities to the Flaki Limestone Formation of Birkenmajer (1977) from central and western parts of the Pieniny Klippen Belt. All these deposits contain some layers with chert nodules, and chert intercalations. However, the red or reddish to greenish colour of both limestones and cherts differs from grey or bluish colours of cherts typical of the Flaki Limestone Fm. Moreover, the nodular limestone intercalations recognized in the member B of the Beňatina section were never observed in the Flaki Limestone Fm. On the other hand, occasional silicification and nodular structures have been reported from the Smolegowa Limestone Fm, which is typical for the Czorsztyn Succession. However, the crinoidal limestones of the Smolegowa Limestone Fm. are generally grainstones, devoid of bedding or poorly bedded with characteristic high portion of detrital quartz and lithoclasts. The Flaki Limestone Fm. is known from central and western parts of the Pieniny Klippen Belt from successions deposited on the southern slope of the Czorsztyn Swell (Ridge) such as the Czertezik Succession and the Kysuca/Branisko Succession, but also from the Haligovce Succession which paleogeographical position is still debatable (see below).

The oldest deposits of the ammonitico-rosso type in the Beňatina section are developed as nodular limestones with variable amount of the marly matrix. They show the presence of the filament microfacies and yield ammonites of the latest Bajocian-Bathonian age. Still younger deposits found in loose blocks in the quarry, but very probably representing the same succession – are more massive, indistinctly nodular limestones of the *Globuligerina* microfacies of the Oxfordian age. There is undoubtedly a close similarity of the studied deposits in the Beňatina section to the Czorsztyn Limestone Formation well known from the Czorsztyn Succession of western and central parts of the Pieniny Klippen Belt (cf. Wierzbowski et al., 1999; Schlögl, 2002). The nodular limestones corresponding to the Czorsztyn Limestone Fm., and spanning the same stratigraphical interval, are known also from the areas located south of the Pieniny Klippen Basin, e.g. from the Manín Succession (e.g. Rakús, 1977). Although the detailed palaeogeographic position of the Haligovce-Manín Units within the Carpathians basins is still not fully cleared, they are placed either within the southern part of the Pieniny Klippen Basin (Haligovce Succession – after Birkenmajer, 1977) and in the neighbouring to the south – the so called Manín Basin (e.g. Andrusov, 1945, Rakús & Marschalko, 1997; Mišík, 1997), or even more to the south close to the High Tatra Succession (Plašienka, 2003).

Another problem remains palaeogeographical position of the Lower Cretaceous detritic deposits in the Beňatina section. The occurring here allodapic Urgonian deposits because of their unclear tectonic position cannot be considered with certainty as a part of the succession studied, although such a solution seems highly probable. They have only few equivalents in the Pieniny Klippen Basin – mostly in the Nižná Succession from the Orava part of Pieniny Klippen Belt in western Slovakia (Scheibner, 1967) where they are represented by grey, green-grey medium to coarse grained organodetrital gravel limestones, locally with cherts and fragments of carbonate rocks. Another locality with the Urgonian-like facies is the Haligovce Klippe, but palaeogeographical position of the Haligovce Succession is still doubtfull (see above). The principal difference between these two sections, and the Beňatina section lies in much more deeper character of the Nižná Succession and the Haligovce Succession where the Callovian-Oxfordian radiolarites and radiolarite limestones indicate their deposition below the CCD (like in deep-water Kysuca/Branisko Succession), whereas the Oxfordian red ammonitico-rosso deposits of Beňatina indicate more shallow environment.

Conclusions

The Beňatina quarry is a key locality for studies of the stratigraphy and palaeogeography of the eastern Slovakian part of the Pieniny Klippen Belt. Similar Lower and Middle Jurassic deposits are known also from the Priborzhavskoye and Perechin quarries in the Ukrainian part of the Pieniny Klippen Belt.

The correlation of this succession with other successions from the Pieniny Klippen Basin and the neighbouring areas presents, however, some problems, and it is interpreted in somewhat different manner by the particular authors. Some of us (J.S., M.R., M.K., R.A.) think that the overall development of Lower to Upper Jurassic deposits at Beňatina is typical for drowned platforms developed at the southern margin of the submarine Czorsztyn Swell (Czorsztyn Ridge). The presence of the crinoidal limestones in the Beňatina section in Toarcian and Aalenian probably indicates thus the earlier rising and breaking of the eastern segment of the Pieniny Klippen Basin. Although it is impossible to prove unequivocally that the Upper Aptian detrital limestones from the Beňatina quarry belong to the studied section, their occurrence could be considered as an indication of existence of Urgonian type of shallow-water sedimentation on the Czorsztyn Swell during Early Cretaceous. To distinguish different developments of deposits within the Czorsztyn Succession, Mišík (1997) and other authors usually used the term "variety". This leads us to propose the section of the Beňatina quarry as a new variety of the Czorsztyn Succession. Unlike the deeper-water units, the Czorsztyn Succession is characterized by great complexity and enormous facies variability, where no two localities show identical sections. The most characteristic feature of the Czorsztyn Succession, appears a total lack of the Callovian-Oxfordian radiolarites known mostly in other successions formed in the Pieniny Klippen Basin.

There is, however, possible another palaeogeographical interpretation of the Beňatina succession. The occurrence of deposits of Toarcian and Aalenian age showing features indicating the reduced sedimentation rate may indicate closer relation of the succession studied with areas lying at southern margin of the Pieniny Klippen Basin. The same conclusions may be drawn from occurrence of the Urgonian type deposits which usually are known from the outer margin of the Inner Carpathians, from the carbonate platform zone developed in the Manín-High Tatric areas, or even at southern part of the Pieniny Klippen Basin. According to this interpretation preferred by two authors (B.A.M., A.W.), the studied section of the Beňatina quarry is the first known so far succession of southern origin within the eastern part of the Pieniny Klippen Belt.

Palaeontology

This chapter is not assigned for the systematic description of the whole fauna. Only some Early Jurassic to early Middle Jurassic taxa, which are new or poorly known in the West Carpathian area or they are of greater palaeobiogeographical significance, will be described in detail. Representants of the suborders Phylloceratina and Lytoceratina are shortly discussed in the next paragraph. The palaeontological material described and figured in the paper is stored in the collection of the Department of Geology and Paleontology, Faculty of Sciences, Comenius University in Bratislava (coll. Schlögl).

Phylloceratina from the Aalenian marly crinoidal limestones and marlstones composes in majority of phosphatised smooth internal casts of *Phylloceras perplanum* Prinz (37 specimens, Fig. 7.2), meanwhile constricted genus *Holcophylloceras* is rare, present by a few specimens of *Holcophylloceras* sp. juv. [cf. *H. ultramontanum* (Zittel)] (Fig. 7.3). Other three deformed and fragmented internal casts of *Ptychophylloceras* (*Tatrophylloceras*) cf. *tatricum* (Pusch) have been collected from the overlying grey crinoidal limestones. They are associated with typical fauna of the Middle – Late Aalenian, *L. murchisonae – G. concavum* Zones. Lytoceratina are rare. Only two taxa were collected in the Toarcian red marls and Aalenian grey marly crinoidal limestones. Among the resedimented phosphatised ammonites from *B. bradfordensis/G. concavum* Zone, two fragments of ?*Alocolytoceras* sp., with whorl section, shape of constrictions and the suture line close to *Alocolytoceras ophioneum* (Benecke) were found. Another specimen interpreted as *A. dorcadis* is described below.

Explanations of the abbreviations:

Terminology of the suture line: E – external lobe, S1 – 1st lateral saddle, S2 – 2nd lateral saddle, L1 – first lateral lobe, I – dorsal lobe

Measurements of the shell parameters: D – shell diameter, H – whorl heigth, E – whorl width, O – umbilicus diameter

Lytoceratidae Neumayr, 1875
Alocolytoceratinae Spath, 1927
Alocolytoceras Hyatt, 1900

Alocolytoceras dorcadis (Meneghini, 1881)
Fig. 7.1 a-c
1967 *Alocolytoceras dorcadis* (Meneghini) – Géczy, p. 79, Pl. 22, Fig.1, Pl. 64, Fig. 32, Text-fig. 82 (cum syn.)
2001 *Audaxlytoceras dorcadis* (Meneghini) - Venturi & Ferri, p. 91, 248, non p. 92 a,b

Material: Fragment of a whorl.
Dimensions: Because of only a small part of the ammonite preserved its diameter is not directly measurable. The reconstruction indicates it attains between 350 and 400 mm. H (whorl height) of the fragment is 66 mm and E (whorl width) is 49,5 mm.
Remarks: The taxon *Alocolytoceras dorcadis* is characterized by compressed elliptical whorl section during whole ontogeny. The maximum width is in the middle of the flanks. Another typical character is the high number (6) of the prorsiradiate constrictions, well prononced around the whorl.
Suture line (Fig. 7.1) is typical lytoceratid with shallow E (only ½ of the height of the L1). S1 and S2 are highly differentiated with narrow trunks and deeply cutted folioles. I is cruciform.
As it is clear from the literature the biggest specimens of this taxon do not exceeded 100 mm.
Distribution: Red marls of the Hŕbok Marl Fm., locality Beňatina. It is associated with *Frechiella subcarinata* (Young & Bird), proving its Middle Toarcian age, *H. bifrons* Zone.

Arietitidae Hyatt, 1875
Arietitinae Hyatt, 1875
Coroniceras Hyatt, 1875

Coroniceras lyra Hyatt, 1867
Fig. 7.4 a,b, 8.3 a,b
1966 *Coroniceras lyra* Hyatt - Guerin-Franiatte, p. 134, Text-fig. 35-39, Pl. 22-25, Pl. 26, Fig. 1-3 (cum syn.)
1987 *Coroniceras lyra* Hyatt – Corna, p. 100, Pl. 1, Fig. 5

Material: 3 fragments of big specimens (the biggest attained almost 400 mm).
Remarks: All specimens agree well with the Guerin-Franiatte description of the species (1966: 134). Subadults (diameter cca 100 mm) have a subquadrate whorl section, with H slightly smaller than E. Ventrum is tricarinate and bisulcate (Fig. 7.4b, 8.3b). Lateral keels are pronounced, but smaller than the middle one. The grooves are deep. The ribs are strong, prorsiradiate with short ventro-lateral projection, joining the lateral keel. There are no ventrolateral tubercles on the ribs. The distance between the ribs is two times their thickness. Adult whorl section is round-oval, slightly compressed. Ventral part is bisulcate, ventral keel is very strong. Lateral keels become indistinct. Ribs are robust, prorsiradiate and distant.
Suture line is only partially preserved. E is narrow and deep. S1 is robust, narrowed in the upper part and smaller than S2. L is shalow and attains only ½ of the height of the E.
Distribution: The taxon is well distributed in the continental Europe, but rare in the Western Carpathians. It was found in only two localities: Beňatina and Butkov (lgt. Dr. J. Michalík). Early Sinemurian, *A. semicostatum* Zone.

Coroniceras (Paracoroniceras) Spath, 1924
Coroniceras (Paracoroniceras) cf. *charlesi* Donovan, 1955
Fig. 8.2

Material: Fragment of internal cast of an adult whorl.
Remarks: At the base of its characteristic whorl section the specimen can be very probably assigned to species *C. (P.) charlesi.* Adult whorl section is subtriangular with relatively narrow, tricarinate and bisulcate ventrum. The maximum width is in the periumbilical third of the whorl. *Coroniceras (Paracoroniceras) crossi* (Wright) (sensu Corna 1987, Pl. 1, Fig.7) is very close to our specimen in the similar whorl section but the grooves in this taxon are less pronounced. Moreover the species *C. (P.) crossi* is frequently considered as synonym of the *C. (P.) charlesi* (cf. Guerin-Franiatte, 1966, p. 153).
Distribution: In the West Carpathians the taxon was found only in the Dolný Mlyn Fm. in the locality Beňatina. Early Sinemurian, *A. semicostatum* Zone.

Hildoceratidae Hyatt, 1867
Bouleiceratinae Arkell, 1950
Frechiella Prinz, 1904

Frechiella subcarinata (Young & Bird, 1822)
Fig. 9.8 a-d
2003 *Frechiella subcarinata* (Young & Bird) – Rulleau et al., p. 332, Figs. 13 (2, 3, 5), 14 (1) (cum syn.)

Material: One incomplete internal cast.

Dimensions:	D	H	E	O
	53,6	25,0	24,8	10,0 (phragmocon)

Remarks: It is typical by robust and involute shell with oval whorl section (Fig. 9.8c). Umbilicus is narrow and deep with rounded umbilical wall, gradually passing to slightly arched flanks. Ventrum is bisulcate and tricarinate. Lateral keels are higher but less pronounced than median keel. Juvenile whorls bear radiate, regularly arranged ribs on the flanks which are strong mainly near the periumbilical area. The ribs become less pronounced and more irregularly arranged in the course of ontogeny.

The suture lines are crowded at the end of the preserved phragmocon. E and relatively narrow L1 are similarly deep. S1 is large, divided in two by central shallow accessory lobe. S2 is almost as hight as S1 but narrower. Auxiliary saddles are low, less divided and apparently smaller than S2.

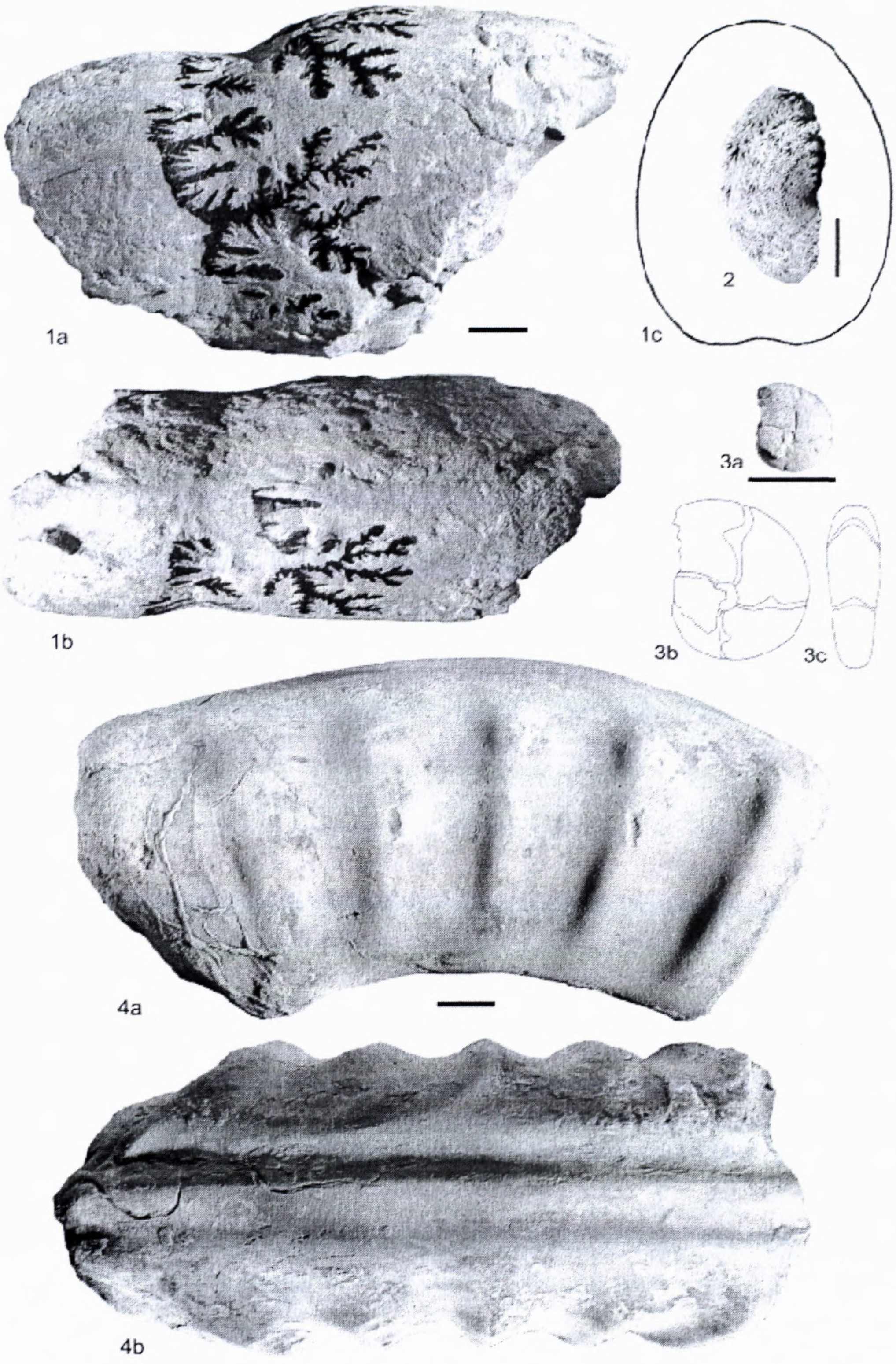


Fig. 7. 1a-c. *Alocolytoceras dorcadis* (Meneghini), Middle Toarcian, Hŕbok Marl Fm. 2. *Phylloceras perplanum* Prinz, Aalenian, Member A. 3. *Holcophylloceras* sp. juv. [cf. *H. ultramontanum* (Zittel)]. 4a, b. *Coroniceras lyra* Hyatt, Early Sinemurian, Dolný Mlyn Fm. (Scale bar = 1 cm)

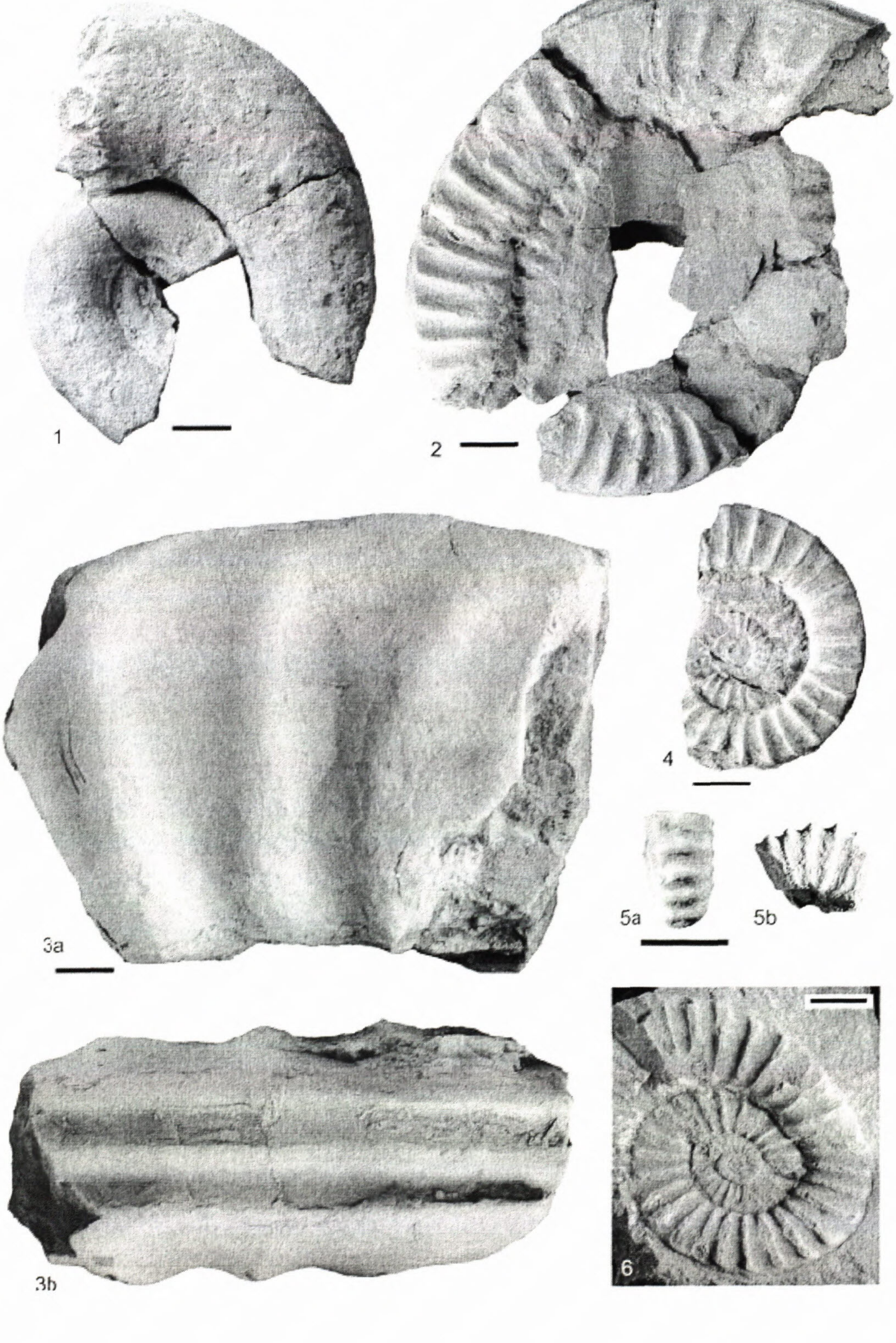


Fig. 8. *Lytoceras* cf. *sublineatum* (Oppel), Late Toarcian, Hŕbok Marl Fm. 2. *Coroniceras (Paracoroniceras)* cf. *charlesi* Donovan, Early Sinemurian, Dolný Mlyn Fm. 3a, b. *Coroniceras lyra* Hyatt, Early Sinemurian, Dolný Mlyn Fm. 4. *Arnioceras semicostatum* (Young & Bird), Early Sinemurian, Dolný Mlyn Fm. (ex situ). 5a, b. *Bifericeras* sp., Late Sinemurian, Allgaü Fm. (ex situ). 6. *Arnioceras* sp., Early Sinemurian, Dolný Mlyn Fm. (ex situ). (Scale bar = 1 cm)

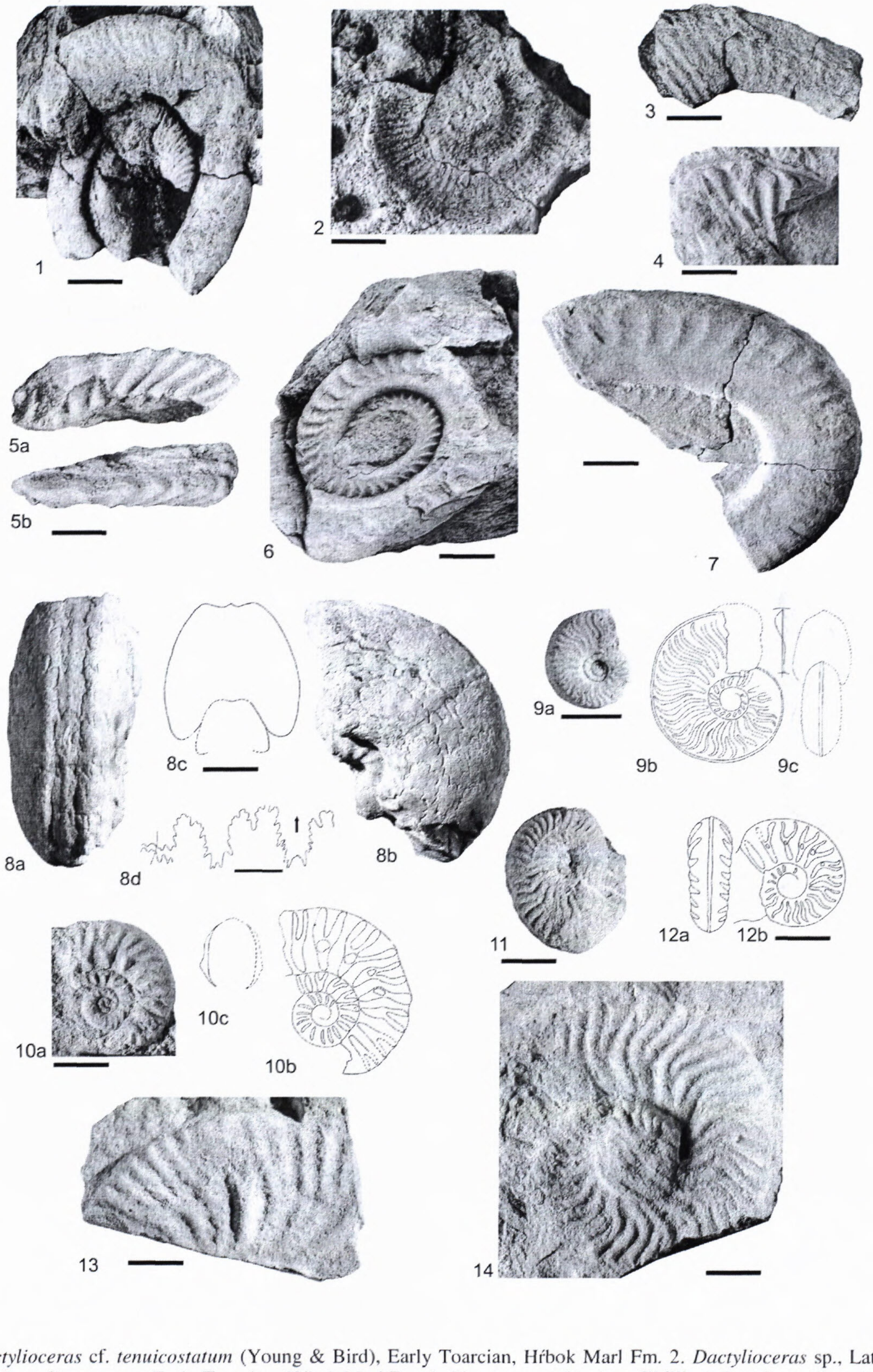


Fig. 9. 1. *Dactylioceras* cf. *tenuicostatum* (Young & Bird), Early Toarcian, Hŕbok Marl Fm. 2. *Dactylioceras* sp., Late Domerian, Hôrka Fm. 3. *Dactylioceras* sp., Early Toarcian, Hŕbok Marl Fm. 4. *Pleuroceras* cf. *solare* (Phillips), Late Domerian, Allgäu Fm. 5a, b. *Pleuroceras* cf. *spinatum* (Bruguière), Late Domerian, Allgäu Fm. 6, 7. *Hildoceras lusitanicum* Meister, Middle Toarcian, Hŕbok Marl Fm. 8a-d. *Frechiella subcarinata* (Yound & Bird), Middle Toarcian, Hŕbok Marl Fm. 9a-c. *Brasilia (B.)* sp. juv. [cf. *Brasilia (B.) bradfordensis* (Buckman)], reworked phosphatised cast, Aalenian, crinoidal limestones, Member A. 10a-c, 12a, b. *Ludwigia* sp., reworked phosphatised casts, Aalenian, Member A. 11. *Brasilia (B.)* gr. *bradfordensis* (Buckman), Aalenian, crinoidal limestones, Member A. 13. *Graphoceras* sp., Aalenian, crinoidal limestones, Member A. 14. *Ludwigia* (*Pseudographoceras*) sp., Aalenian, crinoidal limestones, Member A. (Scale bar = 1 cm)

Slovak Geol. Mag., 10, 4 (2004), 241 – 262

Distribution: The taxon is restricted to the Middle Toarcian, *H. bifrons* Zone. It is very rare in the Western Carpathians, known from two localities only, Beňatina and Červený Kameň – Podbiel (Rakús, 1994).

Graphoceratidae Buckman, 1905
Graphoceratinae Buckman, 1905
Ludwigia Bayle, 1878

Ludwigia sp.
Fig. 9.10 a-c, 9.12 a,b

Material: Four incomplete subadult specimens.
Remarks: All material is represented by juvenile and subadult specimens. They are evolutely coiled with suboval whorl section. Ventrum is arched, bearing a blunt keel. Subadult whorl section becomes high-oval with arched ventrum, without distinct keel. Flanks are only slightly convex, almost parallel in the middle of the flanks (Fig. 9.10c).
The first two whorls are smooth, the first simple but strong ribs appear on the third whorl. On the fourth whorl they become bifurcate, always alternating with the simple ones. On the fifth whorl the ribs are irregularly divided: first trifurcate ribs appear. They bear small tubercles at the point of division. The ribbing fade out on the ventrolateral margin.
Suture is visible on the juvenile whorls only, E and L are of the same depth. Also the lateral saddles are of the same heigh.
Distribution: The material comes from grey marly crinoidal limestones. The specimens are associated with *Brasilia (B.)* sp. juv. [cf. *B. (B.) bradfordensis*], indicating Aalenian, *L. murchisonae* Zone.

Ludwigia (Pseudographoceras) sp.
Fig. 9.14

Material: One incomplete negative imprint.
Remarks: The specimen comes from the light-grey slightly sandy limestones. The shell is weakly involute (D = 55 mm) with narrow and arched ventral side. The ribs are sigmoidal, bifurcate and their radial line is versiradiate (sensu Gabilly, 1976, p. 59). The type of ribbing indicates its belonging to the subgenus *Pseudographoceras*.
Distribution: Grey slightly sandy crinoidal limestones, *L. murchisonae* Zone.

Graphoceras Buckman, 1898
Graphoceras sp.
Fig. 9.13

Material: Two incomplete imprints of the outer whorls.
Remarks: Involutely coiled ammonite with narrow umbilicus, flat and high whorls with rursiradiate strong and bifurcate ribs. Ventral side is narrow and arched. Radial line is anguliradiate – cranked in the form of a largely open V. These characters are typical of *Graphoceras*.
Distribution: Light-grey fine-grained crinoidal limestones, Aalenian, probably *G. concavum* Zone.

Brasilia Buckman, 1898

Brasilia (B.) sp. juv. [cf. *Brasilia (B.) bradfordensis* (Buckman, 1887)]
Fig. 9.9 a-c

Material: One incomplete phosphatised internal cast of a juvenile ammonite.
Remarks: Although the specimen is juvenile, at the base of the type and density of ribbing it can be assigned to the species *B. (B.) bradfordensis*. It is involute with relatively narrow umbilicus (Fig. 9.9 a,b). The whorl section is compressed with arched ventral side and flat convergent flanks. Umbilical wall is rounded. The whorls bear dense, bifurcate, slightly sigmoidal ribs. Radiale line is versiradiate with long proximal segment.
Distribution: Taxon is rare in the Western Carpathians, untill now known only from the locality Litmanová (Scheibner, 1964) and from the locality Lukoveček, Hostýnske vrchy (Rakús, 1987). It is also known from the Ukrainian part of Pieniny Klippen Belt (Kalinitchenko et al., 1965). Aalenian, *L. murchisonae* Zone.

Notes on ammonite fauna

Early Sinemurian (Dolný Mlyn Fm.) as well as Toarcian deposits (Hŕbok Marl Fm.) yielded a quite ubiquitous ammonite fauna, almost essentially composed of Arietitidae and Hildoceratidae (Fig. 12). The genera *Arnioceras, Coroniceras, Hildoceras, Frechiella* and *Dactylioceras* are largely known from the epiplatform and epioceanic areas of the Early Jurassic Tethys (Dommergues et al., 1987, Mouterde & Elmi, 1991). The same can be state for the Aalenian deposits, where the Graphoceratidae constitutes 100% of the Ammonitina. On the other hand, during the Domerian and very probably also during Carixian the area of study (Czorsztyn Ridge) clearly stayed under strong Sub-boreal influence. The Sub-boreal taxa *Pleuroceras* and *Amaltheus* are common in the Domerian deposits of the Pieniny Klippen Belt successions (Rakús, 1990b, Schlögl et al., 2000). Another Sub-boreal genus *Liparoceras* was also frequently cited from the Carixian (e.g. Schlögl, 1998).
Presence of Phylloceratina and Lytoceratina was controled by local ecological factors. They are generally associated with deeper, pelagic Tethyan environments. Their scarcity or absence in certain formations points to unfavourable palaeoecological situation. Lytoceratina were completely absent in the Early Sinemurian and Late Domerian and very rare in the *L. murchisonae* and *G. concavum* Chrons of the Aalenian (Fig. 12). Phylloceratina were totally absent during the Early Sinemurian. In the Late Domerian, Toarcian and Aalenian they constitute between 15% and 25% of the whole fauna. Their anomalous high percentage among reworked phosphatised fauna of the Middle Aalenian (more than 70%) could be caused by several primary or secondary processes, such as local oxygen-depleted conditions during the deposition of the dark marly layers. Sorting by bottom currents including size-sorting could also influenced the final ammonite spectrum. About 50% of both these necto-pelagic groups

in the Lower Bathonian ammonitico rosso deposits agrees with the assumed trend of Middle Jurassic deepening of the Czorsztyn Ridge (e. g. Wierzbowski et al., 1999).

During the Middle Jurassic the fauna had a typical Mediterranean character. Immigration of some South-Tethyan taxa took place during the Z. *zigzag* Zone of the Early Bathonian. Beňatina is the first Carpathian locality where the true Arabian ammonites were found (see Schlögl & Rakús, in press). Three specimens of *Micromphalites (M.)* aff. *pustuliferus* (Douvillé) have been collected. Early Bathonian *Micromphalites* are considered as imigrants from the Arabia - Sinaï area along the North-African and East-European continental margins (Enay et al., 2001, Schlögl & Rakús, in press). The Mediterranean

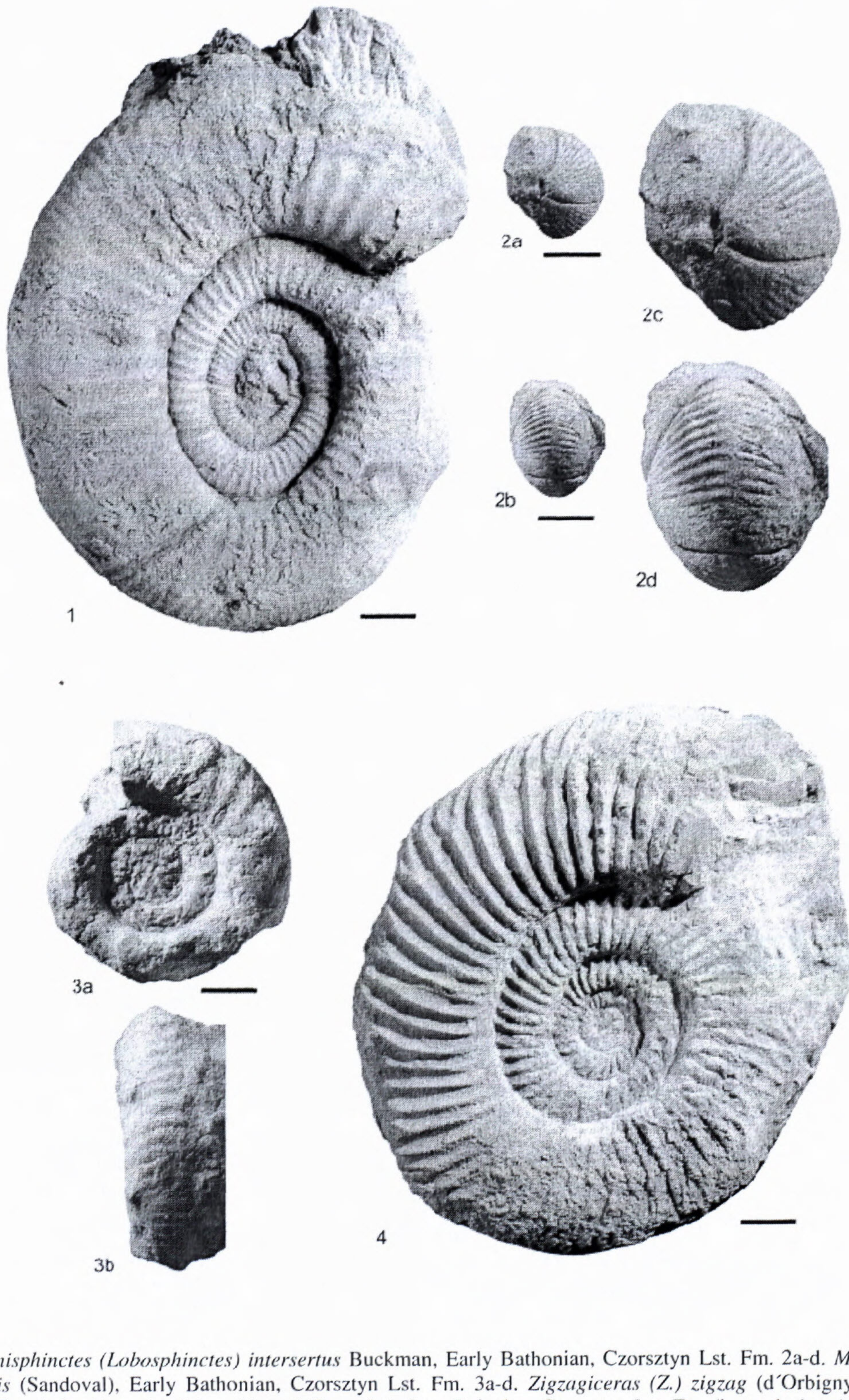


Fig. 10. 1. *Planisphinctes (Lobosphinctes) intersertus* Buckman, Early Bathonian, Czorsztyn Lst. Fm. 2a-d. *Morphoceras (M.)* cf. *dimorphitiformis* (Sandoval), Early Bathonian, Czorsztyn Lst. Fm. 3a-d. *Zigzagiceras (Z.) zigzag* (d'Orbigny), Early Bathonian, Czorsztyn Lst. Fm. 4. *Parkinsonia (P.) parkinsoni* (Sowerby), Late Bajocian, Czorsztyn Lst. Fm. (barscale 1 cm)

Slovak Geol. Mag., 10, 4 (2004), 241 – 262

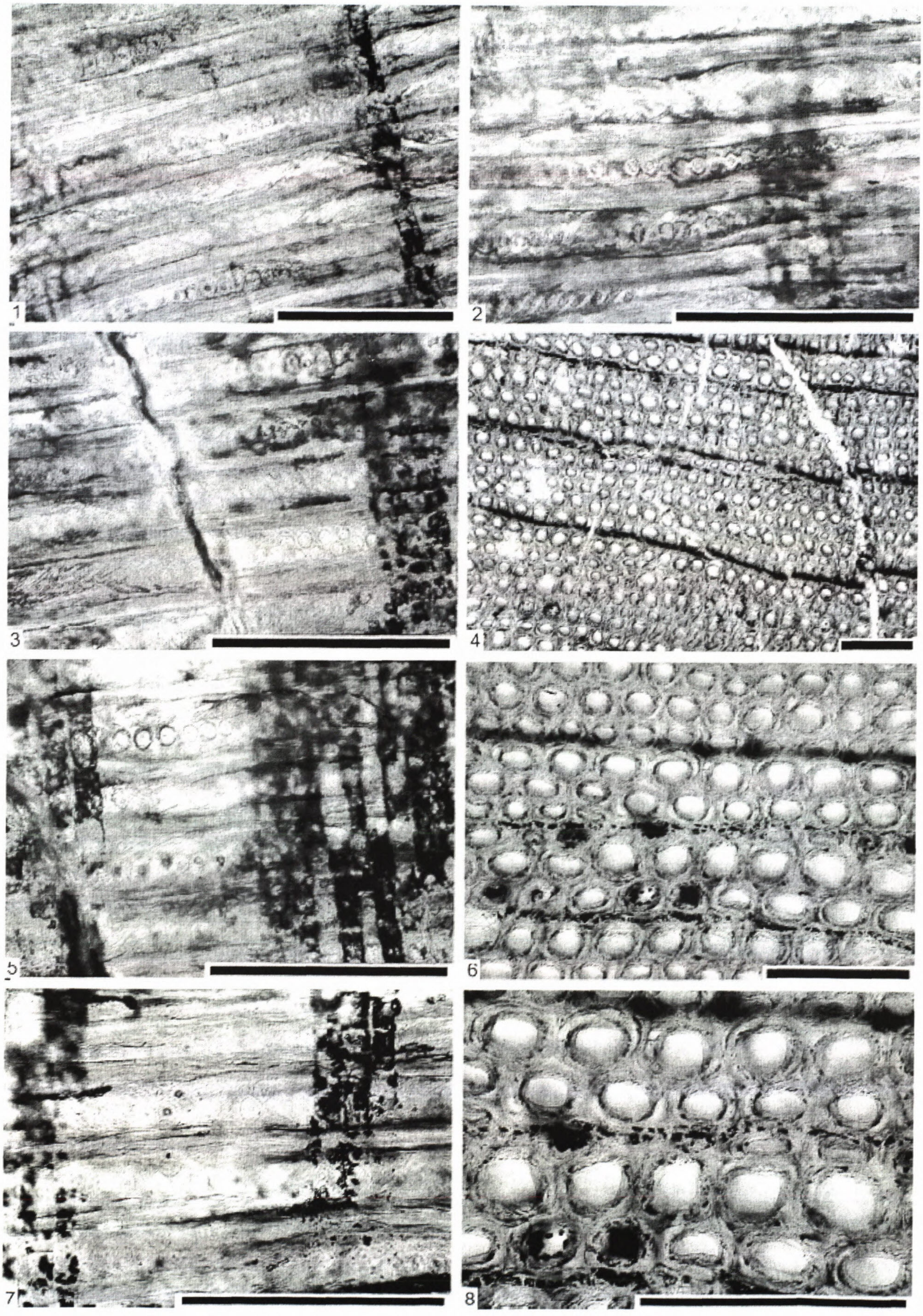


Fig. 11. *Brachyoxylon* sp., longitudinal (1 - 3, 5, 7) and transversal (2, 4, 6, 8) sections. Late Aptian, Nižná Unit. (Scale bar = 0,25 mm)

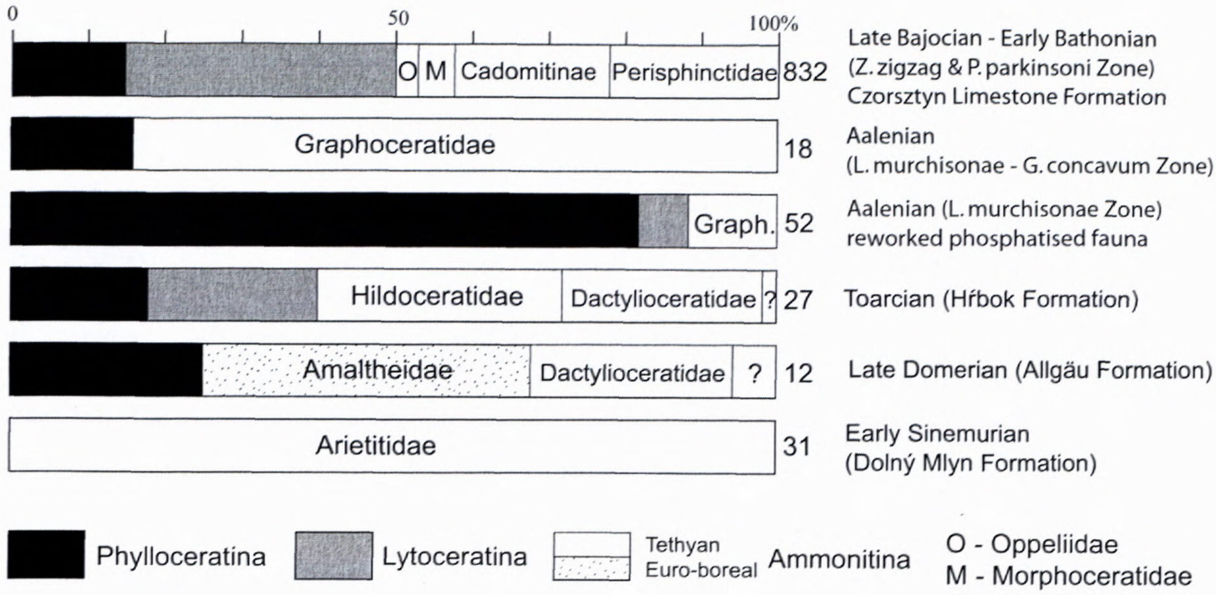


Fig. 12. Relative abundances of ammonite higher taxa from the most fossiliferous parts of the studied Beňatina sections. Dark and grey taxa represent necto-pelagic ammonites.

character of the Late Bajocian - Early Bathonian fauna (*P. parkinsoni* and *Z. zigzag* Chrons) is proved by high proportion of Phylloceratina and Lytoceratina (63%), which extensively prevail over Ammonitina (37%). Among Lytoceratina the genus *Nannolytoceras* is the most abundant (90 %), which is a common feature shared by the most localities studied in the Pieniny Klippen Belt area. The Ammonitina shows a very high percentage of Cadomitinae. This fact is caused by local abundance of very rare taxon *Benatinites* (*B.*) gr. *schlageri* (Krystyn) (Schlögl et al., in press). Presence of both Morphoceratidae and Parkinsoniinae allows the biostratigraphical correlations with the Mediterranean and NW-European areas.

Palaeobotany

Some layers within the Early Cretaceous part of the section contain incrusted wood fragments with well preserved internal structure. On the base of their anatomy they clearly belong to conifers (Pinopsida), most probably to the genus *Brachyoxylon*. Perpendicular and transversale sections show typical araucarian and abietineous type of pitting (Fig. 11). Very similar forms have been described by Laudoueneix (1973) from the Tchad (Central Africa). Another occurences (under the name *Brachyoxylon brachyphylloides* (Torrey) were reported from USA (Torrey, 1923) and from Tunisia (Boureau, 1952). Stratigraphic range of the species is from Middle Jurassic to Middle Cretaceous.

Acknowledgements

The study was carried out within the project KBN 6 P04D 022 21 of the Polish State Comittee for Scientific Research and the NATO grant project: ST.CLG.980120: Environment, Ecology and Geologic Evolution of the Jurassic Basins. The work was also supported by grant VEGA 2/4095/4A: Geological structure and tectonic evolution of the Pieniny Klippen Belt. S. J. wish to thank AAPG for awarding him by Raymond C. Moore memorial grant in the year 2004. We are also grateful to Dr. Ewa Glowniak for determination of the Oxfordian ammonites.

References

Andrusov, D., 1931: Étude géologique de la Zone des Klippes Internes des Carpathes Occidentales. I[ière] Partie: Introduction. II[ième] Partie: Stratigraphie. Rozpravy Státního geologického Ústavu ČSR, 6, 167 p. [in Czech and French].

Andrusov, D., 1945: Geological research of the Inner Klippen Belt, Western Carpathians. Part. IV: Stratigraphy of the Dogger and Malm. Part. V: Stratigraphy of the Cretaceous. Práce Štátneho geologického Ústavu, 13, 176 p.

Aubrecht, R., Mišík, M. & Sýkora, M., 1997: Jurassic synrift sedimentation on the Czorsztyn Swell of the Pieniny Klippen Belt in Western Slovakia. In: Plašienka, D., Hók, J., Vozár, J. & Elečko, M. (eds.), Alpine evolution of the Western Carpathians and related areas, Abstracts & Introductory articles to the excursion. Dionýz Štur Publishers, GSSR, Bratislava, 53 – 64.

Birkenmajer K., 1977: Jurassic and Cretaceous lithostratigraphic units of the Pieniny Klippen Belt, Carpathians, Poland. Studia Geologica Polonica, 45, 158 p.

Birkenmajer, K. & Myczyński, R., 1994: Pliensbachian (Early Jurassic) fauna from the Pieniny Klippen Belt, Carpathians, Poland: its stratigraphic and palaeogeographic position. Bulletin of the Polish Academy of Sciences, Earth Sciences, 42, 4, 223 – 245.

Boureau, E., 1952: Contribution à l´étude paléoxylologique de l´Afrique du Nord. IV: Sur un échantillon de Brachyoxylon (Telephragmoxylon) du Jurassique moyen de Tunisie. Bulletin de la Societé géologique de France (Paris), 6 série, 2, 169 – 174.

Cecca F., Savary B., Bartolini A., Remane J. & Cordey F., 2001: The Middle Jurassic - Lower Cretaceous Rosso Ammonitico succession of Monte Inici (Trapanese domain, western Sicily): sedimentology, biostratigraphy and isotope stratigraphy. Bulletin Societé géologique de France, 172, 5, 647 - 660.

Corna, M., 1987: Élements de phylogienie des Arietitidés d´apres les données du Jura méridional. Cahiers Institut Catholique Lyon, 1, 93 - 104, Lyon.

Dommergues, J.-L., Marchand, D. & Thierry, J., 1987: Biogéographie des ammonites jurassiques et réconstitution palinspastic de la Téthys. Geodinamica Acta, 1, 4/5, 273 – 281.

Dulai, A. 2003: Hettangian and Early Sinemurian (Early Jurassic) brachiopods of the Transdanubian Central Range (Hungary) II. Resultationes Investgationum Rerum Naturalium Montium Bakony 27, 5-144. [in Hungarian].

Slovak Geol. Mag., 10, 4 (2004), 241 – 262

Enay R., Gauthier H., Trevisan M., Berton J.-B., Brivet L., Brodbeck J.-L-, Demaizieres J.-F., Donc P., Fourel A. & Trehour M., 2001: Les *Micromphalites* (Ammonitina) du Bathonien inférieur de la Nièvre (France): installation sur la marge européenne de la Téthys de formes sud-téthysiennes d´origine arabique et description d´un néotype de *M. busqueti* (de Gross.). Revue de Paléobiologie, 20, 2, 503 - 524.

Fernández-López, S., 1985 : El Bajociense en la Cordillera Iberica. Thesis Doctoral Universidad Complutense, Madrid, 850 p.

Gabilly, J., 1976 : Le toarcien à Thouars et dans le centre-ouest de la France. Éditions du CNRS, Comité Français de stratigraphie, Paris, 3, 217 p.

Galácz, A., 1980: Bajocian and Bathonian ammonites of Gyenespuszta (Bakony Mts., Hungary). Geologica Hungarica, Seria Palaeontologica, 39, 227 p.

Géczy, B., 1967: Ammonites jurassique de Csernye, montagne Bakony, Hongrie. - Part II (exl. Hammatoceratidae). Geologica Hungarica, Ser. Paleontologica, 35, 413 p.

Guerin - Franiatte, S., 1966: Ammonites du Lias inférieur de France. Psilocerataceae: Arietitidae. Centre National de Recherches Scientifiques, 455 p., Paris.

Hlôška M., 1992: Geology of the Pieniny Klippen Belt in the area north of Stará Turá. Unpublished MsC Thesis, Comenius University, Bratislava, 41 p. [in Slovak].

Kalinitchenko, T. D., Kruglov, S. S. and Migacheva, E. E., 1965: Ammonites of the Dogger from the Pieniny Klippen Zone (Transcarpathians). Paleontologicheskij Sbornik, 2, 42 - 47, Lwow. [in Russian].

Krobicki, M., Kruglov, S. S., Matyja, B. A., Wierzbowski, A., Aubrecht, R., Bubniak, A. & Bubniak, I., 2003: Relation between Jurassic klippen successions in the Polish and Ukrainian parts of the Pieniny Klippen Belt. XVIIth Congress of the Carpathian-Balkan Geological Association, Bratislava, September 1-4, 2002, Post-congress Proceedings, Mineralia Slovaca, 35, 1, 56-58.

Laudoueneix, M., 1973: Sur deux bois homoxylés de la region de Layon (Tchad). Comptes rendus du Quartrevingt-seizième Congrés Nationale des Societés Savantes, Toulouse 1971, 107 – 131.

Mišík M., 1997: The Slovak part of the Pieniny Klippen Belt after the pioneering works of D. Andrusov. Geologica Carpathica, 48, 4, 209 – 220.

Mouterde, R. & Elmi, S., 1991: Caractères différentiels des faunes d´ammonites du Toarcien des bordures de la Téthys. Signification paléogéographiques. Bulletin de la Societé géologique de France, 162, 6, 1185 – 1195.

Plašienka, D., 2003: Dynamics of Mesozoic pre-orogenic rifting in the Western Carpathians. Mitteillungen der Österreichischen Geologischen Gesellschaft, 94 (2001), 79 – 98.

Rakús, M., 1977: Complementary lithostratigraphic and palaeogeographical data of the Jurassic and Cretaceous of the Manin Unit, middle Váh Valley. Geologické práce, Správy 68, 21 – 38. [in Slovak].

Rakús, M., 1987: Cephalopod fauna of the Lias and Dogger from olistholiths of Rača Unit of the Magura Flysch (locality Lukoveček). Západné Karpaty, séria Paleontológia, 12, 7 – 30.

Rakús M., 1990a: Ammonites and the stratigraphy of the base of the Czorsztyn Limestone in the Klippen Belt in Slovakia and Ukrainian Carpathians. Knihovnička Zemního plynu a nafty (Hodonín), zv. 9b, 73 – 108. [in Slovak].

Rakús M., 1990b: Paleobiogeography of Pliensbachian ammonites in the West Carpathian Mountains. Mémoires de la Societé Géologique de France, Nouvelle série, 154, 41 - 44.

Rakús, M., 1994: Jurassic and Lower Cretaceous sequence of the Červený Kameň Klippe near Podbiel (Orava, Western Carpathians), In: Borza, V., Ondrejíčková, A., Halásová, E., Rakús, M., Vašíček, Z. and Boorová, D. (eds.), Abstract Book in the IGCP 362 Project Annual Meeting, Smolenice, 83, Bratislava.

Rakús, M., 1995: The first appearance of Dactylioceratides in the Western Carpathians. Slovak Geological Magazine, 1, 5, 165 – 170.

Rakús, M. & Marschalko R., 1997: Position of the Manín, Drietoma and Klape Units at the boundary of the Central and Outer Carpathians. In: Plašienka, D., Hók, J., Vozár, J. & Elečko, M. (eds.), Alpine evolution of the western Carpathians and related areas, Internat. Conf. Bratislava 1997, Abstracts & Introductory articles to the excursion, 79 – 97.

Rakús, M. & Potfaj, M., 1997: Mesozoic of the Klippen Belt. In: Žec B. (ed.), Explications to the geological map of the Vihorlatské and Humenské vrchy Mountains 1:50 000. Dionýz Štúr Press, GSSR, Bratislava, 39 - 48. [in Slovak].

Rulleau, L., 1998: Évolution et systématique des Phylloceratidae et des Lytoceratidae du Toarcien et du Dogger inférieur de la region lyonnaise. Documents des Laboratoires de Géologie Lyon, 149, 167 p.

Rulleau, L., Bécaud, M. & Neige, P., 2003: Les ammonites traditionnellement regroupées dans la sous-famille des Bouleiceratinae (Hildoceratidae, Toarcien): aspects phylogénétiques, biogéographiques et systématiques. Geobios, 36, 317 – 348.

Savary B., 2000: L´Ammonitico Rosso du Jurassique moyen et supérieur de la zone Trapanaise (Sicilie W, Italie): genèse des structures sédimentaires, discontinuités et implications paléogeographiques. D.E.A., PalSed, Univ. Claude Bernard, Lyon, 49 p.

Scheibner, E., 1964: Contribution to the knowledge of the Murchisonae Beds in thr Klippen Belt of the West Carpathians in Slovakia. Geologicky Sborník 15, 1, 1 - 28 Bratislava.

Scheibner, E., 1967: Nižná Subunit – new stratigraphical sequence of the Klippen Belt (West Carpathians). Geologický Sborník, 18, 133 – 140.

Schlegelmilch, R., 1976: Die Ammonites des süddeutschen Lias. Gustav Fischer Verlag, Stuttgart - New York, 96 p.

Schlögl J., 1998: Geological structure of the area between Vršatské Podhradie, Červený Kameň and Dolné Dúžavy. Unpublished MsC Thesis, Comenius University, Bratislava, 69 p. [in Slovak].

Schlögl, J., 2002: Sedimentology and biostratigraphy of the Ammonitico Rosso deposits of the Czorsztyn Formation of the Czorsztyn Unit, Pieniny Klippen Belt, Unpublished Ph.D. Thesis, Comenius University, Bratislava, 196 p. [in Slovak].

Schlögl J. & Rakús M., in press: Ammonites of Arabian origin from the Lower Bathonian deposits of the Czorsztyn Unit, Pieniny Klippen Belt (Western Carpathians, Slovakia). Neues Jahrbuch für Geologie und Paläontologie.

Schlögl J., Aubrecht, R. & Tomašových A., 2000: The first find of the Orava Unit in the Púchov section of the Pieniny Klippen Belt (Western Slovakia). Mineralia Slovaca, 32, 45 – 54.

Schlögl J., Elmi S., Mangold C., Rakús M. & Ouahhabi M., in press: Specialization and iterative evolution of some Western Tethyan Bathonian ammonites (*Benatinites*, *Lugariceras* and *Hemigarantia*). Geobios.

Siblík, M. 1993: Lower Liassic Brachiopods from the Steinplatte-Kammerköhralm area near Waidring (Northern Calcareous Alps, Salzburg). Jahrbuch der Geologischen Bundesanstalt, 136, 4, 965-982.

Siblík, M. 1999: New data on the Hettangian brachiopod fauna of the Northern Calcareous Alps. Abhandlungen der Geologischen Bundesanstalt, 56, 2, 419-438.

Torrey, R. E., 1923: The comparative anatomy and phylogeny of Coniferals. Part. 3. Mesozoic and Tertiary coniferous woods. Memoirs of the Boston Society of Natural History, 6, 2, 39 – 106.

Venturi, F. & Ferri, R., 2001: Ammoniti Liassici dell´Appennino Centrale. 3ª Edizione, ampliata e corretta, Perugia, 268 p.

Wierzbowski, A., Jaworska, M. & Krobicki, M., 1999: Jurassic (Upper Bajocian – Lower Oxfordian) ammonitico rosso facies in the Pieniny Klippen belt, Carpathians, Poland: its fauna, microfacies and sedimentary environment. Studia Geologica Polonica, 115, 7 – 74.

Rochovce metagabbro: Elemental and isotopic contamination by Late Cretaceous granite (the Western Carpathians)

JÁN KRÁĽ[1], ĽUBOMÍR HRAŠKO[1], MARTIN KOVÁČIK[1] and ROBERT BACHLIŃSKI[2]

[1]Geological Survey of Slovak republik (ŠGÚDŠ), Mlynská dolina 1, 817 04 Bratislava
[2]Institut Nauk Geologicznych PAN, ul. Twarda, 50/55, Warszava, Poland

Abstract: The drilling into the body of hidden granitic intrusion near Rochovce village revealed (Klinec et al., 1979) the location of approximately 100 m thick body of dark metamorphosed gabbroidic rocks directly above the Cretaceous Rochovce granite. The compiled petrographic, geochemical and isotopic data support the arguments about the autochthonous, pre-granite position of Rochovce gabbro above the Rochovce Late Cretaceous granite. The intrusion of granite caused not only the gabbro penetration by aplitic veinlets, but significantly influenced its former material (mineral, chemical) and isotopic compositions. The impacts of contamination processes were selective. They resulted mainly in the extreme enrichment of metagabbro by Rb and LREE. The isotopic composition of strontium $(^{87}Sr/^{86}Sr)_{76}$ in gabbroid after the granitic contamination generally corresponds with its original composition, but the isotopic composition of Nd is significantly lowered. As a result of contamination, the isotopic characteristics of Nd and Sm/Nd ratio in gabbro copy those of underlying granite. This is the reason, why these data cannot be used as characteristic end-member in geochemical considerations about interaction (mixing) of mafic and acid magmas during the genesis of Hercynian granitoids of the crystalline basement of Western Carpathians. The geological, structural and partially also petrographic data allow to limit the lower age of investigated gabbroidic body with the age of Hercynian granitoids intrusions in Veporicum (350 – 300 Ma) and upper age with Alpine (Cretaceous) tectonic processes – the Cretaceous intrusion of Rochovce granite. The $^{40}Ar/^{39}Ar$ dating of amphiboles yield the age of origin of newly formed amphiboles in gabbro during the contact metamorphic recrystallization caused by intrusion of Rochovce granite and suggests the complete loss of accumulated radiogenic $^{40}Ar^*$. The age of amphibole from metagabbro 75.9 ± 1.8 Ma represents an independent proof of intrusion age of Rochovce granite.

Key words: Veporic unit, Rochovce, Alpine granite, metagabbro, elemental and Sr, Nd isotope interactions

Introduction

The existence of hidden granitoid intrusion has been supposed in the area of southeastern boundary of the Kohút zone of Veporicum and at its tectonic contact with Gemericum already earlier (Vrána, 1964a). The drilling works at the end of the 1970´s (borehole KV-3, Klinec et al., 1979) proved the presence of granitoid body with supposed Alpine age, appearing in the approximate depth 700 m. The appox. 100 m thick body of dark metamorphosed gabbroidic rocks is located above this so-called Rochovce granitic body. This article aims to evaluate geochemical and isotopic data from gabbro and granite and to determine whether the present data are usable for the conception of mutual geochemical (and isotopic) interaction of both bodies.

Brief summary of former works

The geological setting of the Pre-Alpine units in the wider area of the Rochovce village is complicated with the hidden Alpine granitic intrusion forming contact aureole with biotite, cordierite, occasionally also with andalusite (Klinec et al., 1980; Vozárová, 1990). Petrographic, mineralogical and geochemical characteristics of the Rochovce granite differ from granitoids of Veporicum and Gemericum (Határ et al., 1989). The Upper Cretaceous age of this body was proved by two independent zircons U-Pb datings - 82 ± 1 Ma and 76 ± 1.1 Ma (Hraško et al., 1999; Poller et al., 2001). Directly above the Rochovce granite the approximately 100 m thick body of dark metamorphosed gabbroidic rocks is located (borehole KV-3). The drilling works have shown, that in the basal part of the gabbroidic body the weak Ni-Co-(Cu) mineralization is present (Ivanov, 1981, 1983). In the past this finding led to more detail studies, concerning the petrogenetic, metallogenetic and metamophic topics. The metagabbro genesis and its relation to granite is interpreted by various authors differently. The differences preferably concerned the reasons of metagabbro metamorphic changes, including evaluated P-T conditions. Some authors prefer the Hercynian regional metamorphism (Krist et al., 1988; Korikovskij et al., 1989), others suppose the metamorphism of the body to be a result of the heat from underlying Cretaceous granitoid intrusion (Kantor & Rybár 1979a; Ivanov 1981, 1983). Hovorka (1983) connects the origin of mineral neoblasts and mainly the metasomatic replacement of amphibole by biotite with the thermal effect of underlying granite; the temperature increase in the granite exocontact he estimated to 550-600 °C.

According to Krist et al. (1988) and Korikovsky et al. (1989), the protolith – subalkaline, biotite–pyroxene-amphibole gabbro was metamorphosed in conditions of garnet zone of epidot-amphibolite facies (T = 440 – 450 °C, medium pressure conditions) during Hercynian regional metamorphism, coinciding with the metamorphic conditions of basic rocks (amphibolites) of the complex of Hladomorná dolina valley (sensu Vrána, 1964b). Krist et al. (l.c.) supposed the tectonic contacts of granite with gabbro, because no evidences of contact metamorphism by granite were found in the gabbro.

No special attention was paid to the age of metagabbro in above cited works, despite the geological indications (Ivanov, 1981), that it is younger in comparison with phyllites and micaschists of the Hladomorná dolina valley (Lower Paleozoic-Devonian; Klinec & Planderová, 1981, resp. Slatviná Formation of the Upper Carboniferous age according to Vozárová & Vozár, 1982) and older than the intrusion of Rochovce granite. The Carboniferous age of the gabbro was supposed by Ivanov (1983). Kantor & Rybár (1979b) published the K/Ar ages from amphibole, resp. biotite of the metagabbro 82 resp. 75 Ma, being interpreted as a product of temperature influence of the Rochovce granite on gabbro.

2. Geological position of metagabbro

The metamorphosed gabbroidic body is a constituent of the lower part of rock sequence being in the past regarded as the migmatitized part of crystalline basement, resp. aplitoid granites without adequate categorization. After the reevaluation of drilling material we regard these rocks to be the Hercynian granitoids, and mainly granodiorites of Vepor type and their aplitoid varieties, which suffered the Hercynian as well as Alpine regional deformation and recrystallization.

Accordingly, in the drilling profile the gabbroidic body is located in the underlier of complex of metagranitoids of Vepor type and directly in the contact with Rochovce granite (Fig. 1). The question about mutual relation of these two bodies was until now not unambiguously answered. As we document in the further text, the overlying rock complexes including the metagabbro alone, are penetrated with subvertical veins of granite-aplite (Fig. 2A), being derived from underlying granite and oriented relatively perpendicularly to mineral lination (most probable of Alpine age) of metagranitoids and metamorphites and penetrating into the brittle structures without more distinct interactions with rocks. Part of the body expresses also older granitization process (Fig. 2B), probable relating with the uppermost thermal reworking of gabbroid, accompanied with production of leucotrondhjemitic aplitic veins and bulges. The coarse-grained xenoliths of overlying metagabbro are present in granitic matrix of the uppermost part of granite (Fig. 2C). They differ from the microgranular enclaves found in granite (Hraško et al., 1998). The age of emplacement of gabbro into the recent position in the overlier of granite is therefore pre-granitic and not post-granitic, as suppose Krist et al. (1988). The relation of metagabbro and overlying metagranitoid probable resemble the relation of Hercynian

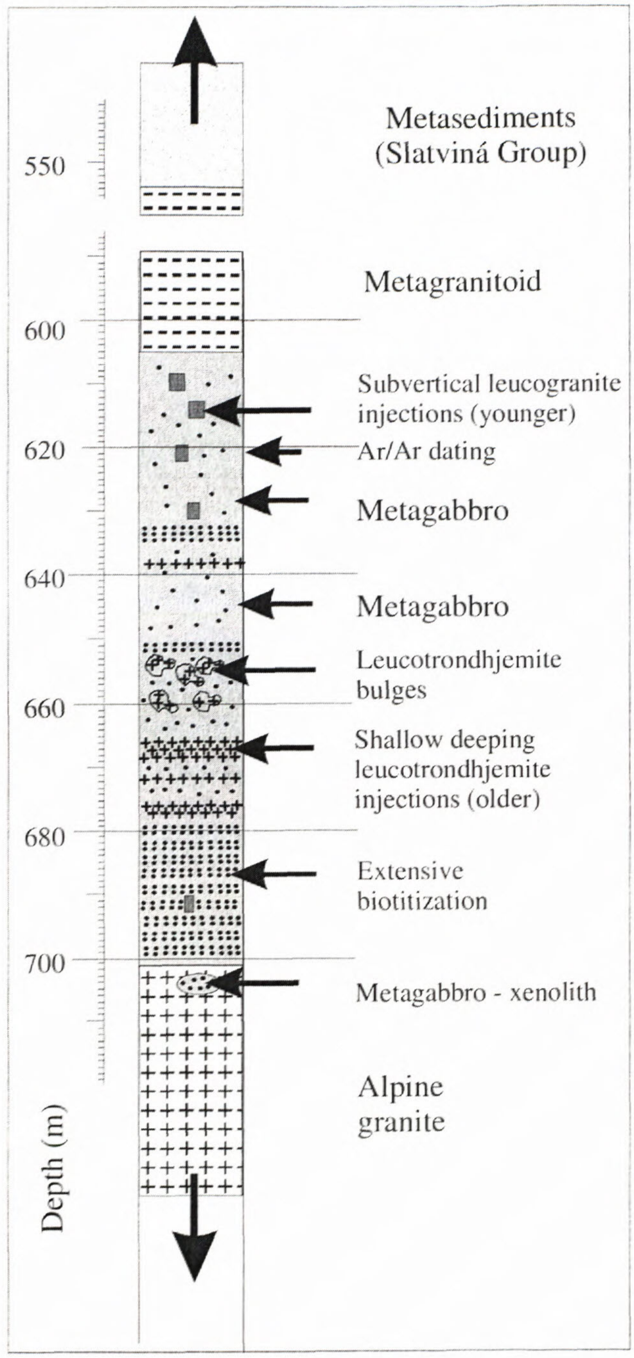


Fig. 1 Position of metagabbro and Late Cretaceous granite (borehole KV-3) near Rochovce village. The metagabbro was found only in borehole KV-3.

granitoids and hornblendites in the Stolica massif. The position of metagabbro beneath Veporic metagranitoids of the Kohút massif can be explained also in the case that gabbroidic rock is Alpine and intruded before the granite intrusion – so the metamorphic imprint in the mineral association of metagabbro are related only to the influence of granitic intrusion.

3. Petrographic description of analysed sample

Analysed sample was taken from the uppermost part of metagabbro in the approximate distance 80 m from the

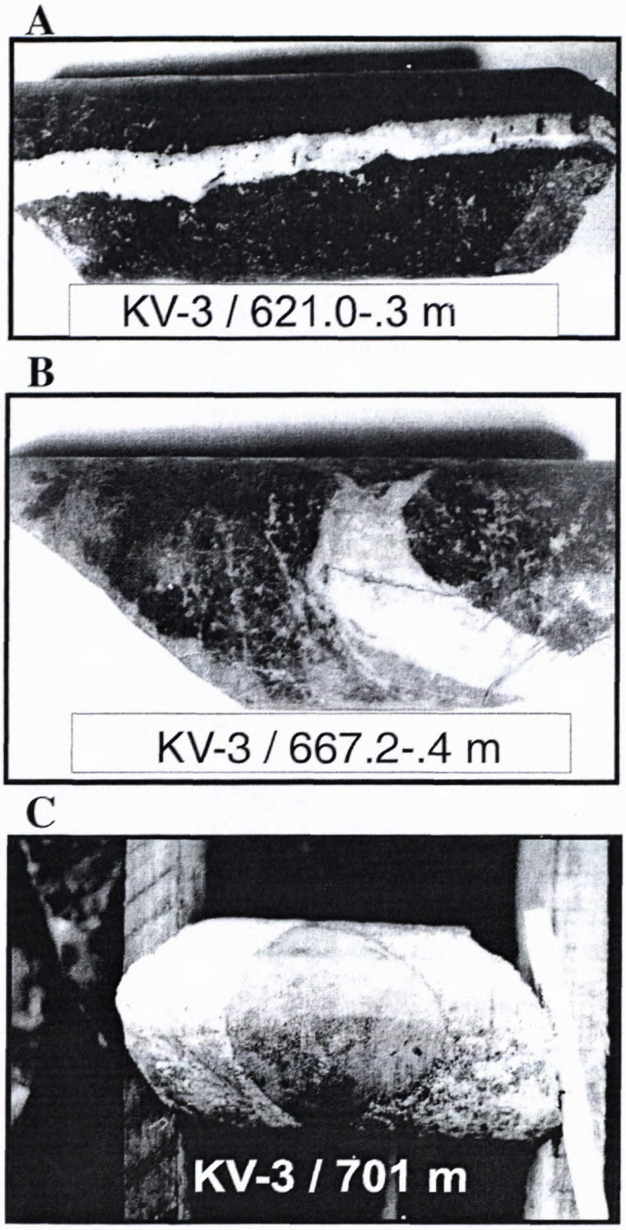


Fig. 2 Mutual relation of Rochovce granite and gabbro. A) Penetration of the Rochovce granite vein into the metagabbro. B) Aplitic, leucotrondhjemitic veins and bulges in metagabbro (products of melting of gabbroidic protolith?) C) Xenolith of metagabbro in the upper part of Rochovce intrusion.

contact with underlying granite. The approximately 1 cm thick subvertical aplite veinlet is coursing around (Fig. 2A) and its contact with metagabbro is sharp. The more fine-grained aplite development is visible at the margin, indicating, that during granite intrusion the metagabbro was already solidified and had distinctly lower temperature than the temperature of aplitic leucocratic magma.

Studied rock is of dark-brown colour (predominance of biotite) with green nests of prevailing amphibole. Amphiboles usually reach millimetre size and structurally belong to primary magmatic association. There is often the formation of randomly oriented fine-grained amphiboles closed in idiomorphic remnants of former porphyrocrysts of amphibole, with their composition reflecting rather a metamorphic genesis. The sample contains two basic types of amphibole – the prevailing dark-green amphibole (Tab. 1, analyse 2) can be classified as edenite (sensu Leake et al., 1997) and pale-greenish amphibole represents the actinolite close to projection field of tremolite (an. 3). The rare phases of amphibole with brown pleochroism are characterized with increased content of Ti – the mineral correspons to pargasite (Tab. 1, an. 1), which can represent the relict magmatic amphibole. The relative age and genetic relations between individual amphibolic phases are not unambiguous and their analysis is above the frame of this chapter – in the majority of cases there is valid the overgrowth of strongly pleochroic amphiboles by pale-green tremolite (Fig. 3 right upper side). The nests of actinolite appear locally also in older position, so there cannot be excluded that they represent the pseudomorphs after magmatic olivine. Regarding the superimposed metamorphic recrystallization we can speculate that both amphibole types are more-or-less syngenetic. Hb2 is only very rarely replaced by neoblasts of minute biotite.

The dominating final rock overprint was biotitization. It affects preferably the strongly pleochroic amphiboles because of their suitable chemical composition. Tiny randomly oriented flakes, denoted Bt2, occasionally represent more than 90 % of the amphibole volume. They penetrate also the large-flakes of biotite Bt1. It proves their relative younger age. This secondary biotitization (Bt2) is accompanied with origin of accessoric minerals like titanite, apatite, epidote and allanite (Fig. 3). The chemical composition of newly-formed allanite (Tab. 3, analyses 2 a 3) contributed significantly to the increase of the total REE content in the rock. The biotite formation is rather younger than the origin of amphiboles and blasteses prograde from the development of bigger porphyroblasts (Bt1) till the ubiquitous fine-grained biotite aggregates (Bt2) of identical chemical composition than Bt1. Biotite locally associates with rare syngenetic chlorite.

Plagioclases (An_{33}) large to 5 mm are not intensively recrystallized. They originated most probable from magmatic phase. Their relatively homogenous composition

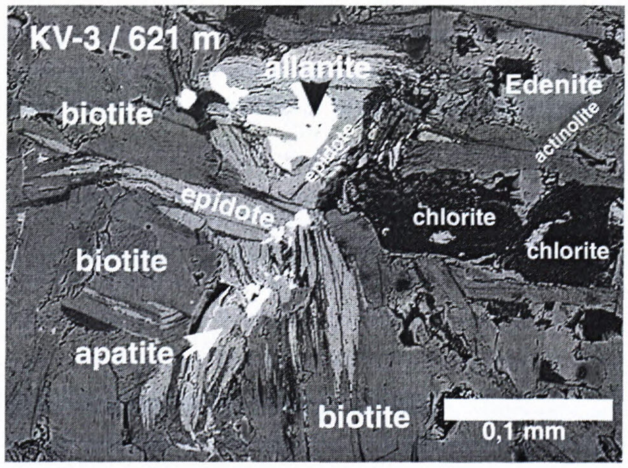


Fig. 3 Scanning picture depicting the younger metamorphic mineral association expressed mainly by biotitization („bt 2"), being accompanied by the development of epidote and syngenetic allanite – the main bearer of increased REE contents in the rock (cf. Tabs. 2 and 3).

Slovak Geol. Mag., 10, 4 (2004), 263 – 276

Tab.1 Representative chemical composition of amphiboles in sample KV-3/621 (all iron as Fe^{2+})

Mineral	Hornblende		
sample	KV-3 / 621 m		
	an. 1	an. 2	an. 3
SiO_2	41,86	45,57	56,11
TiO_2	2,09	0,68	0,02
Al_2O_3	13,69	11,86	3,31
FeO tot	10,19	9,91	5,85
MgO	13,28	14,94	20,22
MnO	0,26	0,18	0,17
CaO	10,04	10,85	11,51
Na_2O	2,03	1,73	0,45
K_2O	1,11	0,94	0,12
Total	94,55	96,66	97,76
	calculated on basis of 23 oxygens p. f. u.		
Si IV.	6,291	6,645	7,769
Al IV.	1,709	1,355	0,231
sum	8,000	8,000	8,000
Al VI.	0,716	0,683	0,309
Ti VI.	0,236	0,075	0,002
Mg	2,975	3,248	4,173
Fe2+	1,073	0,994	0,516
sum	5,000	5,000	5,000
Fe2+B	0,208	0,214	0,161
Mn	0,033	0,022	0,020
Ca	1,616	1,694	1,707
Na	0,143	0,070	0,112
sum	2,000	2,000	2,000
NaA	0,449	0,419	0,009
K	0,213	0,175	0,021
sum	0,662	0,594	0,030
M/MF	0,748	0,777	0,894

Tab. 2 Chemical analyses of newly formed epidote (an. 1) and allanite (an. 2, 3) as the main bearers of REE in the rock.

	anal. 1	**anal. 2**	**anal. 3**
SiO_2	36,481	33,628	31,627
Al_2O_3	19,032	19,910	16,622
CaO	21,973	16,224	12,232
FeO	16,340	11,067	10,269
TiO_2	0,168	0,333	0,592
MgO	0,000	0,545	2,338
MnO	0,086	0,411	0,185
P_2O_5	0,008	0,065	0,021
F	0,071	0,000	0,280
Cl	0,019	0,012	0,003
La_2O_3	0,000	2,940	6,955
Ce_2O_3	0,088	5,492	10,680
Pr_2O_3	0,005	0,617	1,272
Nd_2O_3	0,000	2,551	2,841
SmO	0,099	0,232	0,204
EuO	0,135	0,171	0,162
Gd_2O_3	0,006	0,637	0,898
Tb_2O_3	0,096	0,025	0,121
Dy_2O_3	0,044	0,000	0,000
Ho_2O_3	0,135	0,000	0,055
Er_2O_3	0,074	0,036	0,000
Tm_2O_3	0,157	0,000	0,073
Yb_2O_3	0,039	0,014	0,044
Lu_2O_3	0,211	0,385	0,000
Y_2O_3	0,035	0,150	0,046
U_2O_3	0,000	0,000	0,000
SrO	1,472	0,430	0,087
ZrO_2	0,008	0,000	0,000
HfO_2	0,000	0,117	0,576
ThO_2	0,000	1,622	0,856
total	96,781	97,612	99,041

can indicate, that the metamorphic conditions persisted in the field of stability of plagioclase of this composition. The coexistence of both amphiboles in association with plagioclase of similar composition reflects metamorphic conditions of upper part of greenschist facies, where in low-pressure conditions at 420-450 °C the actinolite is transformed to amphibole of hornblenditic composition (Maruyama et al., 1983). Though, in the drill core also domains with lower degree of superimposed metamorphism occur – the results of these changes are also amphiboles of bimodal composition. In fine-grained development, there is also present chlorite, albite and carbonate with inclusions of actinolite of needle shape. The character of this metamorphic overprint resembles more the Alpine regional metamorphism as we know from overprinting reactions in Hercynian amphiboles (Kováčik et al., 1996). In the regional scale the intermediary plagioclase in Pre-Alpine mafic rocks is usually changed to albite and fine-grained mixture with prevailing clinozoisite and older amphiboles to amphibole of actinolitic type, chlorite and biotite. These less metamorphosed zones can also express the lower thermal conditions of Rochovce aureole. Generally the newly formed mineral assemblages of Rochovce gabbro are in the large extent tied with allochemical metamorphic processes and correspondingly demonstrate the marked spatial variability. The Alpine regional deformation (preferably the penetrative lineations), being observed in the rocks of broad surrounding, is not so typical for gabbroidic rocks. It can be explained by several ways – for example by the more resistant gabbro rheology, the younger intrusive age than the bulk Alpine deformation, or by postdeformation recrystallization of amphibolite and biotites.

4. Chemical and isotopic composition of metagabbro

From until now published metagabbro geochemical data only those of Ivanov (1984) about the metagabbro REE content are known. Further analyses are from unpublished archive data (analyses of major elements) and three new analyses of main and trace elements.

Tab. 3 a,b: Chemical analyses of metagabbro from the borehole KV-3 (including data from archives – Klinec, Ivanov, ŠGÚDŠ laboratory)

Depth (m)	611,0	617,5	621,0	622,5	624,2	624.5	625.0
Author	Ivanov	SGUDS	Hrasko	SGUDS	Klinec	Hrasko	Hrasko
SiO_2		45,31	48,76	45,97	48,26	47,89	50,72
TiO_2	0,86	0,95	0,78	1,10	1,74	0,78	0,62
Al_2O_3		11,39	11,22	10,68	9,29	10,53	9,79
Fe_2O_3		7,78	2,34	7,22	1,29	2,32	2,25
FeO		0,20	5,16	0,71	6,29	4,93	4,84
MgO		14,77	16,21	15,77	14,80	16,69	16,08
MnO		0,210	0,165	0,130	0,180	0,133	0,134
CaO		11,02	7,44	11,01	9,89	8,82	7,16
Na_2O		1,55	1,74	1,60	2,50	1,69	1,55
K_2O		2,95	2,76	3,30	2,61	2,78	2,41
P_2O_5		0,41	0,34	0,39	0,22	0,33	0,35
H_2O+		2,50	2,50	1,00	2,46	2,00	1,14
H_2O-		0,33	0,25	0,09	0,10	0,16	0,43
CO_2			0,70	n.a.	n.a.	1,20	3,04
Total		99,37	100,37	98,97	99,63	100,25	100,51

Depth (m)	625.0	625.0	629,3	630,0	634,0	650,0	653,4
Author	SGUDS	SGUDS	Ivanov	Klinec	Klinec	Ivanov	Klinec
SiO_2	45,70	46,34		46,76	47,71		49,93
TiO_2	0,95	0,90	0,83	1,83	1,49	0,97	1,24
Al_2O_3	9,45	9,30		8,39	8,53		6,97
Fe_2O_3	1,68	2,34		3,43	3,59		3,48
FeO	5,69	5,62		5,65	4,85		4,63
MgO	16,21	17,05		16,60	16,06		14,67
MnO	0,150	0,140		0,300	0,280		0,270
CaO	10,47	11,00		9,25	9,78		12,56
Na_2O	1,30	1,50		1,87	1,88		2,30
K_2O	3,64	2,72		3,17	2,48		0,82
P_2O_5	0,39	0,20		0,36	0,29		0,18
H_2O+	2,20	1,20		1,75	2,60		2,35
H_2O-	0,12	0,05		0,31	0,04		0,10
CO_2	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Total	97,95	98,36	0,83	99,67	99,58		99,50

Depth (m)	684,5	689,5	692,5	693,0	695,2	695,6	696,0
Author	Ivanov	SGUDS	SGUDS	SGUDS	SGUDS	SGUDS	Klinec
SiO_2		43,65	46,29	44,50	44,58	45,20	46,94
TiO_2	0,92	0,88	0,95	0,65	0,78	0,79	1,13
Al_2O_3		7,25	11,02	8,06	7,85	7,12	10,43
Fe_2O_3		5,76	3,31	5,23	2,95	1,89	2,57
FeO		4,54	5,30	10,95	5,36	6,04	5,31
MgO		19,04	12,99	13,00	13,35	16,46	16,16
MnO		0,160	0,220	0,210	0,210	0,150	0,220
CaO		11,52	9,99	10,00	16,36	15,95	11,17
Na_2O		0,98	2,45	1,10	1,05	1,00	2,00
K_2O		1,60	2,85	1,50	2,72	2,29	1,38
P_2O_5		0,68	0,68	0,26	0,59	0,28	0,19
H_2O+		2,50	2,50	2,50	2,50	2,50	2,00
H_2O-		0,15	0,24	0,12	0,19	0,19	0,30
CO_2	n.a	n.a	n.a	n.a	n.a	n.a	n.a
Total		98,71	98,79	98,08	98,49	99,86	99,80

Tab. 3 a, b displays the contents of major and trace elements from metagabbro. In comparison with the mean values of the element contents in the average basic rocks of this type (Rösler & Lange, 1972) the metagabbro is significantly enriched by alkalies (Cs, Rb, Li – Fig. 4, Tab. 3), U, Th and light REE (La, Ce, Eu, Nd, Sm). The contents of Cr, Ba and Sr can probable represent the primary geochemistry of the body. The significant changes of the primary chemical composition can be assigned to the interaction of fluids derived from underlying Cretaceous intrusion with former gabbro (in the same way like it was interpreted by Hovorka, 1983). The mechanism of changes could be similar like that during the changes of chemical composition of mafic enclaves in granitic magma being influenced by diffusion of ions from granitic magma into the environment rich in amphiboles – one of its conspicuous effects is the biotitization and forming of allanite as a main carrier of LREE (Tab. 2). These processes were described for example by Orsini et al. (1991) and in Western Carpathian granitoids by Petrík & Broska (1989), Broska & Petrík (1993) and Hraško et al. (1998).

Tab. 3b

Depth (m)	611.0	621,0	624.5	625.0	629,3	650,0	684,5	699,0
Author	Ivanov	Hraško	Hraško	Hraško	Ivanov	Ivanov	Ivanov	Ivanov
Ba		635,5	677,9	670,6				
Be				0,1				
Ce	143,0	109,7	104,4	128,0	157,0	161,0	161,0	148,0
Co		43,0	46,0	48,3				
Cr		634,0	608,0	600,0				
Cs				8,7				
Cu		6,0	27,0	32,0				
Eu	3,5	2,5	2,6	2,8	3,4	4,1	4,0	3,7
Ga				6,80				
Hf	3,2	5,1	4,2	3,1	3,3	3,4	3,3	2,9
La	53,0	60,0	59,5	60,0	62,0	61,0	57,0	64,0
Li		47,0	37,0	25,0				
Lu	0,19	0,19	0,38	0,27	0,26	0,26	0,21	0,28
Nb	6,8	4,8	4,2		7,6	9,0	9,4	10,0
Nd	97,0	76,2	79,0	55,0	97,0	104,0	97,0	74,0
Ni		283,0	293,0	171,0				
Rb		139,0	83,0	62,0				
Sc	31,0			29,9	30,0	45,0	36,0	53,0
Sm	12,6	9,9	10,2	12,7	13,0	14,3	16,4	13,0
Sn				< 5				
Sr		637,9	1 809,6	720,0				
Ta	0,3	0,5	0,5	0,4	0,3	0,3	0,3	0,2
Tb	1,0	0,5	0,5	1,0	1,0	1,5	1,0	1,0
Tm	0,24				0,35	0,32	0,32	0,28
Th	8,2	8,8	8,1	11,7	8,9	8,6	10,1	10,9
V		118,0	121,0	110,0				
U		4,0	3,0	2,1				
Y	19,0	18,0	17,0	16,0	18,0	22,0	20,0	18,0
Yb	1,5	1,4	1,3	1,9	0,0	2,2	1,8	1,8
Zn				90,0				
Zr	100,0	122,9	89,5	115,0	114,0	112,0	108,0	132,0

Slovak Geol. Mag., 10, 4 (2004), 263 – 276

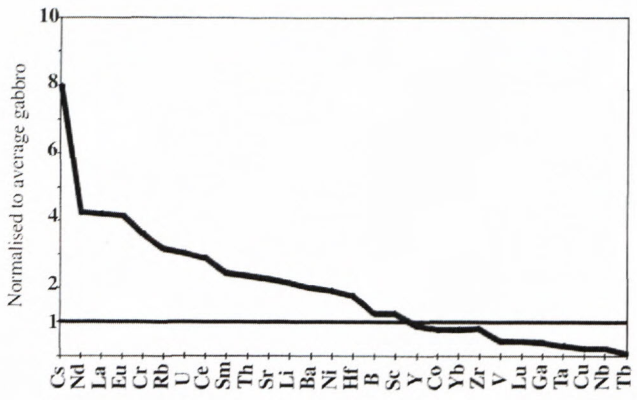


Fig. 4 Comparison of concentration of chosen elements in metagabbro and in rocks of similar type. Normalization is done to average gabbro (data in Rösler & Lange, 1972).

The judgement of influence of younger changes for chemical and isotopic characteristics of gabbroidic body is important also from the viewpoint of interpretation of basic end-member characteristic during the genesis of Hercynian granites (Kohút et al., 1999) as well as evaluation of validity of use of this data in genetic models of Hercynian granitoids.

During study of biotitization effects for the major element content we have used the classification diagrams by Debon & LeFort (1983), Irvine & Baragar (1971), Winchester & Floyd (1977) and Le Maitre (1989) – Fig. 5 A, B, C, D. It is obvious that biotitization caused the overal decrease of the SiO_2 content in gabbroidic rock and increase of K_2O. In the classification diagram it is manifested by the shift of projection points from the association of subalkaline to alkaline basaltoid magmas (Fig. 5 – B, C), eventually into the area away of common magmatic associations (Fig. 5D) and with moderate increase of aluminium content – Fig. 5A (shift from the field V – associations with clinopyroxene towards the field IV – associations with hornblende and biotite). It is obvious, that the composition of rocks before biotitization was close to composition of hornblendites from the closely located Hercynian granitoid of Stolica massif (original data by authors).

From the spiderogram of normalized values of composition towards MORB (Fig. 6A) there follows, that the Ti, Y , Zr, Hf, Nb and HREE contents have the typical MORB characteristics, while the further elements are relatively enriched in decreasing enrichment trend from Cs, Rb, Ba, Th, U, K, and LREE, with decreasing degree of enrichment from La towards Eu and correspondingly with the enlargement of Nd/Sm ratio in comparison with the primary composition.

The relative stability of Ti, Zr, Y (Mn, P) allows use of diagrams by Mullen (1983) and Pearce & Cann (1973) for classification characteristic of the former gabbroid. The calc-alkaline character of original magma is shown in Fig. 7 A, B.

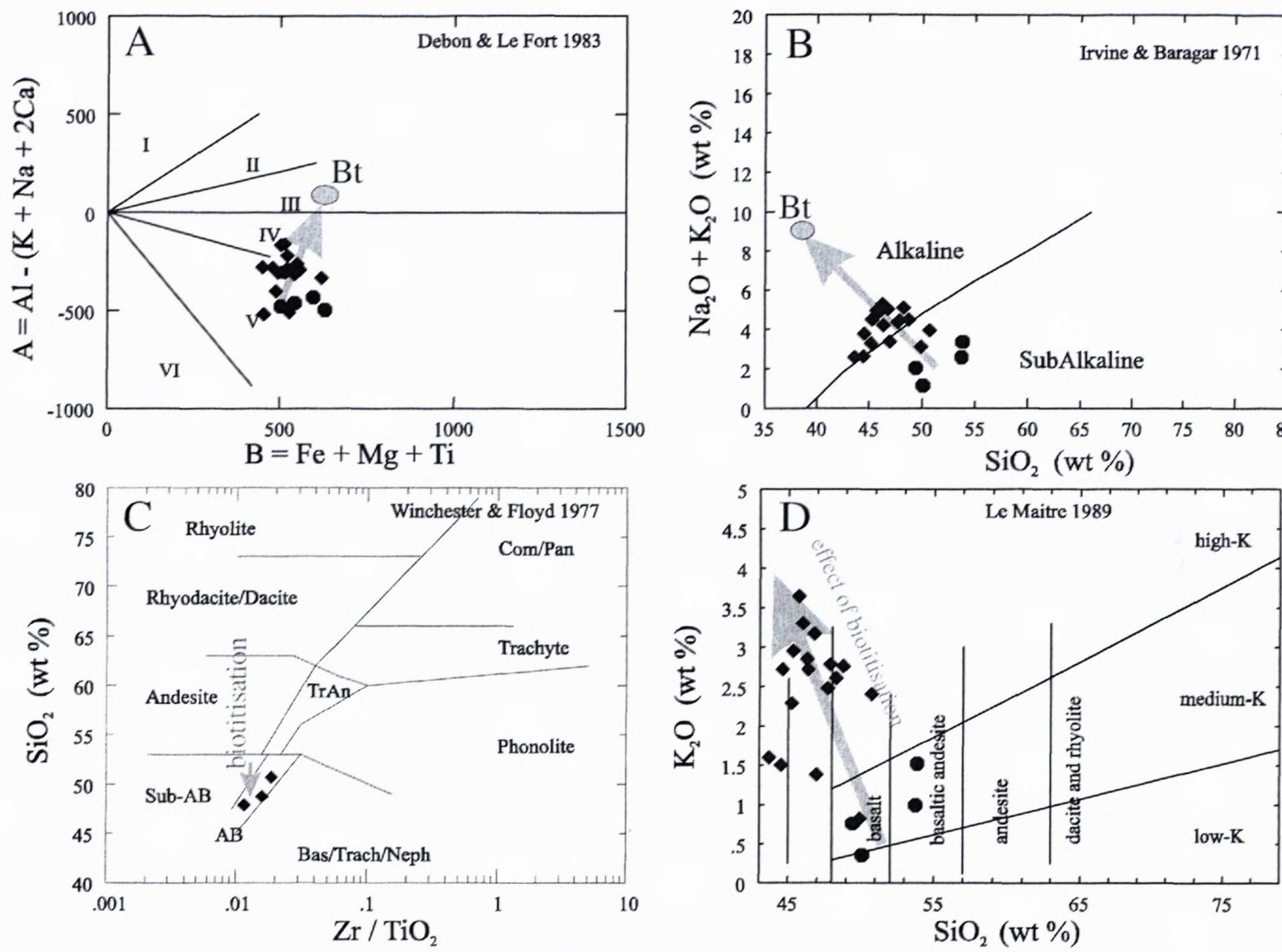
Naturally, the distinct changes of former chemical composition had to be manifested also in the change of former isotopic composition of Sr and Nd. In Tab. 4 we overviewed already published basic analytical data about isotopic composition of Nd from metagabbro, being taken from the work by Hraško et al. (1993) and later re-cited by Kohút et al. (1999). The value of Sr isotopic composition from metagabbro is taken from the work of Kohút et al. (1999) and the value of Sr and Nd from Rochovce granite is taken from the works by Kovách et al. (1986), Cambel et al. (1989), resp. Hraško et al. (1998). Values ε(Nd,Sr) partially differ from data published until now, because for the isotopic development DM we took parameter from the work by Michard et al. (1995).

In comparison of analytical data from gabbro and granite there is remarkable the high content of Rb in gabbro (Tab. 4). For average gabbro the Rb concentrations in the range 18–30 ppm are stated by Heier (1972) and the average 32 ppm by Faure (2001). The Sr concentration are in the range 97–534 ppm (Faure, 1978), the average 293 ppm; the published range for alkaline gabbro is 445–2115 ppm (Faure, 2001). Thompson et al. (1982) found from Paleocene basalts the Rb concentrations 2-22 ppm and Sr contents in the range 279–658 ppm ($^{87}Rb/^{86}Sr$ = 0.01–0.08), with recent $^{87}Sr/^{86}Sr$ ratios between 0.70342–0.70495. The Rb/Sr isotopic signatures of Neocomian basalts indicate, that depleted mantle has $^{87}Sr/^{86}Sr<0.703$ with Rb/Sr ratio <0.01(Samoilov et al., 1998).

*Tab. 4: Principal geochemical and isotopic data from the Rochovce gabbro and granite. Rb/Sr data from gabbro (1 sample) are taken from Kohút et al. (1999). Rb/Sr data from granite are taken from the works by Kovách et al. (1986) and Cambel et al. (1989) – 4 samples. Sm/Nd ratio from gabbro and granite (1 sample) is taken from Hraško et al. (1993, 1998) and Kohút et al. (1999). *- data calculated using the values for crust (McCulloh & Bennet, 1994), **- data calculated using the values for DM (according to Michard et al. 1985).*

	metagabbro	granite
Rb(ppm)	139	98-244
Sr (ppm)	638	440-993
$^{87}Rb/^{86}Sr$	0.630	0.711-1.003
$^{87}Sr/^{86}Sr$	0.70330	0.7093-0.7137
$(^{87}Sr/^{86}Sr)_{76}$	0,702620	0.7083 – 0.7126
$\varepsilon_{Sr}(0)$*	10.7	+6.4 » -55.2
$\varepsilon_{Sr}(76)$*	1.3	-3.4 » -63.4
Sm (ppm)	11.39	6.73
Nd (ppm)	65.68	39.28
$^{147}Sm/^{144}Nd$	0.10515	0.10385
$^{143}Nd/^{144}Nd$	0.512715	0.512435
$(^{143}Nd/^{144}Nd)_{76}$	0.512663	0.512383
$\varepsilon_{Nd}(0)$**	-7.8	-13.2
$\varepsilon_{Nd}(76)$**	-6.7	-12.1
T(DM) in Ma**	521	876

The Rb concentration in Rochovce gabbro reaches the Rb concentration of the samples from granite. From it follows also the high $^{87}Rb/^{86}Sr$ ratio in gabbro, but at distincly low ratio of $^{87}Sr/^{86}Sr$. When using these parameters for the evolution of Sr isotopes in gabbro in 521 Ma there would the $^{87}Sr/^{86}Sr$ ratio lower than BABI = 0.69899 (Papanastassiou & Wasserburg, 1969), which is unrealistic. The line of DM evolution the gabbro crosses at the model age 91 Ma. In comparison with granite, the Sm/Nd ratio is also near, similarly as the Nd isotopic composition. The average concentrations of Sm and Nd in gabbros (Herrman, 1970) vary between 0.9–5.9 ppm, resp. 4.3–20 ppm, and in granites the average for Sm concentration is 8.3 ppm with higher Nd content (46 ppm). Similarly like in granites, also in gabbro the Nd concentration is higher than Sm concentration. The position of gabbro and granite from Rochovce is shown in the graph $^{143}Nd/^{144}Nd$ vs $^{87}Sr/^{86}Sr$ (Fig. 8). The recent $^{87}Sr/^{86}Sr$ value of gabbro still falls into the field of MORB, but $^{143}Nd/^{144}Nd$ is markedly lower. The Late Cretaceous Rochovce granite is lying in the field of Western Carpathian Hercynian granitoid rocks



Obr. 5 Effect of biotitization on geochemical composition of gabbroidic rock in classification diagrams: A. Debon & LeFort (1983); B. Irvine & Baragar (1971); C. Winchester & Floyd (1977); D. Le Maitre (1989). Explanations of symbols: full circles – Paleozoic hornblendites in the Stolica granitic massif; full squares – Rochovce metagabbro; grey arrow depicts the trend of chemical composition changes of the main elements at biotitization.

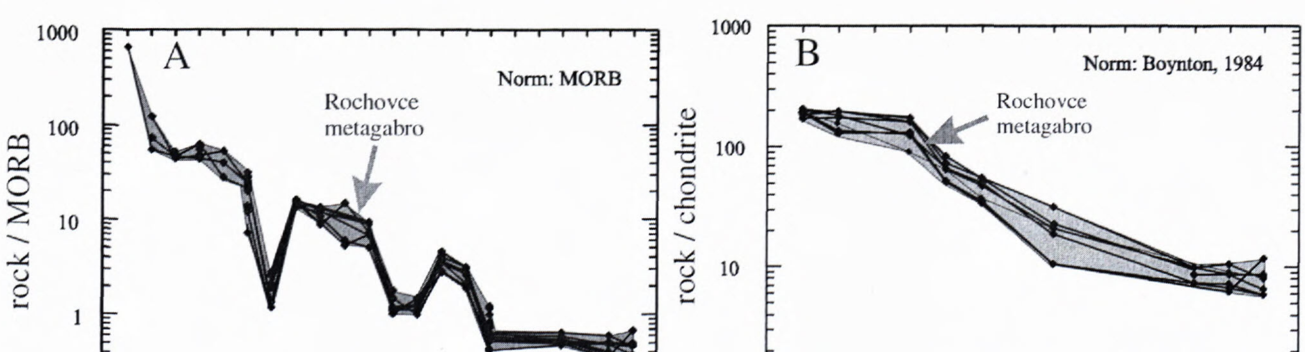


Fig. 6 Courves of normalized element contents: A. Rochovce metagabbro vs. MORB; B. REE normalized courves (norm coefficients according to Boynton in Henderson, 1984) for Rochovce metagabbro.

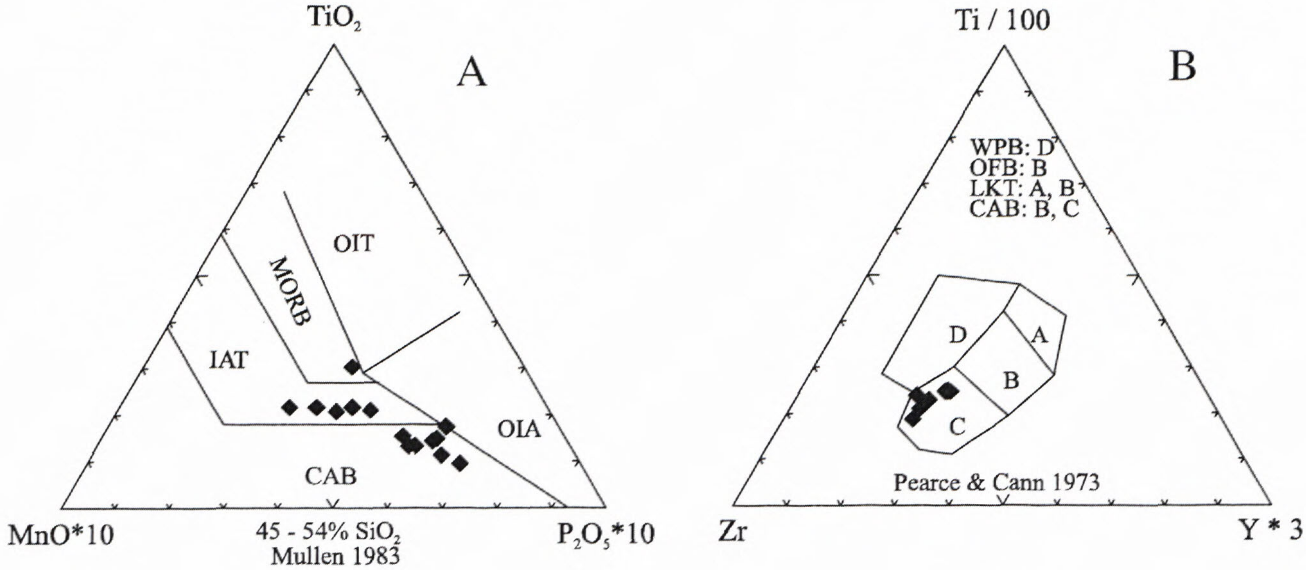


*Fig. 7 Classification diagrams reflecting the primary character of Rochovce metagabbro. A. Diagram MnO*10-TiO$_2$-P$_2$O$_5$ (Mullen, 1983): CAB – calc-alkaline basalts, IAT - island arc tholeiites, OIA - ocean island andesites, OIT - ocean island tholeiites, MORB - middle oceanic ridge basats. B. Diagram Zr–Ti/100–Y*3 (Pearce & Cann, 1973): WPT - within plate basalts, OFB – ocean floor basalt, LKT – low K tholeiites, CAB - calc-alkali basalts*

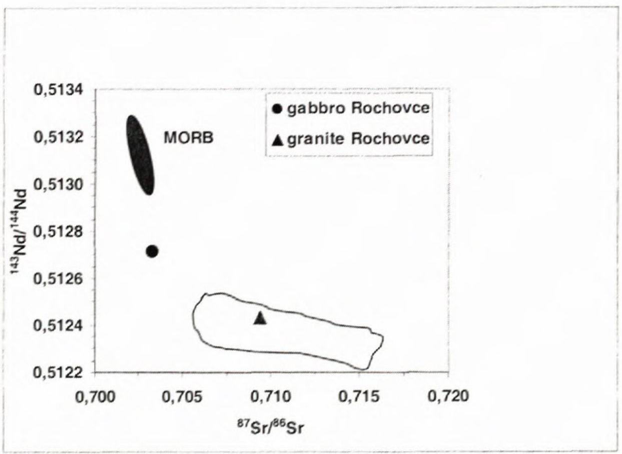


Fig. 8 Position of gabbro and granite at Rochovce in graph $^{143}Nd/^{144}Nd$ vs. $^{87}Sr/^{86}Sr$. Recent value $^{87}Sr/^{86}Sr$ of the gabbro reaches the MORB field, $^{143}Nd/^{144}Nd$ is significantly lower. The Late Cretaceous Rochovce granite is located in the field of Western Carpathians Hercynian granitoid rocks (shaded area drawn on the basis of data by Kohút et al., 1999).

(weakly shadowed area being drawn using data by Kohút et al., 1999). The summarized data therefore indicate the distinct changes of former chemical and isotopic composition of gabbro.

Information about the estimated initial ratio $(^{87}Sr/^{86}Sr)_{76}$ of Rochovce granite is discrepant. The $^{87}Sr/^{86}Sr$ evolution lines from the four until now published whole-rock analyses of the Rochovce granite are more-or-less parallel and has no common starting point. The values of calculated initial ratio $(^{87}Sr/^{86}Sr)_{76}$ for individual samples vary between 0.7083–0.7126 (Tab. 4, Fig. 9). The reason of this phenomenon is until now unknown. The data indicate the isotopic inhomogeneity of Rb-Sr system, which in no case fulfil the criteria of isochron concept (Nicolaysen, 1961). Though the isotopic inhomogeneities were described in the case of young as well as old plutonic rocks (USGS, 1986; Kostitsyn & Volkov, 1990), they have significantly lower variability than the samples of Rochovce granite. We hardly can exclude also the contamination of granite by strontium from gabbro having lower isotopic ratio (< 0.70262). In this case the scattering of $^{87}Sr/^{86}Sr$ in granite indicates the differing volume of contaminating strontium and also the high initial ratio of $^{87}Sr/^{86}Sr$ in granite (ca 0.713).

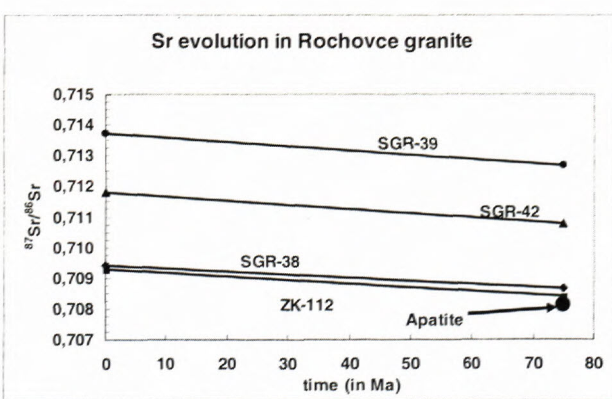


Fig. 9 Evolution of $^{87}Sr/^{86}Sr$ ratio in the samples of the Rochovce granite. Samples do not fulfil the condition of isochron concept (Nicolaysen, 1961). As an initial value $(^{87}Sr/^{86}Sr)_{initial}$ the mean value 0.70809 ± 0.00026 (± 2xSD) can be accepted, being found from three samples of accessoric apatite (Tab. 4).

Contrasting to stated inditions of isotopic inhomogeneity in Rochovce granite, the $^{87}Sr/^{86}Sr$ ratio, being found in accessoric apatite from granite of different depths (Tab. 5), documents only small variability around the mean value 0.70809 ± 0.00026 (±2SD). This value, regarding to very small Rb/Sr ratio in apatite (Faure, 2001), can be supposed as a initial value $(^{87}Sr/^{86}Sr)_{initial}$ in Rochovce granitic body. Only two whole-rock samples taken from Kovách et al. (1986) and Cambel et al. (1989) converge to this value and their calculated ratios $(^{87}Sr/^{86}Sr)_{76}$ are ca 0.7083. The $^{87}Sr/^{86}Sr$ ratio in apatites is slightly higher than estimated $(^{87}Sr/^{86}Sr)_{initial}$ ratios from the whole rock isochrons of Hercynian Western Carpathians granitoid rocks with S-type tendency (Kráľ, 1994).

Tab. 5 $^{87}Sr/^{86}Sr$ in accessoric apatite from drill cores localized in the Rochovce granite. Analytical error of isotopic measurements (± 2xS.E. – standard error of the mean) relates to the last two digits of isotopic ratio. The measured isotopic ratio $^{87}Sr/^{86}Sr$ was adjusted on the value NIST 987 = 0.710248. Apatite KV-3 was separated from granite in the proximity of gabbro. In the boreholes RO-2, RO-6 the gabbro is not present.

Borehole/depth (meters)	$^{87}Sr/^{86}Sr$ ± 2x S.E.
KV-3/ 723,5 – 723,8 m	0.707945 ± 21
RO-2/ 630 – 633 m	0.708200 ± 28
RO-6/ 370 – 372 m	0.708118 ± 21

5. $^{40}Ar/^{39}Ar$ dating

The $^{40}Ar/^{39}Ar$ dating of separated amphibole from the borehole KV-3 was made in Geozentrum, University Wien, using methodology described in more details in the work by Kráľ et al. (1996). The hand-picked amphibole using the binocular microscope has a minimal amount of tiny biotites ingrowths without possibility to be removed from the amphibole. The separated amphibole grains were optically controlled by polarizing microscope. The purity of analysed sample was ca 95 %. The obtained apparent ages spectrum is shown in Fig. 10A together with the graph of K/Ca ratio variability during analysis (Fig. 10B). The analytical data are given in Tab. 6.

Tab. 6 $^{40}Ar/^{39}Ar$ analytical data from hornblende, KV-3/621-622 m metagabbro, borehole, Rochovce.

Step	T (°C)	$\%^{39}Ar$	$\%^{40}Ar^*$	$^{40}Ar^*/^{39}Ar$	Age (Ma) ± 2 SD
1	730	3,8	40,0	13,43 ± 2,5	71,2 ± 1,8
2	780	3,6	55,6	15,46 ± 1,7	81,8 ± 1,4
3	820	4,4	66,6	13,94 ± 0,5	73,9 ± 0,4
4	840	3,1	56,2	17,47 ± 1,7	92,2 ± 1,5
5	870	4,0	63,4	15,07 ± 1,3	79,7 ± 1,0
6	900	7,8	80,3	14,20 ± 1,5	75,3 ± 1,1
7	930	7,6	84,5	14,29 ± 0,7	75,7 ± 0,5
8	980	30,2	92,0	14,77 ± 0,4	78,2 ± 0,3
9	1020	23,0	76,2	14,08 ± 1,0	74,6 ± 0,7
10	1060	7,5	89,4	13,82 ± 0,9	73,3 ± 0,6
11	1100	5,0	72,5	13,80 ± 2,2	73,2 ± 1,6

J = 0.002868 ± 0.4 % total gas age: 76,5 ± 2,4 Ma
81 % gas age: 75,9 ± 1,8 Ma

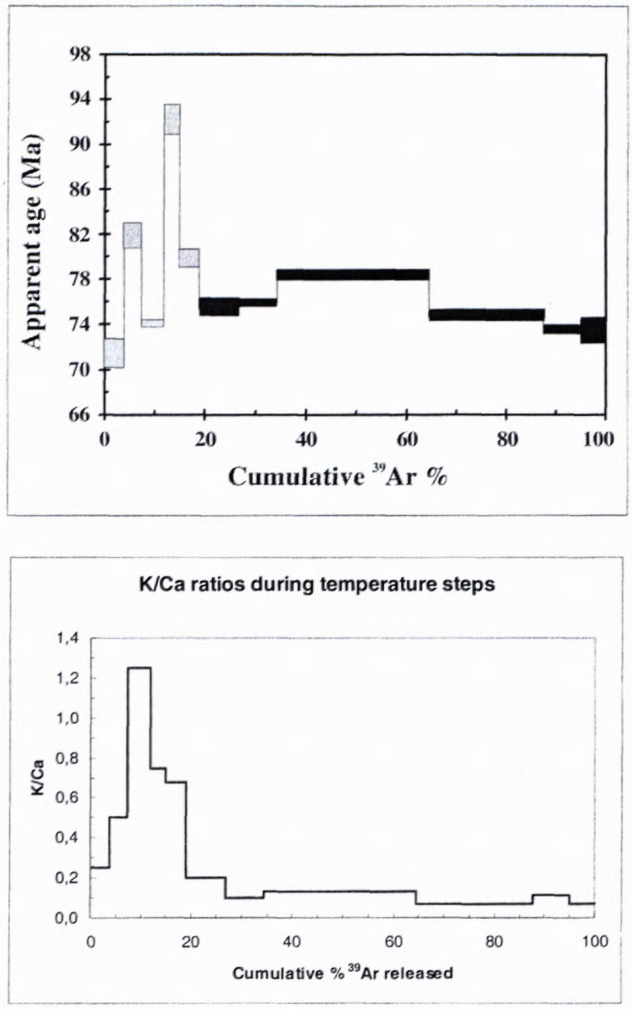


Fig. 10 Plot of $^{40}Ar/^{39}Ar$ apparent ages spectra from amphibole of Rochovce gabbro (A) and graph of variability of K/Ca ratio during the course of $^{40}Ar/^{39}Ar$ analysis (B). The higher variability of apparent ages and increase of K/Ca ratio in the lower temperature part of the spectrum is probable caused by degassing of tiny biotite inclusions.

The spectrum of apparent $^{40}Ar/^{39}Ar$ ages of step-by-step degassing of the sample varies in the range from 71.2 Ma to 92.2 Ma. The biggest variability of apparent ages is registered in the first four steps of low-temperature part of the spectrum. Correspondingly there was registered the increasing K/Ca ratio. We suppose, that in the first steps the outgassed ^{40}Ar is partially derived from inclusions of fine biotite in the amphibole grains. The spectrum of apparent ages in the low-temperature steps in analysed sample is clearly different from the amphibole spectra of Veporic amphiboles of Paleozoic age, being characteristic in the low-temperature part of the spectra with high apparent ages – up to 1500 Ma (Kráľ et al., 1996). The apparent ages in the higher temperature part of the analysed sample spectra vary in the more narrow range (78.2–73.2 Ma). The resulting age from this part of the spectra (five last temperature steps) is 75.9 ± 1.8 Ma, being in the range of analytical error identical with the U/Pb dating of zircons from the Rochovce granite (Poller et al., 2001). From the published $^{40}Ar/^{39}Ar$ ages of amphiboles from Veporicum it is until now the youngest age.

Slovak Geol. Mag., 10, 4 (2004), 263 – 276

It is possible, that $^{40}Ar/^{39}Ar$ spectrum (Fig. 10A) is derived from the mixture of at least two amphibolite types (Tab. 2) without possibility to be mutually separated. It can express the contact-metamorphic change by the temperature overreaching the closing temperature of K-Ar system in amphibole (ca 500 °C; Harrison, 1981). The final age therefore represents the rapid cooling/uplift of studied area. Different intepretation can be found in the process of blastesis or recrystallization of amphiboles, occurring synchronously with the contact effects of Rochovce granite and so the temperature conditions of their origin can be slightly lower than the blocking temperature of amphibole.

6. Discussion

The arguments presented above do not allow to interpret the metagabbro position in the overlier of Rochovce granite like the post-granitic displaced allochthonous body in tectonic position above granitoid. Also xenoliths of metagabbro found in the upper part of Rochovce granite (Fig. 2C) as well as the penetration of metagabbro by subvertical veins of later phases of Rochovce intrusion (Fig. 2A) exclude the tectonic position of metagabbro. The veinlets of granite composition has fine-grained development at their margin, which indicates the quick cooling and the relative lower temperature of metagabbro in comparison with intruded granitic body (above 800 °C, Hraško et al., 1998) No alteration of gabbroidic rock is related with the origin of these last veinlets (Obr. 2A). Older shallow dipping veins of leucotrondhjemitic aplites (Fig. 2B) and bulges of leucotrondhjemitic melts (Fig. 1) probably represent the utmost stage of thermal effect in relation with intrusion of the Rochovce granite. The discussed area (contact zone of Gemericum with Veporicum) was during the intrusion of Rochovce granite coolled to ca 300 °C, as is documented by K/Ar data on biotites from the Kohút zone (Kantor, 1959, 1960), and moreover these from the Rochovce area belong among the youngest from the Veporicum (Kantor & Rybár, 1979a; Cambel et al., 1980). The zones with intensively superimposed metamorphic recrystallization we connect with the thermal influence of the Rochovce granite. The changes of primary olivine, pyroxene and magmatic amphibole have postkinematic character and indicate slightly higher temperature conditions like the Alpine regional dynamometamorphism. The higher metamorphic degree of studied sample is indicated not only by the amphibole of hornblenditic composition (Leake et al., 1997), but mainly by the newly formed plagioclase of andesine composition. Contrary to this, in the regional scale in Pre-Alpine mafic rocks the intermediate plagioclase is usually changed to albite and fine-grained mixture with the prevailing clinozoisite.

The main mineral and chemical changes of the former composition of metagabbro relate with the temperature and material effect of the Rochovce granite intrusion. When we admittedly accept the older age of gabbro, then the $^{40}Ar/^{39}Ar$ amphibole dating proves the K-Ar system resetting and total lost of *in situ* accummulated radiogenic $^{40}Ar^*$ in gabbro by the temperature above 500 °C during the granite intrusion, which is the blocking temperature of K/Ar system for amphibole (Harrison, 1981). The amphibole $^{40}Ar/^{39}Ar$ plateau ages therefore can be interpreted as an independent confirmation of the intrusion age of the Rochovce granite.

The K-Ar and Ar^{40}/Ar^{39} data allow a real assumption, that during that time the studied area could be cooled to 300 °C temperature level (review of K/Ar data is available in Cambel et al., 1990; Kováčik et al., 1996; Janák et al., 2001). On the other hand some of the age spectra suggest, that also in Upper Cretaceous the temperature about 300 °C persisted in some parts of Kohút crystalline basement, which allows possible interconnection of Alpine regional metamorphism and Rochovce contact aureole.

The increase of Alpine overheating towards NE appears in the Kohút zone. It is simultaneously manifested by partial decrease of K/Ar and Ar/Ar ages (Kováčik, 1998). From three episodes of the schematic division of Alpine metamorphic processes, the first two have a character of Barrovian regional metamorphism. The last metamorphic episode was caused by the Rochovce thermal aureole being situated exactly in the studied north-eastern part of the Kohút zone. The relation of this contact metamorphic episode to preceding regional Cretaceous metamorphism is not fully clear. Shortly before the time of intrusion of Rochovce granite the collisional-compressional conditions, accompanying the Alpine regional metamorphism, were probable changed to crustal extension with the increased geothermic gradient.

From the above stated arguments we can deduce, that specially the intrusion of the Rochovce granite had the decisive influence on geochemical characteristics and isotopic composition of gabbro, as is recently known. Using above listed data we suppose the recent isotopic composition of Sr, Nd and concentration of Rb, Sr, Sm and Nd resp. further elements in the gabbro as a result of contamination by intruded granite. With a high probability we can suppose, that after the intrusion of Rochovce granite and following cooling of the region accompanied with uplift, the isotopic (geochemical) systems were quickly closed. The only thing we can reconstruct with certainty, using the evolution diagrams of Sr and Nd isotopes, is the time interval in the range Late Cretaceous (76 Ma) ⇒ Present (0 Ma). The isotopic resp. geochemical characteristics of gabbro before intrusion of the Rochovce granite are not fully clear, but using analysis of geochemical data we can subtract the biotitization effect (Fig. 4). The reconstruction of these data can be based only on more-or-less speculative assumptions, however being limited by published data. Firstly, the depleted mantle according to Dosso et al. (1999) has no character of homogenous source: it is typical with variability of $^{87}Sr/^{86}Sr$ between 0.70215-0.70290 and low ratios $^{87}Rb/^{86}Sr$ (0.005-0.04). The data about isotopic composition of Mesozoic and Paleozoic basic melts in the Western Carpathian area are not available until now. The isotopic characteristics of the mantle in Carpathian-Pannonian region (CPR), obtained from basic volcanic rocks (Upper Cretaceous–Pliocene) indicate three different components (Embey-Isztin & Dobosi, 1995; Downes & Vaselli, 1995; Rosenbaum et al., 1997). It is reflected in the isotopic signature of volcanites and xenoliths. The oldest basic alkaline volcanites in this area (basanites from Poiana Rusca, Rumania (48-58 Ma) have ratios $(^{87}Sr/^{86}Sr)_{initial}$ and $(^{143}Nd/^{144}Nd)_{initial}$ 0.7029–0.7032, resp. 0.51293–0.51286 (Downes et al., 1995). The use of the isotopic ratios of Sr and Nd allows us to suppose, that the mantle in CPR was depleted earlier, already before Upper Cretaceous (Rosenbaum et al., 1997).

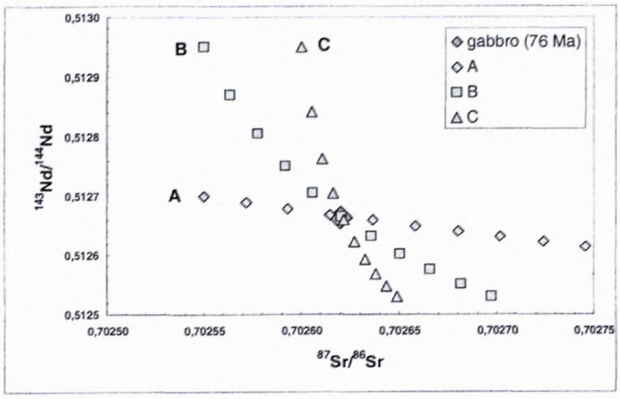


Fig. 11 The results of binary mixing of Sr and Nd between granite and gabbro . A – 0.005, B – 0.01, C – 0.002.

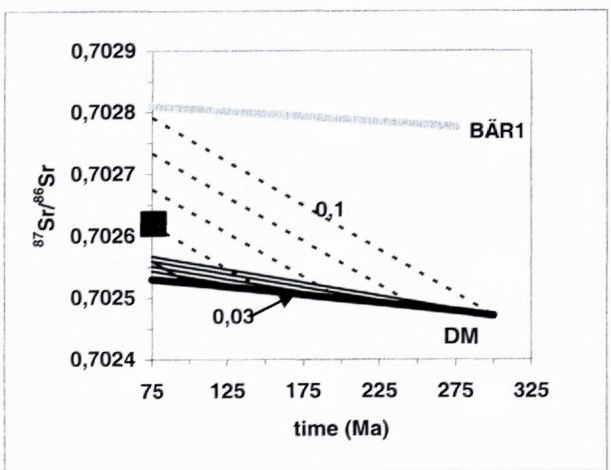


Fig. 12 Evolution lines $^{87}Sr/^{86}Sr$ in hypthetic gabbro unmixed from DM (thick line)m, of different age with various $^{87}Rb/^{86}Sr$ ratios (0.1 – dashed line, 0.03 – full line). Full square shows the value $(^{87}Sr/^{86}Sr)_{76}$ after gabbro contamination by Rochovce granite and represents the uppermost limit for former isotopic composition of strontium in the gabbro. BÄR1-evolution line for unchanged gabbro (Koralpe, Thöni & Jagoutz, 1992).

When accepting an idea, that $(^{87}Sr/^{86}Sr)_{76}$ and $(^{143}Nd/^{144}Nd)_{76}$ are the results of binary mixing of isotopic systems, then two end-members of the mixing with the particular concentrations of Sr, Nd and their isotopic ratios would have their restrictions. Though also this allows a large variability of input data. The results of three variations of binary mixing and input parameters in different combinations we introduce in Fig. 11 and Tab. 7. Instead of the element concentrations we state rather the ratios of concentrations, because in used calculation there are not determining the absolute concentrations, but their mutual ratios between the end-members. The calculation was made by procedure according to Faure (1986). For the primeval isotopic composition of gabbro in the time t = 76 Ma there are not many possibilities. The ratio $(^{87}Sr/^{86}Sr)_{76}$ is 0.702620 (already as a result of contamination) and equivalent value of depleted mantle (DM) at this time according to McCulloh & Bennet (1994) is 0.70253. Hence the gabbro before interaction with granite should have the primeval isotopic ratio $^{87}Sr/^{86}Sr$ between these two values. On the other hand, we suppose that the recent distinctly lowered ratio $^{143}Nd/^{144}Nd$ is the result of contamination with the crustal (granitic) Nd. Contrary to this, the gabbro contamination by granitic strontium was minimal, because the low values of $^{87}Sr/^{86}Sr$ were preserved. This finding is a paradox, because during epigenetic, resp. metamorphic changes of basic rocks we can expect the more distinctive changes just in the isotopic composition of strontium (Thöni & Jagoutz, 1992). From Fig. 11 there follows, that if the contamination process would be described by the function of binary mixing, then the most probable alternatives of the initial isotopic composition and Sr, Nd concentrations in granite and gabbro would vary between models A and B, because the models B and C led to the strong increasing of ratios of Nd concentrations in end-members.

During contamination there occurred the change in Rb/Sr and Sm/Nd ratios in Rochovce gabbro. Concentration of Rb in gabbro is apparently extreme, while the Sr concentration can be supposed to be common. The change of Rb/Sr ratio caused the distinct steeper slope of the of Sr evolution line (not showed in Fig. 13), when comparing for example with unchanged and noneclogitized Permian gabbro (BÄR1) from Koralpe (Thöni & Jagoutz, 1992). The change of Sm/Nd ratio caused not only the noticeable lowering of value $^{143}Nd/^{144}Nd$, but also the adjustment of $^{147}Sm/^{144}Nd$ ratio in gabbro with granite (Fig. 12). The slopes of Nd evolution lines of granite and gabbro are nearly parallel (that means the Sm/Nd ratio in both rocks is very close). The Nd isotopic signature in Rochovce gabbro, contrary to the comparing sample BÄR1, copy the granitic Nd signature. This is the reason why the evolution line of Nd isotopes in gabbro is only the reflection of contamination with granitic Sm and Nd and therefore the model age T(DM) is unreally high.

The precise age of Rochovce gabbro is until now not known. Geological, structural and partially also petrographic data demonstrate, that the model ages of gabbro, being published by Kohút (1999), resp. from Tab. 3 are unrealistic. Based on these data, the real age of gabbro can be estimated only in the wide diapason between the formation of Hercynian (Carboniferous) granitoids of Veporicum and the lower age limit is given by the intrusion of the Rochovce granite. The diagram of Sr evolution for differing age and differing $^{87}Rb/^{86}Sr$ ratio (0.1, 0.03) is shown in Fig. 13. The full square shows the isotopic ratio $^{87}Sr/^{86}Sr$ for time t = 76 Ma (after the contamination by granite). For comparison we again use the gabbro BÄR1, whose Sr evolution line under low $^{87}Rb/^{86}Sr$ ratio and the age 275 Ma does not begin from DM - $(\varepsilon Sr)_{275}$ has the value +4.2. If it is the case of

Tab. 7 Input parameters of alternative models for binary mixing of Sr and Nd between Rochovce gabbro and granite. Calculation made according to Faure (1986). Indexes: gb – gabbro, gr – granite. Sr_{gr}/Sr_{gb}, Nd_{gr}/Nd_{gb} – ratio of concentrations Sr and Nd between granite and gabbro. Individual points on mixing lines represent a fraction of granite component against gabbro with the step:

	$(^{87}Sr/^{86}Sr)_{gb}$	$(^{143}Nd/^{144}Nd)_{gb}$	$(^{87}Sr/^{86}Sr)_{gr}$	$(^{143}Nd/^{144}Nd)_{gr}$	Sr_{gr}/Sr_{gb}	Nd_{gr}/Nd_{gb}
A	0,70255	0,512700	0,70800	0,512155	0,79	4
B	0,70255	0,512950	0,70800	0,512220	0,25	12,2
C	0,70260	0,512950	0,70800	0,512300	0,5	100

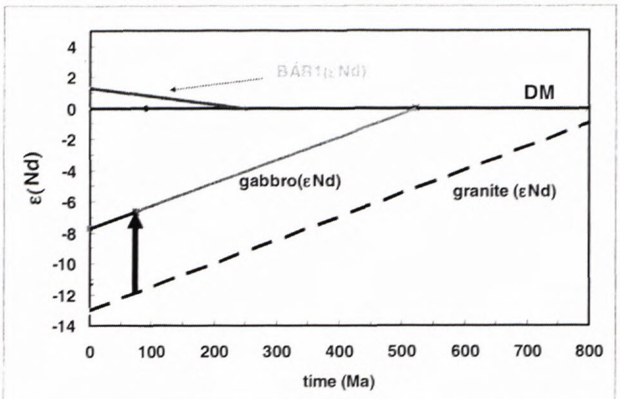


Fig. 13 Evolution of Nd isotopes in Rochovce gabbro and granite. DM – depleted mantle. The development of Nd isotopes in unchanged gabbro (sample BÄR1, Koralpe, Thöni & Jagoutz, 1992) is presented for comparison.

the Rochovce gabbro, then in the case of Late Paleozoic age this value should be much lower. As the Fig. 12 shows, only those $^{87}Rb/^{86}Sr$ ratios can be accepted which, regarding the age, have the $(^{87}Sr/^{86}Sr)_{76}$ ratio lower than the gabbro after contamination. Hence, if the Rochovce gabbro would originate directly from DM, then $(^{87}Sr/^{86}Sr)_{76}$ would be reached after 275 Ma at the range $^{87}Rb/^{86}Sr = 0.05$. These thoughts allow several age alternatives and also the Alpine age cannot be excluded. The Rochovce gabbro is lying in Paleozoic rocks characteristic with the strong mineral lineation, being commonly supposed to be Alpine, as it was well documented from the borehole cores. Though the mylonitic zones exist in the gabbro, the mineral lineation is not present there. It can be explained by stronger rheology of the gabbro, or by its younger, postdeformational age. When accepting the second argument, then the intrusive age of the gabbro would be younger as the origin of lineation, which indicates the Alpine age. Absence of stronger mineral lineations could be obscured also by the postkinematic recrystallization of amphiboles and biotite during the contact metamorphism.

Conclusion

The given petrographic, geochemical and isotopic data manifest, that the position of Rochovce gabbro above the Rochovce Late Cretaceous granite is autochthonous and pre-granitic. The granite intrusion caused not only the origin of aplitic veinlets penetrating gabbro, but also strongly influenced its former chemical and isotopic composition. These contamination processes affected selectively. The process of biotitization and formation of new allanite caused the extreme enrichment of gabbro by alkalies (Cs, Rb, K), U, Th and LREE. Concerning the isotopic composition of strontium $(^{87}Sr/^{86}Sr)_{76}$, after the contamination by granite it remained near the former composition. The Nd isotopic composition is distinctly lowered. The result of the contamination process is, that the isotopic ratio $^{143}Nd/^{144}Nd$ and the Sm/Nd ratio in gabbro practically copy these of granite. This is the reason, why the chemical and isotopic characteristics of the gabbro cannot be used as characteristic end-member in geochemical considerations relating the interaction (mixing) of mafic and acid melts during the genesis of Hercynian granitoid rocks of the crystalline basement of the Western Carpathians.

The dating of amphibole from contact metamorphic gabbro shows the complet loss of till then *in situ* accummulated $^{40}Ar^{*}$. $^{40}Ar/^{39}Ar$ age 75.9 ± 1.8 Ma of amphibole from gabbro corresponds with the U-Pb age of Rochovce granite 76 ± 1.1 Ma (Poller et al., 2001), resp. 82 ± 1 Ma (Hraško et al., 1999), $^{40}Ar/^{39}Ar$ plateau age obtained on amphibole can be interpreted as independent confirmation of the age of intrusion of Rochovce granite. Because that time the studied area was cooled down to the temperature level 300 °C, the determined age represents also the age of the origin of newly formed amphiboles in gabbro during the contact metamorphic recrystallization caused by intrusion of the Rochovce granite.

Until now the intrusion age of the Rochovce gabbro was not exactly determined. Accounting the geological, structural and partially also petrographic data it is possible to limit the upper age by intrusion of Hercynian granites in Veporicum (350 – 300 Ma) and the lower age limit by the Cretaceous intrusion of Rochovce granite. It is not possible to exclude also Alpine age of the gabbro. The ages of the crustal residence T(DM) published by Kohút et al. (1999), resp. stated in this article are unrealistically high and reflect only the result of geochemical (isotopic) interaction of gabbro with granite and in no case they contain the age information.

References

Boynton, W. V., 1984: Geochemistry of the rare-earth elements: Meteorite studies. In: Henderson, P. (ed.): Rare Earth Element Geochemistry, Elsevier, Amsterdam, 63-114.

Broska, I. & Petrík, I., 1993: Magmatic enclaves in Western Carpathians granitoids. Mineralia slov. 25, 2, 104-108.

Brown, G. C. & Hennessy, J., 1978: The initiation and thermal diversity of granite magmatism. Phil. Trans. R. Soc. Lond., A 288, 631-643

Cambel, B., Bagdasarian, G. P., Gukasian, R. Ch. & Veselský, J. 1989: Rb-Sr geochronology of leucocratic granitoid rocks from the

Spišsko-gemerské rudohorie Mts. and Veporicum. Geol. Zbor. Geol. Carpath., 40, 3, 323-332.
Cambel, B., Bagdasarian, G. P., Veselský, J. & Gukasian, R, Ch., 1989: To problems of interpretation of nuclear – geochronological data on the age of crystalline rocks of the West Carpathians. Geol. Zbor., Geol. Carpath., 31, 1-2, 27- 48.
Debon, F. & Le Fort, P., 1983: A chemical-mineralogical classification of common plutonic rocks and associations. Transactions of the Royal Society of Edinburgh Earth Sciences, 73, 135-149.
Dosso, L., Bougault, H., Lagmuir, Ch., Bollinger, C., Bonnier, O. & Etoubleau, J., 1999: The age and distribution of mantle heterogeneity along the Mid-Atlantic Ridge (31-41°N). Earth Planet. Sci. Lett., 170, 3, 269-286.
Downes, H. & Vaselli, O., 1995: The lithospheric mantle beneath the Carpathian-Pannonian region: A review of trace element and isotopic evidence from ultramafic xenoliths. Acta Vulcanologica, 7, 2, 219 – 229.
Downes, H., Vaselli, O., Seghedi, I., Ingram, G., Rex, D., Coradossi, N., Pécskay & Z., Pinarelli, L., 1995: Geochemistry of Late Cretaceous-Early Tertiary magmatism in Poiana Rusca (Romania). Acta Vulcanologica, 7, 2, 209–219.
Embey-Isztin, A. & Dobosi, G., 1995: Mantle source characteristic for Miocene-Pleistocene alkali basalts, Carpathian-Pannonian region: A review of trace elements and isotopic composition. Acta Vulcanologica, 7, 2, 155-166.
Faure, G., 1978: Strontium. Abundance in common igneous rock types. In: Handbook of Geochemistry (ed. K.H. Wedepohl), vol. II-4, Springer, Berlin, 38-E-1 – 38-E-14.
Faure, G., 1986: Principles of isotope geology. Willey, New York, 2nd edition, 589 p.
Faure, G., 2001: Origin of igneous rocks. The isotopic evidence. Springer-Verlag, Berlin, 496 p.
Harrison, T. M., 1981: Diffusion of ^{40}Ar in hornblende. Contrib Mineral Petrol, 78, 324-331.
Határ, J., Hraško, Ľ. & Václav, J., 1989: Hidden granite intrusion near Rochovce with Mo(-W) stockwork mineralization. (First object of its kind in the West Carpathians.) Geol. Zborn., Geol. Carpath., 40, 5, 621–654.
Heier, K. S., 1972: Rubidium. Abundance in common magmatic rocks types; terrestrial abundance. In: Handbook of Geochemistry (ed. K.H. Wedepohl), vol. II-4, Springer, Berlin, 37-E-1 – 37-E-10.
Herrman, A. G., 1970: Yttrium and lanthanides. Abundance in common igneous rocks types. In: Handbook of Geochemistry (ed. K.H. Wedepohl), vol. II-5, Springer, Berlin, 57-71 -E-1 – 57-71 -E-18.
Hildreth, W., 1981: Gradients in silicic magma chambers: Implications for lithospheric magmatism. J. geophys. Res., 86, B11, 10153-10192.
Hovorka, D., 1983: Ore genesis in the Rochovce basite body. Mineralia slov. 15, 5, 445-459. (In Slovak).
Hraško, Ľ. Vozárová, A., Kováčik, M., Hók, J., Filo, M., Határ, J., Greguš, J., Ďurkovičová, J., Martinský, L., Michalko, J., Siman, P., Sládková, M., Wiegerová,V. & Gregor, T., 1993: The Alpine granitoids – possibility of existence within contact zone between Veporicum and Gemericum and their role in the Western Carpathians structure. Open file report, GÚDŠ, Bratislava, 144 p. (in Slovak).
Hraško, Ľ., Kotov, A. B., Salnikova, E. B. & Kovach, V. P., 1998: Enclaves in the Rochovce granite intrusion as indicators of the temperature and origin of the magma. Geol. Carpath., 49, 2, 125–138.
Hraško, Ľ., Határ, J., Huhma, H., Mäntäri, I., Michalko, J. & Vaasjoki, M., 1999: U/Pb zircon dating of the Upper Cretaceous granite (Rochovce type) in the Western Carpathians. Krystalinikum, 25, 163–171.
Irvine, T. N & Baragar,W. R. A., 1971. A guide to the chemical classification of the common volcanic rocks, Canad. J. Earth Sci., 1.8, 523-548
Ivanov, M., 1981: Nickel-cobalt mineralization of liquation-magmatic type in amphibolitic gabbros of the contact zone of Gemericum with Veporicum.. Mineralia slov., 13,3, 193-208. (In Slovak)
Ivanov, M., 1983: Basic intrusive rocks in the area Rochovce-Chyžné and their nickel mineralization. Mineralia slov. , 15, 5, 437–447. (In Slovak)
Ivanov, M., 1984: Rare earth elements in acid and basic magmatic rocks - Rochovce (borehole KV-3). Miner. Slov., (Bratislava), 16, 2, 173-179. (In Slovak).
Janák, M., Plašienka, D., Frey, M., Cosca, M., Schmidt, Th., Lupták, B. & Méres, Š., 2001: Cretaceous evolution of a metamorphic core complex, the Veporic unit, Western Carpathians (Slovakia); P-T conditions and in situ ^{40}Ar/^{39}Ar UV laser probe dating of metapelites. Journal of Metamorphic Geology, 19, 197-216.
Kantor, J., 1959: Contribution to knowledge about Veporic granites using Ar^{40}/K^{40} method. Geol. Práce, Zprávy, 16, 5-10. (In Slovak).
Kantor, J., 1960: Cretaceous orogenetic processes in the light of geochronological research of Veporic crystalline basement (Kohút zone). Geol. Práce, Zprávy, 19, 5-26. (In Slovak).
Kantor, J. & Rybár, M., 1979a: Radiometric ages of granites from the Spiš-Gemer Ore Mts. and neighbouring part of Veporicum. Geol. Práce, Správy 73, 213-234. (In Slovak).
Kantor, J. & Rybár, M. 1979b: Radiometric ages and polyphasic character of Gemeride granites. Geol. Zbor. Geol. carpath. 30, 4, 433-447.
Klinec, A. 1966: To the problem of geological setting and origin of Veporic crystalline basement. Západ. Karpaty, 6, 7-28. (In Slovak)
Klinec, A., Ivanov, M., Planderová, E., Beňka, J., Pulec, M., Hanzel, V., Obernauer, D., Noghe, V., Stránska, M., Dávidová, Š., Krist, E. & Siegl, K., 1979: Final report about the structural borehole KV-3 (Rochovce). Open file report, ŠGÚDS Bratislava. (In Slovak).
Klinec, A. & Planderová, E., 1981: The question of stratigraphic unity of the Hladomorná dolina Series. Geol. Práce, Správy, 75, 13-18. (In Slovak)
Kohút, M., Kovach, V. P., Kotov, A. B., Salnikova, E. B. & Savatenkov, V. M., 1999: Sr and Nd isotope geochemistry of Hercynian granitic rocks from the Western Carpathians: Implications for granite genesis and crustal evolution. Geologica Carpath., 50, 4, 477–487.
Korikovsky, S. P., Krist, E. & Janák, M., 1989: Metamorphic phase equilibria and primary character of metagabbros from borehole KV-3 near Rochovce and of amphibolites of Hladomorná valley Formation (Slovenské rudohorie Mts.). Geol. Zbor., Geol. Carpath., 40, 2, 231–244.
Kostitsyn, Yu. A. & Volkov, V. N., 1990: Primary Sr isotope inhomogeneity and petrogenesis of the Raumid intrusion granites, south Pamir. Geochemistry International, 27, 1, 75-85.
Kovách, A., Svingor, E. & Grecula, P., 1986: Rb-Sr isotopic ages of granitoids from the Spišsko-Gemerské rudohorie Mts., Western Carpathians, Eastern Slovakia. Mineralia Slov. 18, 1, 1-14.
Kováčik, M., 1998: Notes on Alpine metamorphic history of Veporicum Unit. In: Rakús, M. (ed.): Geodynamic development of the Western Carpathians. GS SR - Bratislava, D. Štúr Publishers, 131-142
Kováčik, M., Kráľ, J. & Maluski, H., 1996: Alpine metamorphic and thermochronologic development of South Veporic Pre-Alpine metamorphites. Mineralia slov., 28, 3, 185-202. (In Slovak)
Kráľ, J., 1994: Strontium isotopes in granitic rocks of the Western Carpathians. Mitt. Österr. Geol. Ges., 86, 75-81.
Kráľ, J., Frank, W. & Bezák, V., 1996: ^{40}Ar/^{39}Ar spectra from amphibole of amphibolitic rocks of Veporicum. Mineralia Slov., 28, 501–513. (In Slovak).
Krist, E., Korikovsky, S. P., Janák, M. & Boronikhin, V. A., 1988: Comparative mineralogical-petrographical characteristics of metagabbro from borehole KV-3 near Rochovce and of amphibolites of Hladomorná valley Formation (Slovenské rudohorie Mts.). Geol. Zborn., Geol. carpath., 39, 2, 171–194.
Leake, B. E., Woolley, A. R., Arps, Ch. E., Birch, W. D., Gilbert, M. Ch., Grice, J. D., Hawthorne, F. C., Kato, A., Kisch, H. J., Krivovichev, V. G., Linthout, K., Laird, J., Mandarino, J. A., Maresch, W. V., Nickel, E. H., Rock, N. M., Schumacher, J. C., Smith, D. C., Stephenson, N. C., Ungaretti, L., Whittaker, E. J. &. Youzhi, G., 1997: Nomenclature of amphiboles: Report of Subcommitee on Amphiboles of the International Mineralogical Association, Commission on New Minerals and Mineral Names. Am. Miner., 82, 1019-1037.
Le Maitre, R. W., 1989: A classification of igneous rocks and glossary of terms. Blackwell, Oxford, 193 p.
Maruyama, S., Suzuki, K. & Liou, J. G., 1983: Greenschist-amphibolite transition equilibria at low pressures. Journal of Petrology, Vol. 24, 4, 583-604.
McCulloh, M. T. & Bennet V. C., 1994: Progressive growth of the Earth's continental crust and depleted mantle: Geochemical constraints. Geochim. Cosmochim. Acta, 58, 21, 4717-4738.
Maluski, H., Rajlich, P. & Matte, P., 1993: ^{40}Ar-^{39}Ar dating of the Inner Carpathians Variscan basement and Alpine mylonitic overprinting. Tectonophysics, 223, 319 - 337.
Michard, A., Gurriet, P., Soudant, M. & Albarede, F., 1985: Nd isotopes in French Phanerozoic shales: External vs. internal aspects of crustal evolution. Geochim. Cosmochim. Acta, 49, 601–610.

Slovak Geol. Mag., 10, 4 (2004), 263 – 276

Mullen, E. D., 1983: $MnO/TiO_2/P_2O_5$: A minor element discriminant for basaltic rocks of oceanic environments and its implications for petrogenesis. Earth Planet. Sci. Lett., 62, 53-62.

Nicolaysen, L. O., 1961: Graphic interpretation of discordant age measurements on metamorphic rocks. Ann. NY. Acad. Sci., 91, 198–206.

Orsini, J. B., Cocirta, C. & Zorpi, M. J., 1991: Genesis of mafic microgranular enclaves through differentiation of basic magmas, mingling and chemical exchanges with their host granitoid magmas. In: Didier, J. & Barbarin, B. (eds): Enclaves and granite petrology. Elsevier, Amsterdam, 625 p.

Samoilov, V. S., Yarmolyuk, V. V., Kovalenko, V. I., Ivanov, V. G. & Pokholchenko, Yu. A., 1998: Geochemical and isotopic characteristics and magma sources of the Early Cretaceous trachybasalt of the Gobi-Altai rift zone: An example of grabens in the Arts-Bogdo Range. Geochemistry International, 36,12, 1087-1099.

Papanastassiou, D. A. & Wasserburg, G. J., 1969: Initial strontium isotopic abundances and the resolution of small time differences in the formation of planetary objects. Earth Planet. Sci Lett., 5, 361–376.

Pearce, J. A. & Cann, J. R., 1973: Tectonic setting of basic volcanic rocks determined using trace element analyses. Earth Planet. Sci. Lett., 19, 290-300.

Petrík, I. & Broska, I., 1989: Mafic enclaves in granitoid rocks of the Tríbeč Mts., Western Carpathians: Geochemistry and petrology. Geol. Zborn. Geol. carpath. 40, 667-696.

Poller, U., Uher, P., Janák, M., Plašienka, D. & Kohút, M., 2001: Late Cretaceous age of the Rochovce granite, Western Carpathians, constrained by U-Pb single zircon dating in combination with cathodoluminescence imaging. Geologica Carpath., 52, 1, 41–47.

Rosenbaum, J. M., Downes, H. & Wilson, M., 1997: Multiple enrichment of the Carpathian-Pannonian mantle: Pb-Sr-Nd isotope and trace element constraints. J. Geoph. Res., 102, B-7, 14947–14961.

Rösler, H. J. & Lange, H., 1972: Geochemical tables. Edition Leipzig, 468 p.

Thompson, R. N., Dickin, A. P., Gibson, L. L. & Morrison, M. A., 1982: Elemental fingerprints of isotopic contamination of Hebridean Palaeocene mantle-derived magmas by Archaean Sial. Contrib Mineral Petrol, 79, 159–168.

Thöni, M. & Jagoutz, E., 1992: Some new aspects of dating eclogites in orogenic belts: Sm-Nd, Rb-Sr, and Pb-Pb isotopic results from the Austroalpine Saualpe and Koralpe type locality (Carinthia/Styria, southeastern Austria). Geochim. Cosmochim. Acta, 56, 347–368.

USGS, 1986: Chemical and isotopic studies of Archean granitic rocks, Owl Creek Mountains, Wyoming. U. S. Geological Survey Professional Paper, 48 p.

Vozárová, A. & Vozár, J., 1982: New lithostratigraphic units in the southern part of Veporicum. Geol. Práce, Správy, 78, 169-194. (In Slovak).

Vrána, S., 1964a: Chloritoid and kyanite zone of Alpine metamorphism on the boundary of the Gemerides and the Veporides (Slovakia). Krystalinikum, 2, 125–143.

Vrána, S., 1964b: Petrogenesis of Veporic crystalline in the surrounding of Slavošovce. Geol. Práce, Správy, 33, 5-29. (In Slovak)

Winchester, J. A. & Floyd, P. A., 1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chem. Geology, 20, 325-343.

Slovak Geol. Mag., 10, 4 (2004), 277 – 283

Oligocene larger foraminifers in Paleogene sediments westward of Banská Bystrica (Middle Slovakia)

STANISLAV BUČEK[1] and IVAN FILO[1]

[1]Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic

Abstract: The Lower Oligocene larger foraminifers *Nummulites vascus* JOLY et LEYMERIE and *Nummulites* cf. *fichteli* MICHELOTTI are described from the Western Carpathian Inner Carpathian Paleogene of Sub-Tatric Group for the first time. They were found in several localities in the surrounding of Banská Bystrica in sandstones of Huty Formation (upper sandstone horizon) in the northern part of Zvolen Basin (Middle Slovakia). According to Cahuzac & Poignant (1997) the described species belong to SBZ 21 and are characteristic for transitional development between Sub-Tatric Group and Budín Paleogene.

Key words: larger foraminifers, Western Carpathians, Zvolen Basin, Lower Oligocene

Introduction

The relicts of Paleogene rocks being preserved in the belt from Badín to Kordíky westward of Banská Bystrica (Middle Slovakia) formerly undoubtedly covered the larger and more continual area than in the present time.

Paleogene rocks in this area are known from the time of Štúr (1866, 1868), but literature data about them are very scarce. The age determination of these sediments was mentioned only by Vaňová (1972). She stated that the organogenic sandy limenstones near Králiky contain Upper Eocene assemblage with *Nummulites variolarius* (LAMARCK), *N. incrassatus incrassatus* DE LA HARPE and the calcareous sandstones between Tajov and Králiky contain species *Nummulites variolarius* (LAMARCK), *N. striatus pannonicus* (ROZL.), *N. incrassatus incrassatus* DE LA HARPE and transitional forms from *N. fabianii* (PREVER) to *N. fichteli fichteli* MICHELOTTI. These transitional forms indicate the relatively young age of sediments. The recent investigations not only confirmed this fact, but owing the presence of *Nummulites vascus* JOLY et LEYMERIE the Oligocene age of rocks of Inner Carpathian Paleogene was for the first time proved by the larger foraminifers.

Section in the Malachovský potok stream

According to recently valid knowledge the Paleogene sediments westward of Banská Bystrica belong to transitional development between Sub-Tatric Group sensu Gross et al. (1984) and Budín Paleogene sensu Tari et al. (1992), Gyalog et al. (1996) and Vass (2002).

Minute occurrences of Paleogene rocks are spread from Badín through Malachov, Radvaň, Tajov to Kordíky and belong to various formations. The most complete section can be studied in the Malachovský potok stream (BB-63) westward of village Malachov and 700 m to NW of altitude point Krpcová 935 (Fig. 1). Formation (section

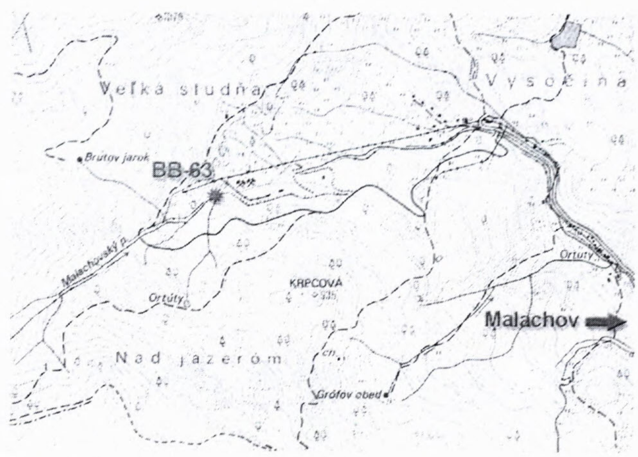


Fig. 1. Location of section Malachov BB-63 westward of Banská Bystrica in topographic sheet 36-143 Banská Bystrica in the scale 1 : 25 000.

in Fig. 2) is allocated to the upper sandstone horizon of Huty Formation and reaches the thickness to 20 m (Filo et al. in Polák et al. 2003).

Sandstones are bedded with rough planes, blue, grey (after weathering yellow), middle to coarse-grained, calcareous. Usually they are irregularly bedded, some layers have distinctive graded bedding with fine-grained upper part. They contain intraclasts of organodetritic (prevailingly Paleogene) limestones, pebbles of dolomites, less often quartzstones, limestones and shales of dimensions to 100 mm, max. 160 mm of spindle and isometric shapes. The quartz fragments are smaller and less reworked. Pebble material is mostly chaotically distributed, sometime the occurrence of bigger pebbles near the bed surface is observable. The large pebbles of dolomite and further rocks toward the hanging wall became gradually rare and the quartz pebbles of 1-8 mm dimension is dominating.

Geological Survey of Slovak Republic, Dionýz Štúr Publisher, Bratislava 2004 ISSN 1335-96X

Slovak Geol. Mag., 10, 4 (2004), 277 – 283

Petrographically the sandstones correspond with calcareous sublithic and lithic arenites consisting from calcite cement (18-33 %), mono- (15-32 %) and polycrystalline (4-7 %) quartz, metamorphites (8-9 %), organic remnants (4-7 %), quartzstones (4-6 %), plagioclase (3-4 %), orthoclase (1-3 %), fragments of carbonates, sandstones, claystones, quartzy porphyries, biotite, microcline and granitoids (Siráňová 2001).

Sandstones locally pass into the fine-grained conglomerates, their bigger pebbles locally form bands or lensoidal clusters of paraconglomeratic character.

Larger foraminifers in the Malachov section

The larger foraminifers in the Malachov section occur either in fragments of Upper Eocene limestones and sandstones, or as isolated tests of Upper Eocene and Oligocene species in the sandstone matrix.

Fragments of Upper Eocene limestones and sandstones are spread in the whole section, but most frequently in horizons 2 to 7 (see section in Fig. 2). The cross-section through the fragment of Upper Eocene organogenic discocycline limestone with cross-sections of *Discocyclina sella* (D´ARCHIAC) is figured in Pl. I, Fig. 1. The fragments of Upper Eocene limestones and sandstones contain unmixed assemblages of larger foraminifers consisting from species *Nummulites striatus* (BRUG.), *N. variolarius* (LAMARCK), *N. chavannesi* DE LA HARPE, *N. incrassatus* DE LA HARPE, *Assilina* (*Operculina*) *alpina* (DOUVILLÉ), *Ass.* (*O.*) *gomezi* (COLOM et BAUZÁ), *Discocyclina sella* (D´ARCHIAC), *D. augustae* VAN DER WEIJDEN, *D. pratti* (MICHELIN), *Asterocyclina* sp. Another organic remnants are rare. These assemblages of Priabonian age belong to SBZ 19 sensu Serra-Kiel et al. (1998).

The fragments of Upper Eocene rocks are sometimes small and occur as clasts in sandstones. The fragment of sandstone with tests *Discocyclina sella* (D´ARCHIAC) are shown in Pl. I, Fig. 2. The axial section through the test *Nummulites fabianii* (PREVER), being still sticked around by former sandy rock, is shown in Pl. I, Fig. 4.

The majority of tests of larger foraminifers is redeposited without remnants of former rock and give the impression that they belong into the original assemblage in sandstones. Such assemblage is displayed e.g. in Fig. 5 of

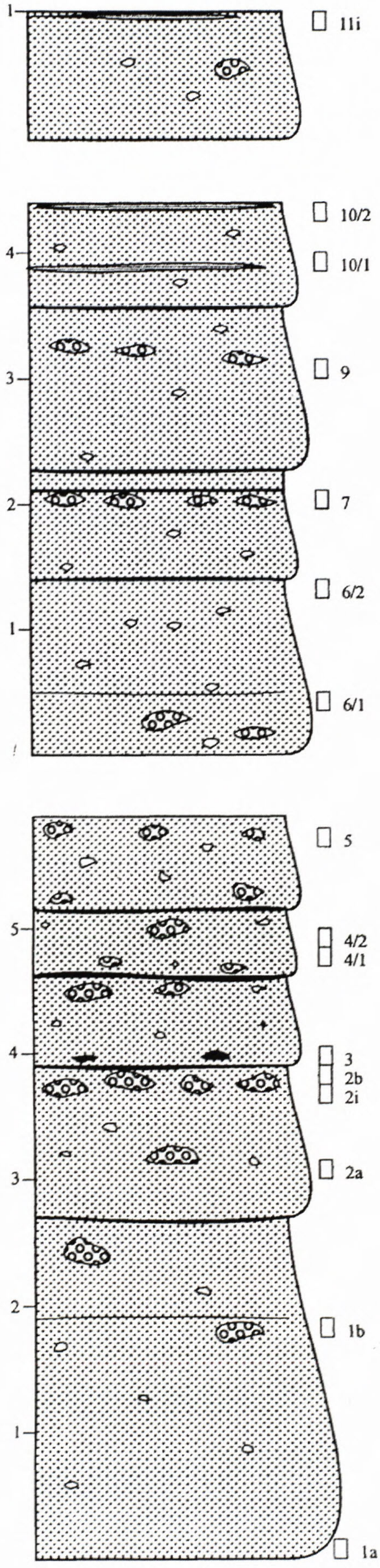
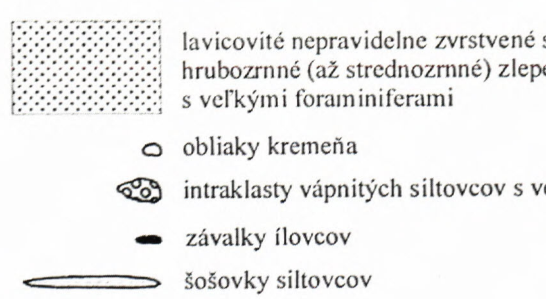


Fig. 2. Section Malachov (BB-63). Left-bank cut of the Malachovský potok stream 700 m to NW of elevation point Krpcová (935), catastral area Banská Bystrica – Malachov.



Pl. I with cross-sections of *Nummulites striatus* (BRUG.) from the horizon 11 in the Malachov section. The majority of assemblage also in the sandstones is formed by Upper Eocene species (Pl. I, Figs. 3 and 6; Pl. II, Fig. 3).

The preservation of tests is usually excellent (e. i. *Nummulites striatus* (BRUG.) in Pl. II, Fig. 4 or *N. incrassatus* DE LA HARPE in Pl. II, Fig. 5), but also damaged tests, being grinded and fragmented (mainly the tests of discocyclines) are present.

The Upper Eocene larger foraminifers whose isolated tests are present in sandstones along the whole section of the Malachovský potok stream, belong to zones SBZ 19 and SBZ 20 sensu Serra-Kiel et al. (1998). The following species were identified: *Nummulites incrassatus* DE LA HARPE, *N. garnieri* BOUSSAC, *N. fabianii* (PREVER), *N. striatus* (BRUG.), *N. chavannesi* DE LA HARPE, *N. pulchellus* DE LA HARPE, *Assilina (Operculina) alpina* (DOUV.), *Ass. (O.) gomezi* (COLOM et BAUZÁ), *Heterostegina reticulata* (RÜTIMEYER), *H. (Grzybowskia) multifida* (BIEDA), *Spiroclypeus carpaticus* UHLIG, *Orbitoclypeus varians* (KAUFM.), *Discocyclina pulcra* CHECCHIA-RISPOLI, *D. sella* (D´ARCHIAC), *D. pratti* (MICHELIN), *D. augustae* VAN DER WEIJDEN, *Asterocyclina* sp. In thin sections very rarely also tests of Middle Eocene species can be recognized, e.g. *Nummulites* cf. *brongniarti* D´ARCHIAC et HAIME in horizon 6 and *N. millecaput* BOUBÉE in horizon 3. Rarely also small fragments of coral line algae, bryozoans, lamellibranchiata and crinoid segments are present. The smaller foraminifers are sporadically represented by miliolid, rotalid and agglutinated forms. The cross-sections through globigerinas are very scarce.

For the age classification of the Malachov section there is determining the presence of Oligocene larger foraminifers (Buček, 2001, Buček in Filo et al. 2003), namely *Nummulites vascus* JOLY et LEYMERIE and *N.* cf. *fichteli* MICHELOTTI, being found in the whole section (horizons 1 to 11, Fig. 2).

Description of Oligocene larger foraminifers in the Malachov section

Nummulites vascus JOLY et LEYMERIE
(Pl. I, Figs. 3, 6; Pl. II, Figs. 3, 6, 7)

The tests of *Nummulites vascus* JOLY et LEYMERIE are frequently present in the Malachov section and we succeeded in obtaining of isotaled individuals for the study in oriented sections (Pl. II, Figs. 6, 7).

The tests are of symmetric lenticular shape, on their surface decorated with radial septal filaments, without central pillar. A-forms are 1.8-3.1 mm large and 0.9-1.2 mm thick, rarely present tests of B-forms have diameter 3.8-4.2 mm and thickness 1.2-1.7 mm. While the A-forms have 3-5 whorls, B-forms have maximally 7 whorls.

The protoconchs of A-forms have largeness 0.15-0.20 mm, the diameter of the first two chambers is 0.25-0.29 mm, the arrangement is isolepidine. The step of whorls grows slowly and regularly. For the radius 1.2 mm there are 4 whorls, for 1.4-1.6 mm 5 whorls. The marginal cord = 1/3 of the chambers height. Partitions are slightly inclined and moderately bended. For 1/4 of the 1. whorl = 2-3, 2. = 3-4, 3. = 4-5, 4. = 6-7 partitions. Chambers are higher than long, from the fourth whorl there is registrable the tendency to obtain the isometric form.

Stated values correspond with those, being stated for *N. vascus* JOLY et LEYMERIE by Blondeau (1972), Schaub (1981) and Jámbor-Kness (1988). With exception to Jámbor-Kness (l. c.), who allows the presence of *N. vascus* JOLY et LEYM. in Upper Eocene, further authors suppose this species to be typical for Oligocene.

The tests *N. vascus* JOLY et LEYM. occur mainly in horizons 1, 2, 3, 6, 8, 10 and 11 of the section Malachov BB-63.

Nummulites cf. *fichteli* MICHELOTTI
(Pl. II, Figs. 1-2)

The tests of this species are relatively rare. We did not succeed in obtaining of isolated individuals for oriented sections and so this species is known only from axial sections. The tests are flat-lenticular to disc-like, sometimes bended, on the surface decorated with irregular fine reticulation. There were found only the tests of A-generation, having the diameter 4.0-6.5 mm and thickness 1.1-1.5 mm and formed maximally by 6 whorls.

The species is present only in Oligocene (Blondeau 1972; Schaub 1981). The tests were found in horizons 3, 10 and 11 of the section Malachov BB-63.

Both *N. vascus* JOLY et LEYM. as well as *N.* cf. *fichteli* MICHELOTTI are of Lower Oligocene age and belong to SBZ 21 sensu Cahuzac & Poignant (1997).

Conclusions

The section Malachov BB-63 contains the mixed assemblage of larger foraminifers formed by Upper Eocene to Oligocene species. The Upper Eocene component should be supposed to be redeposited, which is confirmed with clasts of Upper Eocene species.

The presence of numerous intraclasts and pebbles of large dimensions in the section confirms, that the origin of upper sandstone horizon of Huty Formation was caused by uplift and destruction of the basin margins due to tectonic events or the significant decrease of the sea level at the beginning of Oligocene. The second possibility seems to be more realistic, because the destruction affected only the Upper Eocene part of succession, the fragments from the Middle Eocene Borové Formation were not in the Malachov section found (with exception of very rare tests *Nummulites* cf. *brongniarti* D´ARCHIAC et HAIME and *N. millecput* BOUBÉE, which could be redeposited already to Upper Eocene rocks).

Besides the Malachov section the tests *Nummulites vascus* JOLY et LEYMERIE and *N.* cf. *fichteli* MICHELOTTI were found also at Badín and Tajov.

From the Western Carpathian area the similar assemblage is known only from the outer flysch belt. From the lower Krosno Beds near Baligrod (Poland) Bieda (1963) described the mixed assemblage formed by redeposited tests of Upper Eocene larger foraminifers and tests of *Nummulites vascus* JOLY et LEYM. and *N.* sp. aff.

Slovak Geol. Mag., 10, 4 (2004), 277 – 283

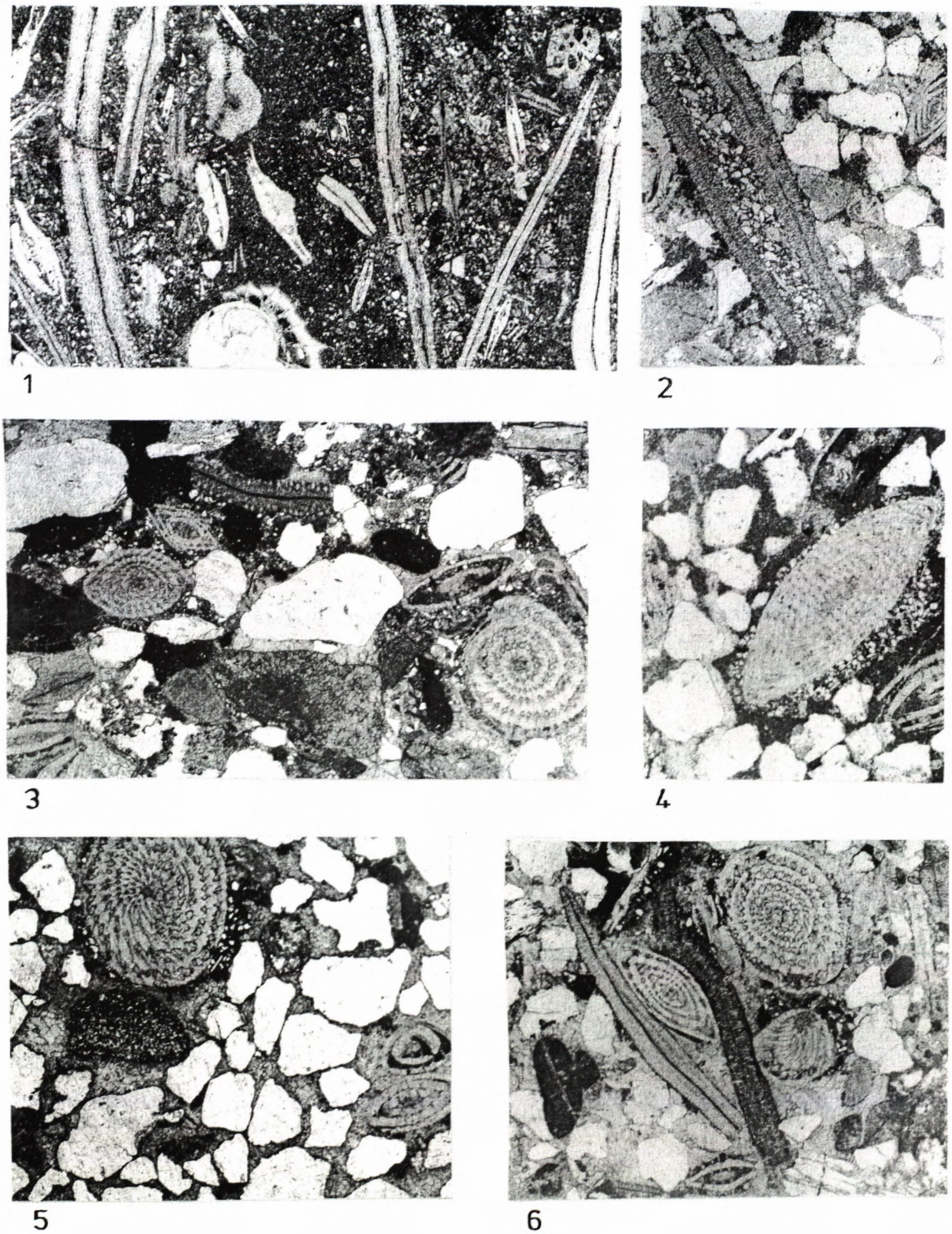


Plate I

Fig. 1 – Organogenic limestone with cross-sections of tests *Discocyclina sella* (D´ARCHIAC), *Assilina* (*Operculina*) *alpina* (DOUV.) and *Ass.* (*O.*) *gomezi* (COLOM et BAUZÁ). Fragment in debris, Malachov BB-63, thin section Bu-934, magn. 10x; Fig. 2 – Fragment of sandstone with *Discocyclina sella* (D´ARCHIAC) in Oligocene sandstone. Right side shows the redeposited test *Nummulites chavannesi* DE LA HARPE. Fig. 3 – Oligocene sandstone with sections of *Nummulites vascus* JOLY et LEYM. (oblique section in the right side), *N. variolarius* (LAMARCK), *Discocyclina pratti* (MICHELIN). Section Malachov BB-63-11, thin section Bu-944, magn. 10x;

intermedius D´ARCH. (= *N. fichteli* MICHELOTTI). This assemblage was designated by Bieda to be probable of Oligocene age. This phenomenon is noticeably similar to the situation in the section of Malachovský potok stream.

Nummulites cf. *vascus* JOLY et LEYM. describes Bieda (1931) from locality Turinok in Orava, but the presence of this species in Orava Paleogene was not confirmed with later works (Gross et al. 1993).

In Budín Paleogene the presence of *N. vascus* JOLY et LEYM. is stated by Kecskeméti (1981) from the section Solymar together with redeposited Upper Eocene nummulites and discocyclines. This author places this locality unambiguously into the Oligocene, similarly as the beds with *N. vascus* JOLY et LEYM. in locality Pilisborosjenö in the Pilis mountain ridge. Jámbor-Kness (1988) introduces this species from formations Tokod a Nagysáp situated to uppermost part of Priabonian.

In the Eastern Carpathians *N. vascus* JOLY et LEYM. in assemblage with *N. fichteli* MICHELOTTI (= *N. intermedius*) is announced by Nemkov (1955, 1967) from sediments of Menilite and Krosno units from Seletin. He does not doubt about their Oligocene age.

Logically there occurs a question, whether also Oligocene fossils in the Malachov section are not redeposited and the formation is not even younger. Despite very detail investigation of foraminifera fauna in this locality the younger sediments than those in SBZ zone 21 (= P 18-19, NP 21-23) of Rupelian age (sensu Cahuzac & Poignant, 1997) were not revealed.

The Huty Formation on northeastern margin of the Kremnica Hills was simultaneously elaborated also by microfauna and microflora studies. According to Zlinská (in Kováč et al. 2001) it corresponds to the age diapason Priabonian – Upper Kiscelian. The considerable differences were found by dating of the calcareous nanoplankton. According to Žecová (2000) the formation is of the age Priabonian - Lower Kiscelian (NP 19–21), according to Andrejeva-Grigorovič (in Zlinská 2001) it corresponds to Kiscelian to Lower Egerian (NP 23–25). The spread of the Huty Formation into Priabonian is confirmed also by the larger foraminifers (so-called basal sandstone horizon among Tajov, Kordíky and Králiky villages; Filo et al. 2003), the overreaching into Egerian appears exceedingly unprobable, also regarding the overal thickness of formation (ca 300 m).

The presence of Oligocene larger foraminifers near Banská Bystrica is surprising not only from the stratigraphic viewpoint, but raises the doubt about the commonly accepted thesis, that in Western Carpathian Oligocene the larger foraminifers were not preserved because of climatic reasons. Though Portnaja (1981) supposes the distinctive cooling at the beginning of Oligocene as a reason of disappearance of discocyclinid foraminifers, she warns, that nummulites could survive also at lowered temperature of the sea water (according to her to 16 °C).

References

Bieda, F., 1931: O kilku nummulinach z Karpat czechoslowackich. Věstn. Stát. geol. Úst. ČSR (Praha), 7, 1, 58-74.

Bieda, F., 1963: Siódmy poziom duźnych otwornic we fliszu Karpat polskich. Roczn. Pol. Tow. geol. (Krakow), 33, 2, 189-218.

Blondeau, A., 1972: Les Nummulites. Vuibert, Paris, 1-254.

Buček, S., 2001: Biostratigraphic evaluation of larger foraminifers in the project No. 150: Starohorské vrchy Hills, Čierťaž and northern part of the Zvolen Basin (map sheet 36-143 Banská Bystrica). Manuscript, archives ŠGÚDŠ, Bratislava. (in Slovak)

Cahuzac, B. & Poignant, A., 1997: Essai de biozonation de l´Oligo-Miocène dans les bassins européens á l´aide des grands Foraminifères néritiques. Bull. Soc. géol. France (Paris), 168, 2, 155-169.

Filo, I., Buček, S. & Siráňová, Z., 2003: Paleogén. In: Polák, M. (ed.), Filo, I., Havrila, M., Bezák, V., Kohút, M., Kováč, P., Vozár, J., Mello, J., Maglay, J., Elečko, M., Vozárová, A., Olšavský, M., Siman, P., Buček, S., Siráňová, Z., Hók, J., Rakús, M., Lexa, J., Šimon, L., Pristaš, J., Kubeš, P., Zakovič, M., Liščák, P., Žáková, E., Boorová, D. & Vančková, H.: Explanations to geological map of Starohorské vrchy Hills, Čierťaž and northern part of the Zvolen Basin 1 : 50 000. ŠGÚDŠ, Bratislava, 91-97. (in Slovak)

Gross, P., Köhler, E. & Samuel, O., 1984: Lithostratigraphic classification of Inner Carpathian Paleogene sedimentary cycle. Geol. Práce, Spr. (Bratislava), 81, 103-117. (in Slovak)

Gross, P., Köhler, E., Mello, J., Haško, J., Halouzka, R., Nagy, A. et al., 1993: Geology of southern and eastern Orava. Geol. Úst. D. Štúra, Bratislava, 7-319. (in Slovak)

Gyalog, L. (ed.), 1996: A földtani térképak jelkulcsa és a rétegtani egységek rövid léirása. Magy. All. Földt. Int. Alkalmi kiadványa (Budapest), 187, 1-171.

Jámbor-Kness, M., 1988: Les grands Foraminifères éocènes de la Hongrie. Geol. Hung., Palaeontol. (Budapest), 52, 3-629.

Kecskeméti, T., 1981: The Eocene/Oligocene boundary in Hungary in the light of the study of larger foraminifera. Palaeogeogr., Palaeoclimatol., Palaeoecol. (Amsterdam), 36, 3/4, 249-262.

Kováč, P., Hók, J., Maglay, J., Filo, I., Lexa, J., Filová, I., Elečko, M., Boorová, D., Siráňová, Z., Buček, S & Zlinská, A., 2001: Explanations to geological map 1 : 25 000, map sheet 36-143 Banská Bystrica. Manuscript, archives ŠGÚDŠ, Bratislava. (in Slovak)

Nemkov, G. I., 1955: Numulitidy i orbitoidy Pokutsko-Marmarošskych Karpat i Severnoj Bukoviny. In: Materialy po biostrat. zap. obl. Ukr. SSR, Gostechizdat, Moskva, 133-227.

Nemkov, G. I., 1967: Numulitidy Sovetskogo Sojuza i ich biostratigrafičeskoje značenije. Nauka, Moskva, 5-318.

Portnaja, V. L., 1981: Orbitoidy Sovetskogo Sojuza i utočnenije ich sistematiky. Izv. Vyšš. učeb. zav., Geol. i razv. (Moskva), 7, 35-39.

Schaub, H., 1981: Nummulites et Assilines de la Téthys paléogène. Taxinomie, phylogenèse et biostratigraphie. Schweiz. Paläontol. Abh. (Basel), 104-106, 3-236.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferràndez, C., Jauhri, A. K., Less, G., Pavlovec, R., Pignatti, J., Samsó, J. M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J. & Zakrevskaya, E., 1998: Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. Bull. Soc. géol. France (Paris), 169, 2, 281-299.

Fig. 4 – Axial section through redeposited test *Nummulites fabianii* (PREVER), still sticked around with original rock. Oligocene sandstone, section Malachov BB-63-2, thin section Bu-1011, magn. 10x; Fig. 5 – Oligocene sandstone with sections of *Nummulites striatus* (BRUG.) (upper part of the picture) and *Nummulites* sp. Section Malachov BB-63-11, thin section Bu-945, magn. 10x; Fig. 6 – Oligocene sandstone with cross-sections of *Nummulites vascus* JOLY et LEYM. (oblique section in the upper part), *N. fabianii* (PREVER) (axial section in the middle), *Discocyclina sella* (D´ARCHIAC) a. o. Section Malachov BB-63-10, thin section. Bu-927, magn. 10x. Photo by the authors.

Slovak Geol. Mag., 10, 4 (2004), 277 – 283

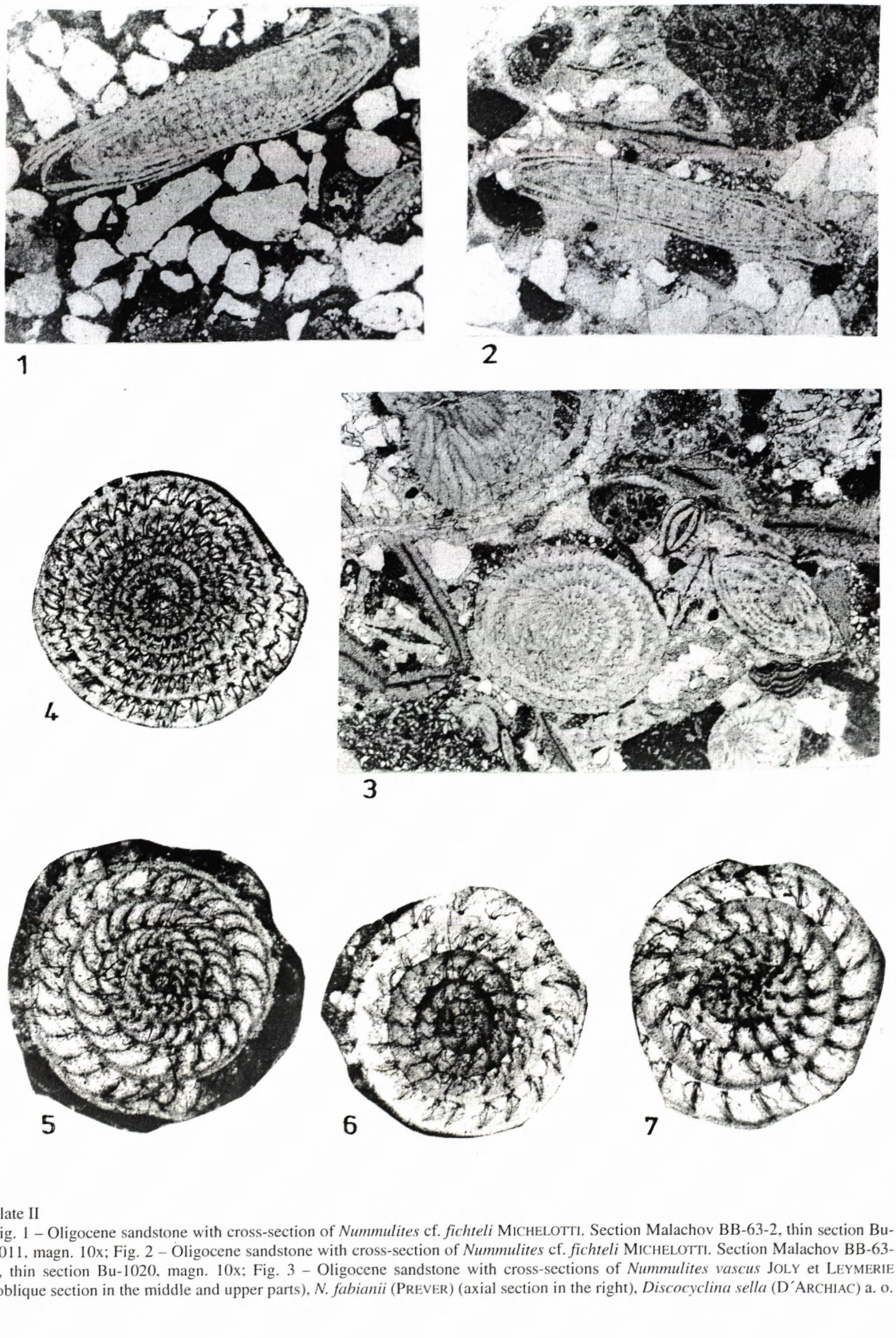


Plate II

Fig. 1 – Oligocene sandstone with cross-section of *Nummulites* cf. *fichteli* MICHELOTTI. Section Malachov BB-63-2, thin section Bu-1011, magn. 10x; Fig. 2 – Oligocene sandstone with cross-section of *Nummulites* cf. *fichteli* MICHELOTTI. Section Malachov BB-63-3, thin section Bu-1020, magn. 10x; Fig. 3 – Oligocene sandstone with cross-sections of *Nummulites vascus* JOLY et LEYMERIE (oblique section in the middle and upper parts), *N. fabianii* (PREVER) (axial section in the right), *Discocyclina sella* (D´ARCHIAC) a. o.

Siráňová, Z., 2001: Petrographic evaluation of thin sections (map sheet Banská Bystrica 36-143 1:25 000). Manuscript, archives ŠGÚDŠ, Bratislava. (in Slovak)

Štúr, D., 1866: Petrefacten von Liptsche. Jb. K. Kön. geol. Reichsanst. (Wien), 16, 1, 57-58.

Štúr, D., 1868: Bericht über die geologische Aufnahme im oberen Waag- und Granthale. Jb. K. Kön. geol. Reichsanst. (Wien), 18, 3, 337-426.

Tari, G., Báldi, T., Báldi-Béke, M., 1992: Paleogene retroarc flexural basin beneath the Neogene Pannonian Basin: A geodynamic model. Tectonophysics (Amsterdam), 226, 433-455.

Vaňová, M., 1972: Nummulites from the area of Bojnice, the Upper Hron Depression, and the Budín Paleogene around Štúrovo. Zbor. geol. Vied, Záp. Karpaty (Bratislava), 17, 5-104.

Vass, D., 2002: Lithostratigraphy of Western Carpathians: Neogene and Budín Paleogene. Št. geol. Úst. D. Štúra, Bratislava, 1-202. (in Slovak)

Zlinská, A., 2001: Microfaunistic evaluation of samples in project No. 150: Starohorské vrchy Hills, Čierťaž and northern part of Zvolen Basin (map sheets 36-141 Staré Hory, 36-142 Lučatín and 36-143 Banská Bystrica). Manuscript, archives ŠGÚDŠ, Bratislava. (in Slovak)

Žecová, K., 2000: Microbiostratigraphic evaluation of calcareous nanoplankton from localities Kordíky, Tajov, Králiky, Ľubietová. Manuscript, archives ŠGÚDŠ, Bratislava. (in Slovak)

Section Malachov BB-63-10, thin section Bu-929, magn. 10x; Fig. 4 – Equatorial section throung A-form of *Nummulites striatus* (BRUG.). Section Malachov BB-63, thin section Bu-IZ/14, magn. 20x; Fig. 5 – Equatorial section through A-form of *Nummulites incrassatus* DE LA HARPE. Section Malachov BB-63, thin section Bu-IZ/1, magn. 20x; Fig. 6 – Equatorial section through A-form of *Nummulites vascus* JOLY et LEYM. Section Malachov BB-63, thin section Bu-IZ/13, magn. 20x; Fig. 7 – Equatorial section through A-form of *Nummulites vascus* JOLY et LEYM. Section Malachov BB-63, thin section Bu-IZ/12, magn. 20x. Photo by the authors.

Genus *Borelis* (Foraminiferida, Alveolinidae) in Paleogene of the Western Carpathians

STANISLAV BUČEK[1] and EDUARD KÖHLER[2]

[1]Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic
[2]Geophysical Institute of Slovak Academy of Sciences, Dúbravská cesta 9, 842 28 Bratislava, Slovak Republic

Abstract: The genus *Borelis* is described from the Paleogene sediments of the Western Carpathians for the first time. It was found in three localities in bioherm limestones in the Borové Formation of the Sub-Tatric Group of the Central Carpathian Paleogene in the northern rim of the Liptovská kotlina basin (Northern Slovakia). The tests were placed in the species *Borelis vonderschmitti* (SCHWEIGHAUSER). The accompanying association (e.g. *Chapmanina gassinensis* SILVESTRI, *Halkyardia minima* (LIEBUS), *Fabiania cassis* (OPPENHEIM) a. o.) corresponds with the association, accompanying this species in the type localities in Northern Italy (Colli Berici) and the same is also the age assignment at the boundary Middle/Upper Eocene (SBZ 18/SBZ 19).

Key words: Foraminiferida, *Alveolinidae*, *Borelis*, Western Carpathians, Liptovská kotlina basin, boundary Middle/Upper Eocene.

Introduction

Alveolinid foraminifers belong among important constituents of Tertiary foraminiferal assemblages. During the period Paleocene-Middle Eocene the genus *Alveolina* was spread into numerous evolutionary lines (Hottinger 1960, Drobne 1977, White 1992 a. o.). It allowed the detail biozonation of referred time interval. The only disadvantage consists of the restricted space distribution of alveolinid foraminifers. They are bounded to protected shallow water environments (lagoons, back-reef environments), where the water depth does not overreach 50 m.

At the end of Middle Eocene the genus *Alveolina* died out soon after the tests of some its species reached dimensions being gigantic for foraminifers (e.g. Lutetian *Alveolina gigantea* CHECCHIA-RISPOLI attained length 6-7 cm). At the boundary of Middle and Upper Eocene it was exchanged by the new genera *Borelis* DE MONTFORT and *Praebullalveolina* SIREL et AÇAR belonging also to the family *Alveolinidae*. Some similarities were manifested also by the genus *Malatyna* SIREL et AÇAR, but this belongs to the family *Riveroinidae*. Contrary to the Middle Eocene alveolinids the tests of these genera are very tiny and their dimensions till the end of Eocene did not overreach 1.25 mm (*Praebullalveolina afyonica* in Sirel & Açar 1982).

The data about the occurrence of genus *Borelis* and *Praebullalveolina* in Paleogene are very sporadic. SIREL & AÇAR (1982) the scarcity of their occurrence explain by the fact, that the shallow water back-reef environments with abundant porcellaneous foraminifers are virtually absent in Upper Eocene.

Occurrences of genera *Borelis* and *Praebullalveolina* in Paleogene sediments

In 1951 Schweighauser described in Northern Italy (Colli Berici, Cave Zengele) the new species *Neoalveolina vonderschmitti* occurring in limestones at the boundary of Middle and Upper Eocene. Recently the genus *Neoalveolina* SILVESTRI is supposed to be the synonym of genus *Borelis* DE MONTFORT (compare Loeblich & Tappan 1987, p. 362). Stratigraphic position of this species in the uppermost Middle Eocene and at the boundary of Middle and Upper Eocene was confirmed also by Ungaro (1969). Bassi et al. (2000) locate the first occurrences of this species to the boundary SBZ 18/SBZ 19 sensu biozones suggested in publication by Serra-Kiel et al. (1998). The stratigraphic range of the species *B. vonderschmitti* was later enlarged to the whole Upper Eocene (Bassi & Loriga Broglio 1999) in the range SBZ 18–SBZ 20. The species occurrences in Paleogene sediments are always very rare. Until now the species *B. vonderschmitti* (SCHWEIGH.) was found besides the type territory (Colli Berici, Northern Italy) also in other areas of Italy (Monti Lessini, Maiella, Umbria), but also in Slovenia, Croatia, Germany and Oman (compare Bassi & Loriga Broglio 1999).

The genus *Praebullalveolina* was defined by Sirel & Açar (1982) for individuals from Upper Eocene limestones with *Nummulites fabianii* (PREVER) in Western Turkey with the type species *P. afyonica* SIREL et AÇAR. The genus is described by Barbin et al. (1997) from the boundary Upper Eocene/Oligocene in the area of Priabona (Northern Italy). The genus *Praebullalveolina* was described also from Eocene of northeastern Spain (Travé et al. 1996), but Sirel & Açar (1998) the Spanish form assigned into the genus *Malatyna* as a new species *M. vicensis* SIREL et AÇAR.

There is worth mentioning also about the genus *Malatyna*, being defined by Sirel & Açar in 1993 with the type species *M. drobnae*. Tests of this genus with their setting are similar the miliolid foraminifers, but belong into the different family (*Riveroinidae* SAIDOVA) and using careful observation they cannot be interchanged with alveolinid foraminifers. The genus appears at the end of Middle Eocene and persists to Upper Eocene.

While the youngest occurrences of the genus *Praebullalveolina* are known from Oligocene, the genus *Borelis* flourish in Miocene (e.g. *Borelis melo* (FICHTEL et MOLL) in Badenian) and survived till recent in the Red sea and in the Indian ocean (Reiss & Gwitzman 1966).

In Paleogene the tests of the genera *Praebullalveolina* and *Borelis* are very similar and for their reliable distinguishing there is necessary to study a bigger number of various sections. Sirel & Açar (1982) state, that their genus *Praebullalveolina* differs from *Borelis* because it has one row of apertures in apertural side and one row of alveoli in the roof of chamberlets. From definitions of both genera by Loeblich & Tappan (1987, pp. 362 and 364, Tabs. 374, 375 and 382) there results that the differences between them are minimal and in non-oriented sections nearly imperceptible.

Genus *Borelis* in Western Carpathians

During detail investigation of bioherm limestones in the northern rim of the Liptovská kotlina basin (Northern Slovakia) the authors found in thin sections from three localities the sections of tests, which could be associated with the genus *Borelis*. The extreme scarcity of this form is manifested by the fact, that in more than 350 studied thin sections from mentioned three localities, there were found only 33 sections of the tests *Borelis*, being enlisted into the species *Borelis vonderschmitti* (SCHWEIGHAUSER). The description of the species is as follows[1]:

Family *Alveolinidae* EHRENBERG, 1839
Genus *Borelis* DE MONTFORT, 1808

Borelis vonderschmitti (SCHWEIGHAUSER, 1951)
(Pl. 1, Figs. 1-6, Pl. 2, Figs. 1-2)

1951 *Neoalveolina vonderschmitti* – Schweighauser, pp. 466-468, Figs. 1-5
1999 *Borelis vonderschmitti* – Bassi & Loriga Broglio, p. 233, Pl. 3, Figs. 1-6 (with detail synonymy).

Studied material: 33 various sections
Description: Tests of porcellaneous, globular to weakly nautiloid form (Pl. I, Figs. 1-5), sometimes weakly deformed (Pl. I, Fig. 6). Equatorial diameter of tests is 0.15-0.71 mm, oblique diameter is 0.50-0.91 and index of elongation 0.95-1.16. Tests with diameter 0.5-0.6 mm have 5-6 whorls, maximal number of whorls is 9 (Pl. I, Fig. 4). Only individuals of megalospheric generation are present. Proloculus is tiny of diameter 0.03-0.045 mm (Pl. I, Figs. 1 and 3). The first two whorls are streptospirally coiled and not divided (Pl. I, Fig. 1). Next whorls are divided with thick septa for chambers (Pl.II, Fig. 2) and chamberlets (Pl. I, Figs. 2 and 4). The last whorl contains 6-8 chambers and 35-40 chamberlets. Cavities of chambers are of oblong to moderately oval outline and are wide 0.020 mm and high 0.030-0.040 mm. Basal layer is very thin (0.010-0.015 mm).

Stated values are corresponding with those being described by Schweighauser (1951) and Bassi & Loriga Broglio (1999), only the diameter of proloculus has in the case of Carpathian occurrences bigger range (above stated authors describe 0.030-0.035 mm), but this range could belong to the variability of species *B. vonderschmitti* (though even Schweighauser (1951) when establishing the species *B. vonderschmitti* presented doubt, whether is it only one species).

Description of localities in Western Carpathians

Three described localities are located between villages Východná and Važec in northern rim of Liptovská kotlina basin (Fig. 1). More detail data concerning geology of Paleogene sediments in studied area are presented in monograph by Gross & Köhler et al. (1980).

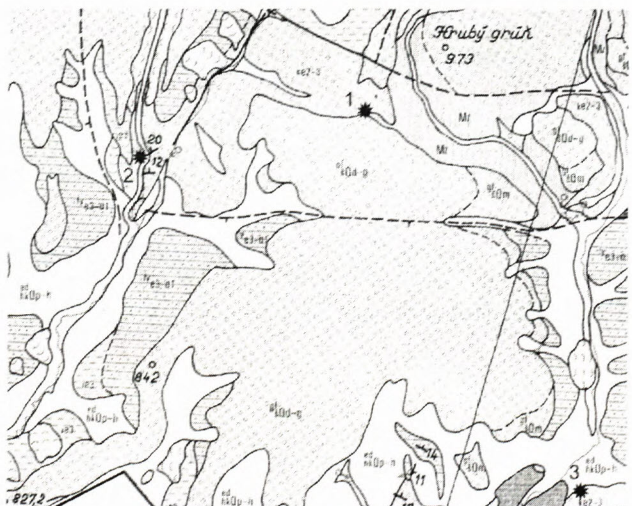


Fig. 1. Part of geological map 1 : 50 000 (Gross et al. 1980, supplemented) of the territory between Východná and Važec villages and studied localities: 1 - Hrubý Grúň, 2 – Hybica, 3 – west of Važec.
Explanations: ke2-3 – basal transgressive lithofacies (breccias, conglomerates, limestones, carbonatic sandstones) = Borové Formation sensu Gross et al. (1984), ie3 – clayey lithofacies = Huty Formation, fye3-o1 – flysch lithofacies = Zuberec Formation, other – Quaternary.

[1]For description of alveolinid foraminifers there was used the terminology established by Reichel (1936-1937) and detaily explained and completed by Hottinger (1960), Drobne (1977) and White (1992).

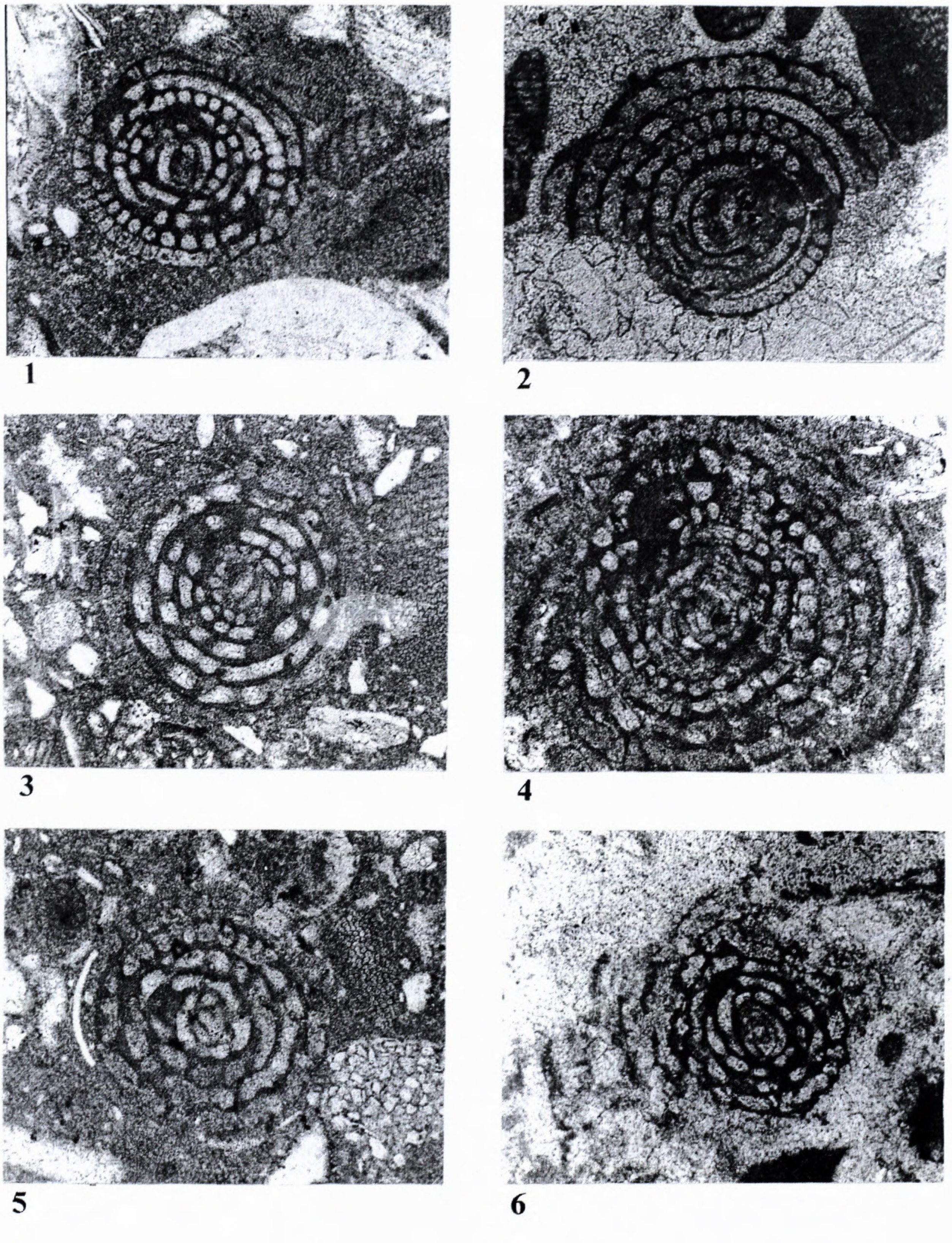


Plate I

1.-6. *Borelis vonderschmitti* (SCHWEIGHAUSER), all figures magnified 80x.

Fig. 1 – Oblique axial section, Važec locality, thin section Ke-1; Fig. 2 – Part of axial section, Važec locality, thin section Bu-113; Fig. 3 – Oblique equatorial section, Važec locality, thin section Ke- 4; Fig. 4 – Oblique section, Važec locality, thin section Ke-11; Fig. 5 – Oblique section, Važec locality, thin section Ke-4; Fig. 6 – Oblique section, Hybica locality, thin section Bu- 202. Photo by the authors.

Slovak Geol. Mag., 10, 4 (2004), 285 – 291

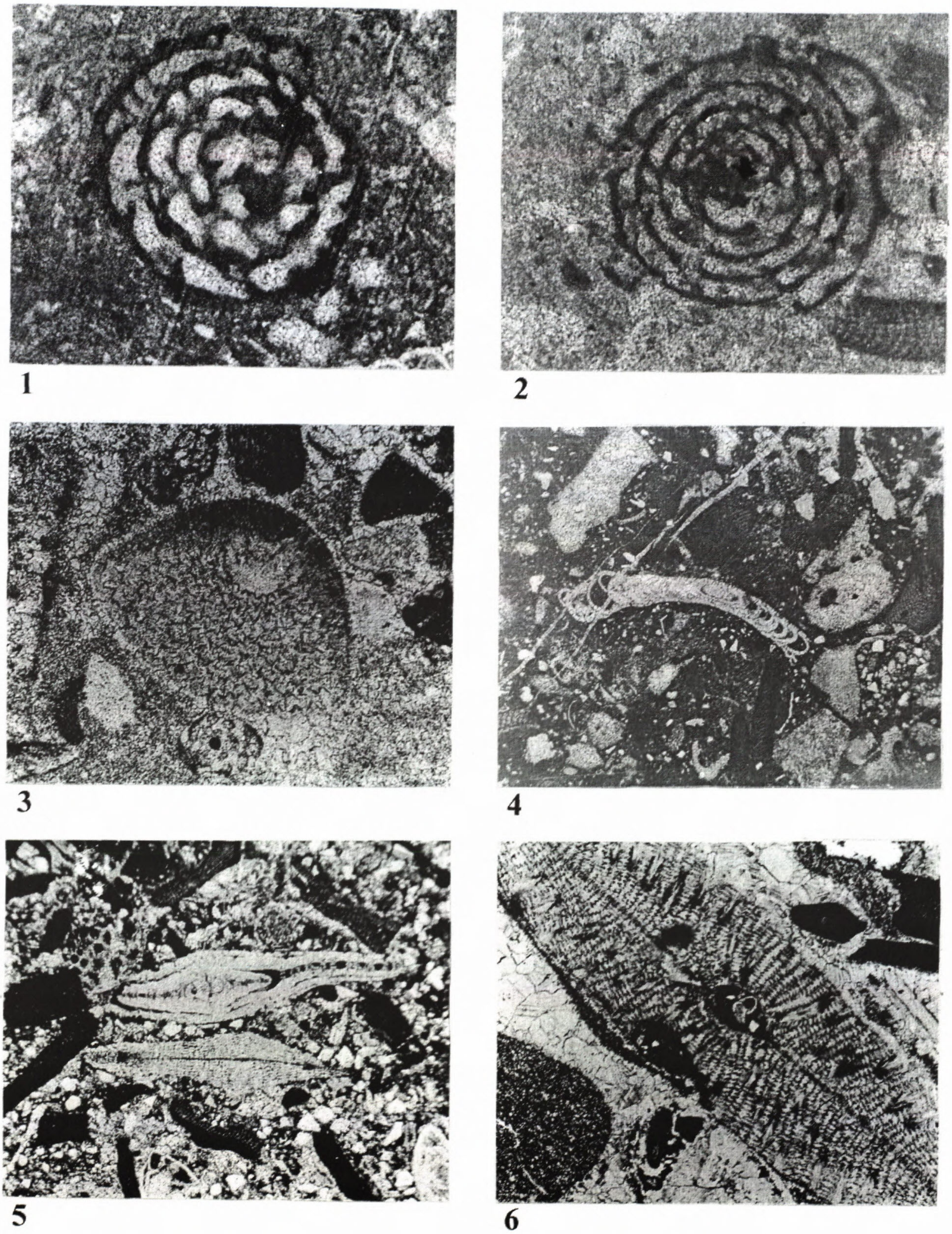


Plate II

1.-2. *Borelis vonderschmitti* (SCHWEIGHAUSER), magnified 80x.

Fig. 1 – Oblique section, Hrubý Grúň locality, thin section Bu- 85; Fig. 2 – Oblique equatorial section, Važec locality, thin section Ke- 4; Fig. 3 – *Halkyardia minima* (LIEBUS) in oblique section, Važec locality, thin section Bu-119, magn. 80x; Fig. 4 – *Linderina* cf. *brugesi* SCHLUMBERGER, oblique section, Važec locality, thin section Ke-3, magn. 25x; Fig. 5 – *Heterostegina* sp. and *Discocyclina* sp. in oblique sections, Važec locality, thin section Ke- 2, magn. 25x; Fig. 6 – *Orbitoclypeus varians* (KAUFMANN) in oblique section, Važec locality, thin section Ke-13, magn. 25x. Photo by the authors.

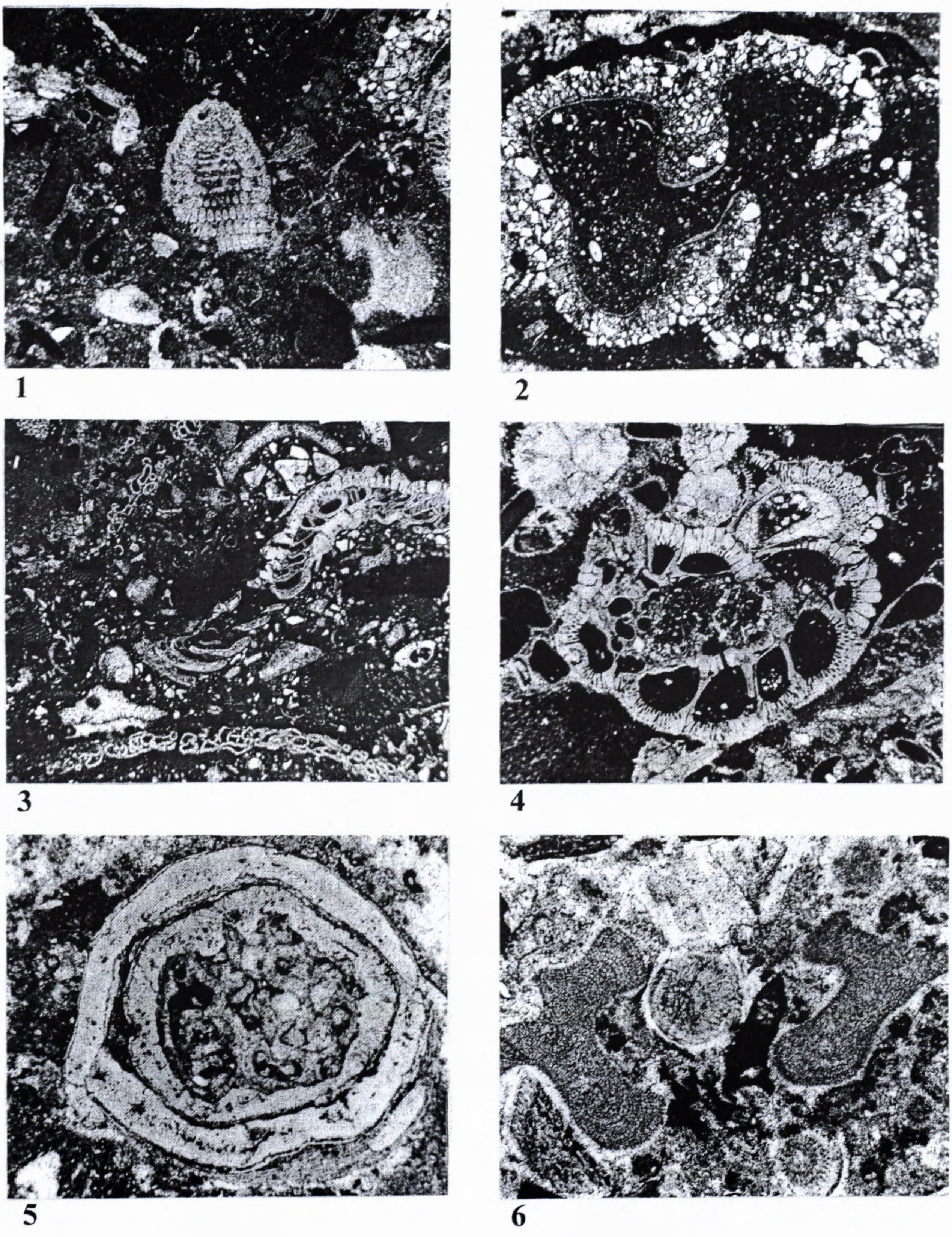


Plate III

Fig. 1 – *Chapmanina gassinensis* SILVESTRI in oblique section, Važec locality, thin section Bu-115, magn. 25x; Fig. 2 – *Haddonia heissigi* HAGN in oblique section, Važec locality, thin section Ke-12, magn. 25x; Fig. 3 – *Fabiania cassis* (OPPENHEIM) in oblique section, Važec locality, thin section Ke-12, magn. 25x; Fig. 4 – *Gyroidinella magna* (LE CALVEZ) in oblique section, Važec locality, thin section Ke-7, magn. 25x; Fig. 5 – *Polystrata alba* (PFENDER) DENIZOT, Hrubý Grúň locality, thin section Bu- 80, magn. 25x; Fig. 6 – *Gypsina* cf. *linearis* (HANZAWA) and *Chapmanina* sp., Hybica locality, thin section Bu- 201, magn. 25x. Photo by the authors.

Slovak Geol. Mag., 10, 4 (2004), 285 – 291

1. Hrubý Grúň, elevation point 933. Near the margin of the road from the village Východná to elevation point Hrubý Grúň (973) opposite to the water tank there are outcropping the underlying Triassic Wetterstein dolomites with rough weathered surface. Depressions in the dolomite surface are infilled with terra rossa. The Paleogene sequence begins with approximately 1.5 m thick conglomerate layer with dolomite pebbles. In overlier the sequence continues with ca 5 m thick bed of organogenic packstones, containing also the *Borelis* tests;

2. Hybica. The Hybica stream flowing southwards from the foothill of the High Tatra Mts. near the elevation point 814 cuts a large body of bioherm Paleogene packstones. The body lying on Mesozoic substrate (Triassic Gutenstein limestones) outcrops in the length more than 100 m and thickness to 12 m. Despite a large number of taken samples, the genus *Borelis* was found only in two of them: In the lowermost bed (sample A) and approximately 8 m above the stream level (sample F).

3. Near the recently weakly used road from Východná to Važec (northward from this road is located a highway), westward from the Važec village there is slightly outcropped app. 10 m thick body of bioherm packstones. The biggest number of sections of *Borelis vonderschmitti* (SCHWEIGHAUSER) (19 from the total number 33) was found there. In the overlier of limestones in abandoned open pits there are outcropping sandstones with rich nummulite fauna of the Upper Eocene (SBZ 20 with *Nummulites fabianii fabianii* (PREVER) and *N. fabianii retiatus* ROVEDA).

In all localities containing the genus *Borelis* the rocks, organogenic packstones (locally also grainstones – Hybica), have roughly the same composition with the main component of coralline algae, the genus *Sporolithon*. Among the algae there are present also abundant sections of *Polystrata alba* (PFENDER) DENIZOT (Pl. III, Fig. 5). Next often present components are the cyclostomate Bryozoa, rare are the fragments of Lamellibranchiata, segments of crinoids, spines of Echinodermata and tubes of worms. The coral fragments – massive as well as solitary forms – are also present.

The foraminifera have an important share in composition of assemblages. The large foraminifers are represented by *Nummulites variolarius* (LAMARCK), *Nummulites* sp., *Chapmanina gassinensis* SILVESTRI (Pl. III, Figs. 1 and 6), *Halkyardia minima* (LIEBUS) (Pl. II, Fig. 3), *Fabiania cassis* (OPPENHEIM) (Pl. III, Fig. 3), *Orbitoclypeus varians* (KAUFMANN) (Pl. II, Fig. 6), *Linderina* cf. *brugesi* SCHLUMBERGER (Pl.. II, Fig. 4) and *Heterostegina* sp. (Pl. II, Fig. 5). From the small foraminifers there can be mentioned *Haddonia heissigi* HAGN (Pl. III, Fig. 2), *Gyroidinella magna* (LE CALVEZ) (Pl. III, Fig. 4), *Gyroidinella* cf. *carpatica* SAMUEL et KÖHLER, *Gypsina* cf. *linearis* (HANZAWA) (Pl. III, Fig. 6), *Acervulina* sp., also the miliolid and rotalid forms are present. The absence of planktonic forms proves, that the assemblage is derived from protected back-reef environment.

The frequent presence of relatively big fragments of massive corals (mainly in the Važec locality) demonstrates at least the existence of smaller coral patch-reefs in this environment.

Conclusions

The assemblages accompanying *Borelis vonderschmitti* (SCHWEIGH.) in described localities are comparable with those accompanying this species in sections in Northern Italy (Colli Berici).

Schweighauser (1951) in accompanying assemblage mentions the presence of *Fabiania*, *Halkyardia* and *Chapmanina*. The limestones with *Neoalveolina* (= *Borelis*) *vonderschmitti* he places into the boundary layers between the uppermost Lutetian and lowermost Priabonian.

Ungaro (1969) describing the profile Mossano (Colli Berici) mentions the presence of *Neoalveolina* (= *Borelis*) with *Nummulites* aff. *biedai*, *N.* aff. *fabianii*, *N.* aff. *striatus*, *Baculogypsinoides* and *Chapmanina*. The beds with this assemblage he places into the uppermost part of Middle Eocene (into "Biarritzian").

Bassi et al. (2000) introduce the presence of *Borelis vonderschmitti* (SCHWEIGH.) in the upper part of Calcari nummulitici formation (uppermost Bartonian/base of Priabonian, SBZ 18/SBZ 19) in assemblage with *Glomalveolina ungaroi* BASSI et LORIGA (the last representant of genus *Alveolina*), *Nummulites variolarius/incrassatus*, *N. beaumonti discorbinus*, *N. ptukhiani*, *Discocyclina augustae*, *D. radians labatlensis*, *Asterocyclina stellata stellaris*, *Nemkovella strophiolata*, *Sphaerogypsina globulus*, *Chapmanina gassinensis*, *Fabiania*, *Gyroidinella* and *Silvestriella tetraedra*. They notice also the presence of encrusting foraminifers – *Victoriella*, *Haddonia*, *Acervulina* and *Gypsina*. The important role in assemblage have also the coralline algae.

The comparison with these assemblages confirms, that also localities Hrubý Grúň, Hybica and Važec can be situated into the transitional beds between Middle Eocene (Bartonian) and Upper Eocene (Priabonian), SBZ 18/SBZ 19. According this also the biostratigraphic data published in monograph by Gross & Köhler et al. (1980) need correction, because these localities were dated as Upper Eocene (Lower Priabonian).

Recent *Borelis schlumbergeri* (REICHEL) allows to estimate also the environment, where the fossil representants of the genus *Borelis* lived. According to Reiss & Gwitzman (1966) in the Gulf of Elat (Izrael) this species is present in the depth between 1.5 to 20 m, most of all above 3 m, but Hottinger (1977) from the same area describes the presence of this species in the depth between 20 and 45 m, most frequently between 30 a 35 m. The individuals from deeper waters are more elongated, from the shallower waters they are more rounded. Hottinger (l. c.) notices the high intra-species variability of *B. schlumbergeri* (REICHEL).

Taking into account the above reviewed and regarding also further members of assemblages, there is necessary to suppose that the fossil representants of genus *Borelis* accommodated shallow protected waters in depths between 3 to 35 m. The spherical form of tests favours the depths 3-20 m. In such depths also bioherm limestones of the northern rim of the Liptovská kotlina basin were deposited.

References

Barbin, V., Decrouez, D. & Menkveld-Gfeller, U., 1997: Présence de *Praebullalveolina* à la limite Eocène supérieur/Oligocène dans la région de Priabona (Vicentin, Italie, Alpes méridionales). Revue Paléobiol. (Genève), 16, 1, 139-144.

Bassi, D., Čosović, V., Papazzoni, C.A. & Ungaro, S., 2000: The Colli Berici. Field Trip Guidebook, 5th Meeting of the IUGS-UNESCO IGCP Project 393, Ferrara, 43-57.

Bassi, D. & Loriga Broglio, C., 1999: Alveolinids at the Middle-Upper Eocene boundary in Northeastern Italy (Veneto, Colli Berici, Vicenza). Journ. Foram. Research (Washington), 29, 3, 222-235.

Drobne, K., 1977: Alvéolines paléogènes de la Slovénie et de l'Istrie. Schweiz. Paläont. Abh. (Basel), 99, 1-132.

Gross, P., Köhler, E. & Samuel, O., 1984: Lithostratigraphic classification of Inner Carpathian Paleogene sedimentary cycle. Geol. Práce, Spr. (Bratislava), 81, 103-117. (In Slovak).

Gross, P. & Köhler, E. (eds.) & Biely, A., Franko, O., Hanzel, V., Hricko, J., Kupčo, G., Papšová, J., Priechodská, Z., Szalaiová, V., Snopková, P., Stránska, M., Vaškovský, I. & Zbořil, Ľ., 1980: Geology of the Liptovská kotlina basin. Geol. úst. D. Štúra, Bratislava, 5-242. (in Slovak)

Hottinger, L., 1960: Recherches sur le Alvéolines du Paléocène et de l'Eocène. Schweiz. Paläont. Abh. (Basel), 75/76, 1-234.

Hottinger, L., 1977: Distribution of larger Peneroplidae, *Borelis* and Nummulitidae (Foraminifera) in the Gulf of Elat, Red Sea. Utrecht Micropal. Bull. (Utrecht), 15, 35-109.

Loeblich, A.R. Jr. & Tappan, H., 1987: Foraminiferal genera and their classification. Van Nostrand Reinhold Co., New York, 970 pp.

Reichel, M., 1936-1937: Etude sur les Alvéolines. Mém. Soc. Paléontol. Suisse (Lausanne), 57, 4, 1- 93; 59, 2, 95-147.

Reiss, Z. & Gwitzman, G., 1966: Borelis from Izrael. Eclogae geol. Helv. (Basel), 59, 1, 437-446.

Schweighauser, J., 1951: Ein Vorkommen von *Neoalveolina* dem vicentinischen Obereocaen. Eclogae geol. Helv. (Basel), 44, 2, 465-469.

Serra-Kiel, J., Hottinger, L., Caus, E., Drobne, K., Ferrandez, D., Jauhri, A.K., Less, G., Pavlovec, R., Pignatti, J., Samsó, J.M., Schaub, H., Sirel, E., Strougo, A., Tambareau, Y., Tosquella, J. & Zahrevskaya, E., 1998: Larger foraminiferal biostratigraphy of the Tethyan Paleocene and Eocene. Bull. Soc. géol. France (Paris), 169, 2, 281-299.

Sirel, E. & Açar, S., 1982: *Praebullaveolina*, a new foraminiferal genus from the Upper Eocene from the Afyon and Çanakkale region (west of Turkey). Eclogae geol. Helv. (Basel), 75, 3, 821-839.

Sirel, E. & Açar, S., 1993: *Malatyna*, a new foraminiferal genus from the Lutetian of Malatya region (East Turkey). Geol. Croat. (Zagreb), 46, 2, 181-188.

Sirel, E. & Açar, S., 1998: *Malatyna vicensis*, a new foraminiferal species from the Bartonian of Vic region (Northeastern Spain). Revue Paléobiol. (Genève), 17, 2, 373-379.

Travé, A., Serra-Kiel, J. & Zamarreno, I., 1996: Paleoecological interpretation of transitional environments in Eocene carbonates (NE Spain). Palaios (Tulsa, Oklahoma), 11, 141-160.

Ungaro, S., 1969: Étude micropaléontologique et stratigraphique de l'Eocène supérieur (Priabonien) de Mossano (Colli Berici). Mém. Bur. Rech. Géol. Min. (Paris), 69, 3, 267-281.

White, M. R., 1992: On species identification in the foraminiferal Genus *Alveolina* (Late Paleocene-Middle Eocene). Journ. Foramin. Res. (Washington), 22, 1, 52-70.

Crocodile remains from the Middle Miocene (Late Badenian) of the Vienna Basin (Sandberg, Western Slovakia)

JÁN SCHLÖGL and PETER HOLEC

Department of Geology and Paleontology, Faculty of Sciences, Comenius University in Bratislava, Mlynská dolina, SK-842 15 Bratislava, Slovakia

Abstract. Remains of crocodiles belonging probably to the genus *Gavialosuchus* are described from the western part of the Vienna Basin for the first time. Although they can not be determined more precisely at the species level, they enhance our knowledge about the spatial distribution of these ectothermal animals during the Middle Miocene. Moreover, they rank among the northernmost Late Badenian crocodile occurrences in the Central Paratethys area.

Key words: Reptilia, Crocodylia, ectotherms, Miocene, Badenian, palaeobiogeography, Vienna Basin, Central Paratethys

Introduction

Spatial distribution of the ectothermal vertebrates provides the information about local ecological conditions. Recently this approach has been used by Böhme (2003) to reconstruct the migration and extinction events of this group in relation to climate changes in the Central Paratethys.

Crocodile remains are very rare in the whole Vienna Basin. The new material described here comes from its northeastern part from Western Slovakia (Fig. 1). Only a few fossil assemblages containing crocodile remains have been mentioned in the literature from the Austrian part of the basin. Toula & Kail (1885) introduced the name *Gavialosuchus* for the long-snouted crocodile from the Early Miocene deposits of the locality Eggenburg. Zapfe (1984) figured two large teeth assigned to *Crocodylus* sp. from the Middle Badenian deposits from the localities Müllendorf and Maustrenk, and three small and slender teeth of *Diplocynodon* sp. from the Badenian basal breccia from Kaiserstenbruch. All these localities are situated in the NE Austria. No more detailed stratigraphical position was given.

Geological Setting

The described crocodile remains were collected at the locality Sandberg near Devínska Nová Ves village, which is situated on the western slope of the Devínska Kobyla hill. It belongs to Malé Karpaty Mts., the easternmost core mountain of the Central Carpathian system (Fig. 1).

The sediments are represented by sand and sandstones, sandy limestones and algal limestones, deposited in the littoral zone (Fig. 2, Sandberg Member, Baráth et al., 1994). The rich autochtonous marine assemblages are mixed with rarer allochtonous remains, originated from streams ending in the deposition area actually represented by Sandberg Member or brought occasionally by storm currents from the emersed neighborhood. Over 300 different invertebrate or vertebrate taxa have been described from the Badenian sediments of the Devínska Kobyla area, but despite more than 100 years of the palaeontological research in the locality, the crocodile remains have never been mentioned. Vertebrates were recently revised by Holec & Sabol (1996, see also Sabol, 2000; Sabol & Holec, 2002).

Age of the fauna

The deposits were dated according to different fossil groups as well as radiometricaly. Late MN6 Zone (*sensu* Steininger, 1999) is actually accepted by most of the authors working in the area. Assemblages of calcareous nannoplankton from Sandberg indicate Late Badenian NN6 Zone. Rich foraminiferal assemblages from Devínska Nová Ves clay pit studied by Hudáčková & Kováč (1993) indicate the *Bulimina-Bolivina* Zone (*sensu* Grill, 1941; 1943). Here uncovered dark pelitic sediments (Studienka Formation) are considered to be the outer shelf equivalent of the Sandberg Member. The value of 13.51 Ma (13.70 – 13.39 Ma) was obtained based on the radiometric Sr-dating on the foraminiferal tests (Hudáčková & Kráľ, 2002) which correlates well with the Late MN6. Similar time interval (MN 6) was assumed by Sabol & Holec (2002) based on large mammals.

Systematic Palaeontology

Order CROCODYLIA Laurenti, 1768
Suborder EUSUCHIA Huxley, 1875
Family CROCODYLIDAE Cuvier, 1807
Subfamily TOMISTOMINAE Kälin, 1955
Genus *Gavialosuchus* Toula & Kail, 1885

Gavialosuchus sp.
Fig. 3(1–2)

Material. Two isolated teeth (housed in Slovak National Museum, SNM Z 26 503, Z 26 504).

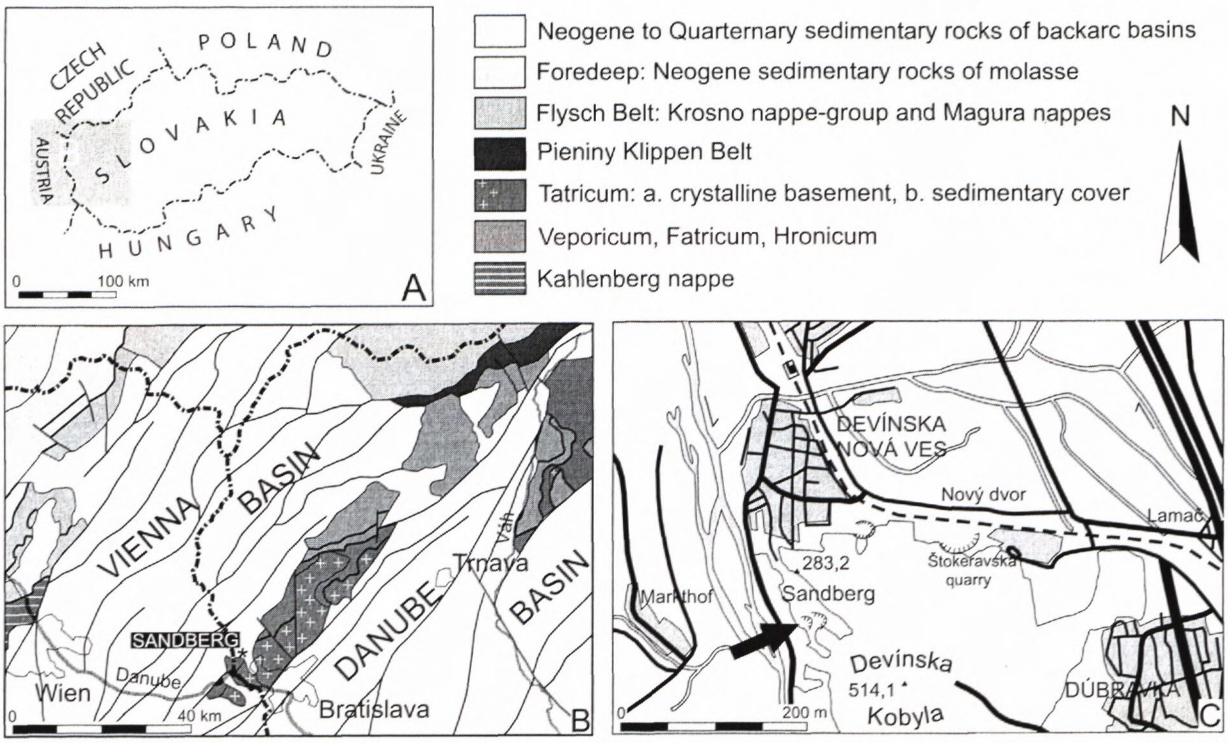


Fig. 1. Geological and geographical setting of the described fauna.
A, C. Geographical position of the locality Sandberg. B. Geological sketch map of the Vienna Basin and surrounding areas.

Description. The first tooth (SNM Z 26 503, Fig. 3(1)) is represented by a crown part, the root is broken off. It is conical with bluntly pointed apex and almost circular cross section. There are two sharp, distinct mesial and distal keels, extending from the apex to the edge of the tooth breakage. The tooth is slightly recurved. The mesiodistal diameter is only slightly greater than the linguobuccal (11,7 mm to 10,8 mm). The enamel is thin, variably transparent, light brown colored. Its ornamentation consists of dense and fine longitudinal wrinkles.

The second tooth (SNM Z 26 504, Fig. 3(2)) is badly preserved but it is markedly more robust. The mesiodistal diameter at the enamel limit is not measurable, linguobuccal diameter is approx. 14 mm. The lateral keel is marked on one side only; the other side is heavily corroded. The tooth is also slightly recurved as it is seen on its lingual side. The preserved enamel is thin and dark brown colored. The ornamentation is identical to that of the first tooth.

Remarks and comparisons.

In majority of cases the isolated teeth are only rarely classifiable into the species level. Our determination is based on the comparison with the taxa known from the European Miocene deposits.
The large size of the new described material is sufficient to exclude *Diplocynodon*, taxon comprising crocodiles of small size. The teeth of this genus are generally smaller and more slender. The mesiodistal diameter is below 10 mm (e.g. Murelaga et al., 2002, Ginsburg & Bulot, 1997; Scherer, 1978; 1981; Antunes & Guinsburg, 1989; Böhme, unpublished data). *Diplocynodon styriacus* (Hofmann) is the only species of this genus known from the MN4, MN5 and probably also MN6 (*D.* cf. *styriacus*, Ginsburg & Bulot, 1997) of Europe.

Long-snouted *Gavialis* has never been reported from the Central Europe, moreover its dentition with pointed and very slender long teeth (e.g. see Antunes, 1994) differs completely from the robust-teethed genera.

Another crocodiles known from the European Miocene are *Tomistoma* and *Gavialosuchus*. They show very similar cross-section and also enamel ornamentation, consisting of faint, irregular longitudinal wrinkles. According to several authors (e.g. Böhme, 2003, Myrick, 2001) both the North-American and European fossil crocodiles assigned to the genus *Tomistoma* are distinctly different from its single modern representant *Tomistoma schlegelii* Müller and they propose to use the name *Gavialosuchus*, or *Thecachampsa*. The mesiodistal diameter is between 16 and 20 mm (Antunes & Guinsburg, 1989; Antunes, 1994; Toula & Kail, 1885), in some cases between 12 and 14 mm (Rossmann et al., 1999). On the basis of shape and dimensions, our material ranges among the smaller sized *Gavialosuchus*.

Zapfe (1984) described several crocodile teeth from the Northern Austria. Besides three *Diplocynodon* teeth, there are two robust and conical teeth with the oval cross-section designated as *Crocodylus* sp., showing the same shape and ornamentation as *Tomistoma* or *Gavialosuchus*. Moreover the presence of the genus *Crocodylus* in the European Miocene has been recently questioned (Antunes, 1994).

Stratigraphic and geographical position. Sandberg, Vienna Basin, Slovakia, Late Badenian, Late MN 6.

Fig. 2. Northern outcrop of the Late Badenian sandstones in the locality Sandberg. Arrows indicate the finding places of tooth SNM Z 26 504 and the bone plate (black) and tooth SNM Z 26 503 (white) (Photo by L. Slíva).

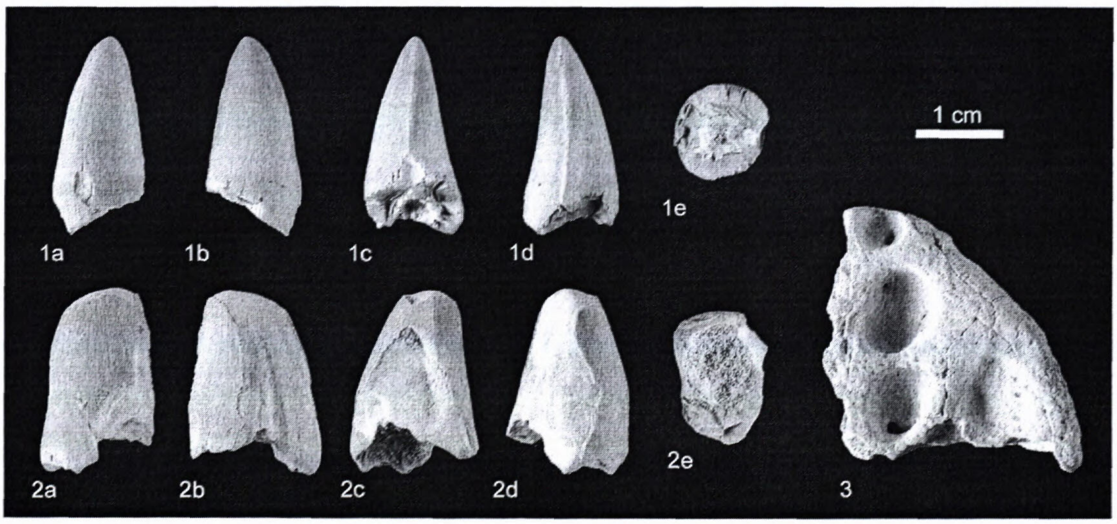


Fig. 3. 1, 2. Gavialosuchus sp., Late Badenian, Sandberg.
1. SNM Z 26 503. 2. SNM Z 26 504 (a – labial, b – lingual, c – distal, d – mesial, e – basal view). *3. Crocodylia:* incertae sedis, bone plate fragment, SNM Z 26 505, Late Badenian, Sandberg.

Crocodylia: incertae sedis
Fig. 3(3)

Material. Fragment of bony plate (SNM Z 26 505, Fig. 3(3)).

Description. The inner side is slightly convex with almost smooth surface. The outer side bears many oval depressions with foramina in their bottoms.

Remarks. The bony plate fragment cannot be precisely determined because of considerable similarity of the bony plates of many crocodylian taxa and also due to scarcity and bad preservation of the material.

Stratigraphic and geographical position. Sandberg, Vienna Basin, Slovakia, Late Badenian, Late MN 6.

Palaeobiogeographical and palaeoecological remarks.

Crocodiles ranks among the best ecological indicators, especially concerning palaeotemperatures. Böhme (2003, see also Markwick, 1998) recently documented a southward disappearance of the ectotherms during the Middle and early Late Miocene. In the Central Europe it succeded the long phase of Miocene Climatic Optimum (from about 18 to 14.0-13.5 Ma, see Böhme, 2003). The drop of the mean annual temperature (cooling) led to a regional extinction of the most thermophilic groups in Central Europe. According to this author the crocodiles *(Diplocynodon)* have disappeared from the palaeolatitudes 38-45° N to 30-37° N between Late MN6 (Late

Badenian) and Late MN9 (Middle Pannonian). The Late Badenian palaeogeographical position of the Vienna Basin is not known, but ecent palaeomagnetic data indicate the Early Miocene position of the Carpathian-North Pannonian domain much more southward than it was thought before (around 31°, Márton & Kováč, 2004), and the fast northward shift of the domain started close to the end of the Early Miocene. Recent latitude of the Vienna Basin is around 48°. Therefore the change of palaeoclimatic conditions were probably not only due to global cooling, but also due to tectonic movement of Alcapa microplate northwards (Csontos et al., 1992, Kováč et al., 1994).

Rivers, lakes, and freshwater swamps are preferred habitat of the recent representants of the genus *Crocodylus*, although some taxa show a certain tolerance for salinity, being found in brackish waters around the coastal areas, in coastal lagoons and in river estuaries. The *Gavialosuchus* remains are found mainly in coastal marine sediments (Antunes, 1994) with only one exception (Buffetaut et al., 1984). This could suggest a rather fluvio-deltaic to coastal marine habitat for this genus, making these animals more independent from continental climate changes. Similar habitat is assumed for the *Gavialosuchus*, which inhabited the eastern margin of the Vienna Basin.

Occurrence of the thermophilic taxa on the eastern margin of the Vienna Basin agrees with the assumed local Late Badenian environmental conditions and is consistent with the data from other fossil groups. Palynological assemblages from the Studienka Formation show great portion of hydrophilous to swamp vegetation elements, but thermophilic taxa *Magnolia, Engelhardia, Platycarpa, Castanea, Ilex, Distylium, Tamarix* or *Myrica* are still abundant (Sitár & Kováčová-Slamková, 1999, Hudáčková et al., 2002), indicating subtropical climate. Chondrichthyes reported from the Sandberg locality suggest at least moderately warm waters, expressed by dominance of the genera such as *Carcharhinus, Galeocerdo, Scyliorhinus, Myliobatis* or *Aetobatus* (Holec, 2001).

Conclusions.

The crocodile remains collected from the marginal deposits of the Slovak part of the Vienna Basin probably belong to an indeterminate species of the genus *Gavialosuchus*. Described occurrence ranks among the northernmost Late Badenian occurences of the Crocodylia in the Central Paratethys.

Their presence on the eastern margin of the Vienna Basin indicates the existence of fluvio-deltaic or coastal marine environments providing suitable life conditions for these ectothermal reptiles. Moreover it complete the existing palaeoclimatical data based on other fossil groups and agree well with warm subtropical climate assumed for the Vienna Basin during the Late Badenian.

Acknowledgement.

Authors are grateful to Prof. M. Mišík from the Department who provided a part of the described material, to Dr. M. Böhme, Prof. J. Klembara and Prof. M. Kováč for important comments and to Peter Richter for language corrections. The research was supported by VEGA grant 1/0002/03.

References.

Antunes, M. Telles, 1994: On Western Europe Miocene Gavials (Crocodylia) their Paleogeography, Migrations and Climatic significance. Comun. Inst. Geol. e Mineiro, 80, 57 – 69.

Antunes, M. T. & Ginsburg, L., 1989: Les Crocodiliens des faluns miocènes de l'Anjou. Bull. Mus. natn. Hist. nat., Paris, 4e sér., 11, 79 –99.

Baráth, I., Nagy, A. & Kováč, M., 1994: Sandberg Member – Late Badenian Marginal Sediments on the Eastern Margin of the Vienna Basin. Geologické práce, Správy 99, 59-66. [in Slovak].

Böhme, M., 2003: The Miocene Climatic Optimum: evidence from ectothermic vertebrates of Central Europe. Palaeogeography, Palaeoclimatology, Palaeoecology, 195, 389 – 401.

Buffetaut, E., Crouzel, F., Juillart, F. & Stigliani, F., 1984: Le crocodilien longirostre *Gavialosuchus* dans le Miocène moyen de Polastron (Gers, France). Geobios, 17, 113 – 117.

Cope, E. D., 1867: An Addition to the Vertebrate Fauna of the Miocene Period with a Synopsis of the Extinct Cetacea of the United States. Proceedings of the Academy of Natural Sciences of Philadelphia, 1867, 136 – 156.

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

Ginsburg, L. & Bulot, C., 1997: Les *Diplocynodon* (Reptilia, Crocodylia) de l'Orléanien (Miocène inférieur à moyen) de France. Geodiversitas, 19, 1, 107 – 128.

Grill, R. 1943: Über mikropaläontologischen Gliederungsmöglichkeiten im Miozän des Wiener Becken, Mitteilungen des Reichsamts für Bodenforschung, 6, 33-44.

Grill, R. 1941: Stratigaphische Untersuchungen mit Hilfe von Mikrofaunen im Wiener Becken und den benachbarten Molasse-Anteilen, Oel und Kohle 37, 595-602.

Holec, P., 2001: Chondrichthyes and Osteichthyes (Vertebrata) from Miocene of Vienna Basin near Bratislava (Slovakia). Mineralia Slovaca, 33, 111 – 134.

Holec, P. & Sabol, M., 1996: Tertiary vertebrates (Vertebrata) of the Devínska Kobyla. Mineralia Slovaca, 28, 519-522. [in Slovak]

Hudáčková, N. & Kováč, M., 1993: Changes of sedimentary environment in the eastern part of Vienna Basin in Late Badenian and Sarmatian. Mineralia Slovaca, 25, 202 – 210. [in Slovak].

Hudáčková, N. & Kráľ, J., 2002: Radiometric dating. In. Kováč, M (ed.), Tectonogenesis of the Western Carpathian sedimentary basins – The Vienna Basin. Manuscript, Geofond, Bratislava, 50 – 52. [in Slovak].

Hudáčková, N., Zlínská, A., Halásová, E. & Slamková, M., 2002: Comparison of the Upper Badenian sediments in the Danube and Vienna Basins (Central Paratethys area) on the basis of for aminifera and calcareous nannoplankton. In. Michalík, J., Hudáčková, N., Chalupová, B. & Starek, D. (eds.), Paleogeographical, Paleoecological, Paleoclimatical development of Central Europe, ESSEWECA/ EEDEN Workshop, Bratislava, 57 – 58.

Kováč, M., Kráľ, J., Márton, M., Plašienka, D. & Uher, P., 1994: Alpine uplift history of the Central Western Carpathians: geochronological, paleomagnetic, sedimentary and structural data. Geologica Carpathica, 45, 2, 83-96.

Markwick, P. J., 1998: Fossil crocodilians as indicators of Late Cretaceous and Cenozoic climates: implications for using palaeontological data in reconstructing palaeoclimat. Palaeogeography, Palaeoclimatology, Palaeoecology, 137, 205 – 271.

Márton, E. & Kováč, M., 2004: Palaeomagnetic contribution to a realistic palaeogeographic - palinspastic model of the Central Paratethys during the Tertiary. ESSEWECA Conference, Bratislava 2004, Abstracts. Available from: <http:// www. fns. uniba. sk/ ~kgp/ esse/ esse.htm>

Murelaga, X., Pereda Suberbiola, X., Lapparent de Broin, F. de, Rage, J.-C., Duffaud, S., Astibia, H. & Badiola, A., 2002: Amphibians and reptiles from the Early Miocene of the Bardenas Reales of Navarre (Ebro Basin, Iberian Peninsula). Geobios, 35, 347 – 365.

Myrick, Jr. A. C., 2001: *Thecachampsa antiqua* (Leidy, 1852) (Crocodylidae: Thoracosaurinae) from Fossil Marine Deposits at Lee Creek Mine, Aurora, North Carolina, USA. Smithsonian Contributions to Paleobiology, 90, 219 – 225.

Rossmann, T., Berg, D. E. & Salisbury, S., 1999: Studies on Cenozoic crocodiles: 3*. *Gavialosuchus* cf. *gaudensis* (Eusuchia: Tomistomidae) from the Lower Miocene of South Germany. Neues Jahrbuch fur Geologie und Paläontologie Monatshefte., 6, 321 – 330.

Sabol, M., 2000: Neogene carnivores of Slovakia. Slovak Geological Magazine, 6, 2-3, 124 – 126.

Sabol, M. & Holec, P., 2002: Temporal and spatial distribution of Miocene mammals in the Western Carpathians (Slovakia). Geologica Carpathica, 53, 4, 269 – 279.

Scherer, E., 1978: Krokodilreste aus der miozänen Speltenfüllung Appertshofen nödlich von Ingoldstadt. Mitteilungen der Bayerischen Staatssammlung fur Paleontologie und historische Geologie, 18, 65 – 91.

Scherer, E., 1981: Die mittelmiozäne Fossil-Lagerstätte Sandelzhausen 12. Crocodylia (abschliesender Bericht). Mitteilungen der Bayerischen Staatssammlung fur Paleontologie und historische Geologie, 21, 81 – 87.

Sitár, V. & Kováčová-Slámková, M., 1999: Palaeobotanical and palynological study of the Upper Badenian sediments from the NE part of the Vienna basin (locality Devínska Nová Ves). Acta Paleobotanica, Proceedings 5th EPPC, Krakow, Suppl. 2, 373 – 389.

Steininger, F. F., 1999: Chronostratigraphy, geochronology and biochronology of the Miocene „European Land Mammal Mega-Zones" (ELMNZ) and the Miocene „Mammal-Zones (MN-Zones)". In. Rössner, G. E. & Heissig, K. (eds.), The Miocene land mammals of Europe. Verlag Dr. Friedrich Pfeil, München, 9 – 24.

Toula F. & Kail, J. 1885: Üeber einen Krokodil-Schädel aus den Tertiärablagerungen von Eggenburg in Niederöesterreich. Denkschriften der Kaiserlichen Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, 50, 299 - 356.

Zapfe, H., 1984: Krokodile im Mittelmiozän des Wiener Beckens. Sitzungsberichten der Österreichische Akademie der Wissenschaften, mathematisch-naturwissenschaftliche Klasse, Abt. I, 193, 161-169.

Use of Distinct Element Method in the Numerical Analysis of Slope Failure Mechanism Study at the Spis Castle

LUCIA BASKOVA and JAN VLCKO

Comenius University Bratislava, Faculty of Natural Sciences, Department of Engineering Geology, Slovak Republic

Abstract: Spis Castle (Eastern Slovakia) is built on a travertine mound overlying the Paleogene soft rocks. The travertine castle rock represents an erosion remnant of an originally larger travertine's formation precipitated during the Miocene/Pliocene epoch. The physical and mechanical properties of travertines are strongly influenced by jointing, weathering and karstification. The travertine body of the castle rock is influenced by to lateral spreading. Slope failure mechanism using 2D numerical modelling (UDEC - professional code) have been analysed and investigated.

Key words: discontinuities, discrete element method, numerical modelling, travertine mound

Introduction

Earth sciences, particularly engineering geology, rock mechanics, and rock slope engineering, etc. belong to those disciplines from which the concept of distinct element method originated. The availability of numerical modelling techniques is sufficient for both continuum and discontinuum materials to be analysed with many advantages with respect to slope failure mechanism study. Distinct element models are appropriate to simulate the blocks as discontinuum materials either rigid or deformable and the weaker underlying layers as elastic - plastic continuum materials. Both 2D and 3D distinct element modelling techniques are available - UDEC and 3DEC (Itasca, 1993).

This paper explores the application of 2D distinct element models in studying slope failure mechanism at Spis Castle. Due to particular geological and geomorphologic features the Spis Castle is suffering from large-scale slope instability phenomena: in the travertine's cliff, due to jointing, karst processes, lateral spreading, topples and rock falls are the common landslide typologies while in the underlying Paleogene outcropping at the lower part of the castle rock are soil creep prevails.

Geological setting

On a travertine mound 200 m above the surrounding land, at the elevation of 634 m, there is one of the most precious cultural monuments in the Spis region that reigns over the Spis Basin - the Spis Castle. It represents the largest medieval fortification system in Central Europe (Fig.1). It was founded in 1120. The historic development of the castle was rather complicated showing traces of many historic epochs up to the Baroque. In 1780 the castle burnt out and since that time it was abandoned and the process of destruction caused both by the natural and man-made factors was going on.

Fig. 1 Location map

From a geological point of view the studied area is located in a zone referred to as Hornadska kotlina Basin (Eastern Slovakia). Spis Castle is built on a travertine mound (Fig. 2), which is underlain by Paleogene soft rocks formed by claystone and sandstone strata (flysh-like formation).

The travertine body reaching more than 52 meters in thickness reflects several features of destruction and is disturbed by a series of faults, cracks and joint systems. Two prevailing joint sets can be found: sub-vertical joints striking approximately NW to SE with a general dip to SW (dip direction/dip 220°-250°/80°-90°) and joints striking approximately N-S dipping to the W (250° to 270°/85°). In relation with orientation of main discontinuities two caves were developed Dark Cave (Temná jaskyňa) and Podhradie Cave (Podhradská jaskyňa; Fussgänger, 1985).

Lateral spreading caused by the subsidence of the strong upper travertine into the soft underlying claystone has fractured and separated the castle rock into several cliffs. The central part of the travertine rock is formed by a block rift (travertine cliffs separated by persistent tensional joints and cracks), the marginal parts of the castle rock are formed by a block field consisting of displaced

Slovak Geol. Mag., 10, 4 (2004), 299 – 303

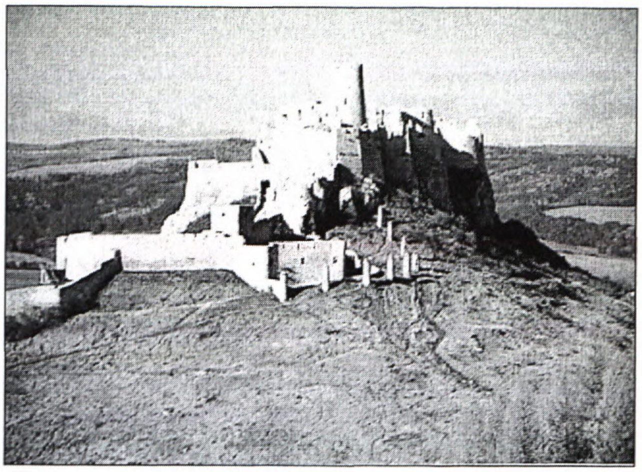


Fig. 2 Spis castle

and tilted cliffs reaching the height from 25 to 30 m, sloping at an inclination of 70° to 80°, in some places up to 90° with a number of overhangs. The absence of a block field in the SW part of the castle rock is due to the uplift of Palaeogene claystones along the fault line (220°/80°) which inhibited total disintegration of the block field, followed by rock falls, toppling and tilting of huge cliffs of travertines (Vlcko et al.1993, Vlcko 2002).

Numerical modelling

Based on the geological setting (Fig. 3) a simplified geo – mechanical model in accordance with the objectives of the analysis was considered. The upper part of the castle rock represented by travertines were assumed as rigid discontinuum medium, the underlain layers formed by Paleogene claystones as elastic-plastic medium, both following Mohr-Coulomb criterion. The contact zone between those two materials with different geomechanical behaviour is always represents the creep zone or the shear plane).

The UDEC program simulates the mechanical behaviour of the discontinuum medium represented as an assemblage of discrete blocks subjected to either static or dynamic loading. The main features of the code can by summarized as follows:

- The discontinuities are treated as boundary conditions between blocks; finite displacements along discontinuities and rotation of block are allowed;
- Blocks may be rigid or deformable; contacts are always deformable;
- The program recognizes new contact as the calculation proceeds;
- Several constitutive behaviour models following linear or non-linear laws are available for both joints and blocks;
- The program can simulate steady or transient fluid flow through the discontinuities.

As introduced in the UDEC code, vertical sides of the model have been assumed to move vertically only and the horizontal ones only horizontally. The rock material and the discontinuities are assumed elastic- plastic when the Mohr-Coulomb failure envelope or tensile failures are reached. Travertine and bedrocks rock have been assumed as fully deformable blocks and then discretized into finite difference triangular elements. The model ran over a number of iterations until the initial equilibrium conditions were attained.

A stepwise modelling procedure we adopted was based upon the back analysis comprised**:**

a) Simulation of travertine sequences over the Paleogene rocks until the state of equilibrium (initial state of stress) was determined. The travertines were assumed as an ideal homogeneous rock body.
b) Introduction of gradual decrease of bedrock material properties (weathering, softening) as well as gradual decrease of tensile strength along the joints in travertines (mainly joint normal stiffness and shear stiffness) were considered.

The physical and mechanical parameters as input data for modelling are summarized in Tab.1 (Baskova, Vlcko 2003). The resulting limit values reported in Tab.1 represent parameters determined by laboratory tests.

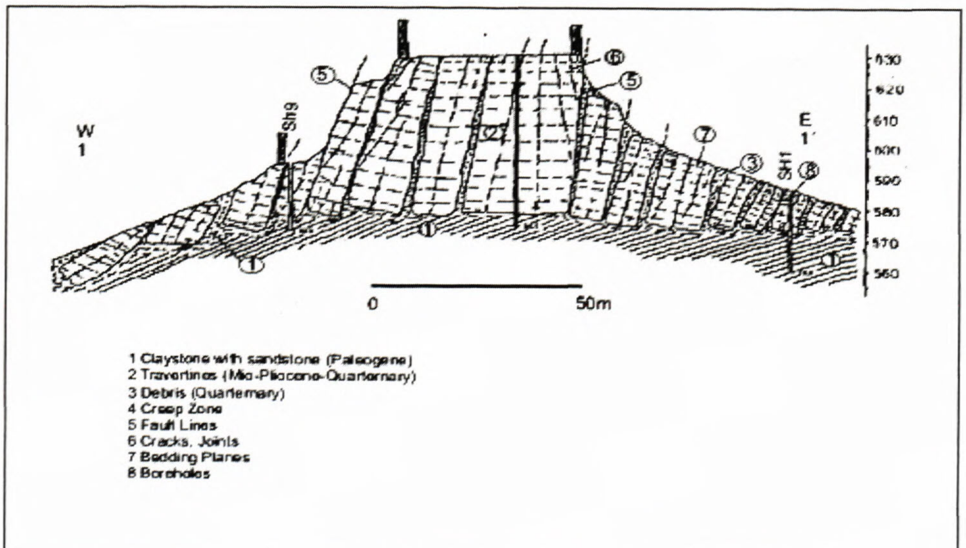


Fig. 3 Geological cross section after Malgot in Vlcko et al. 1993

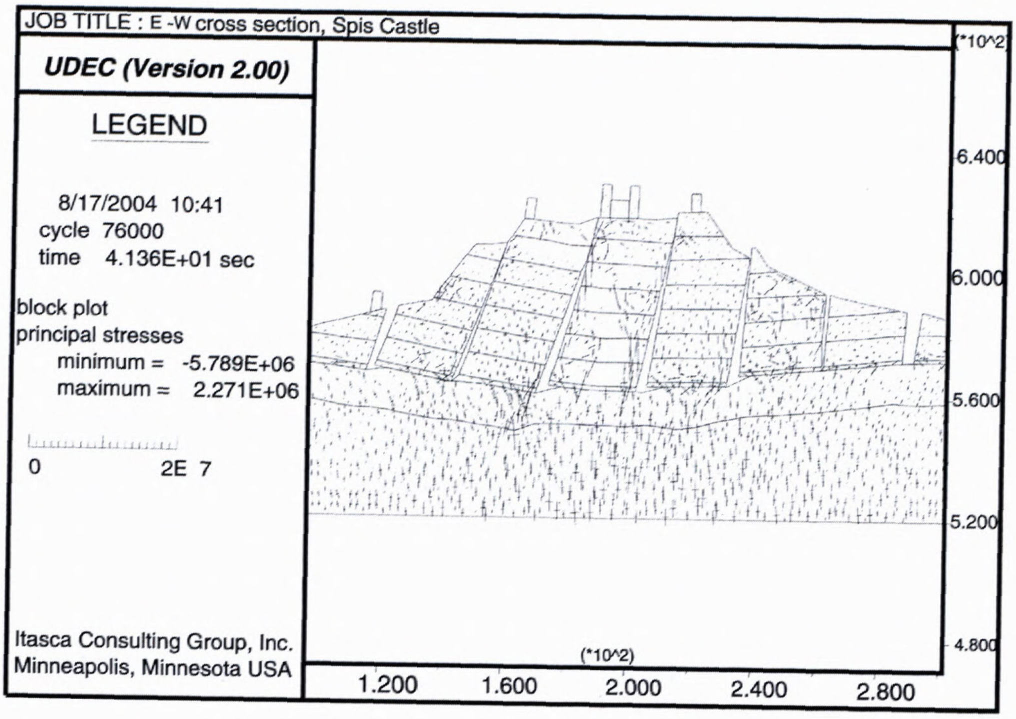


Fig. 4 Numerical analysis at Spis Castle - principal stresses

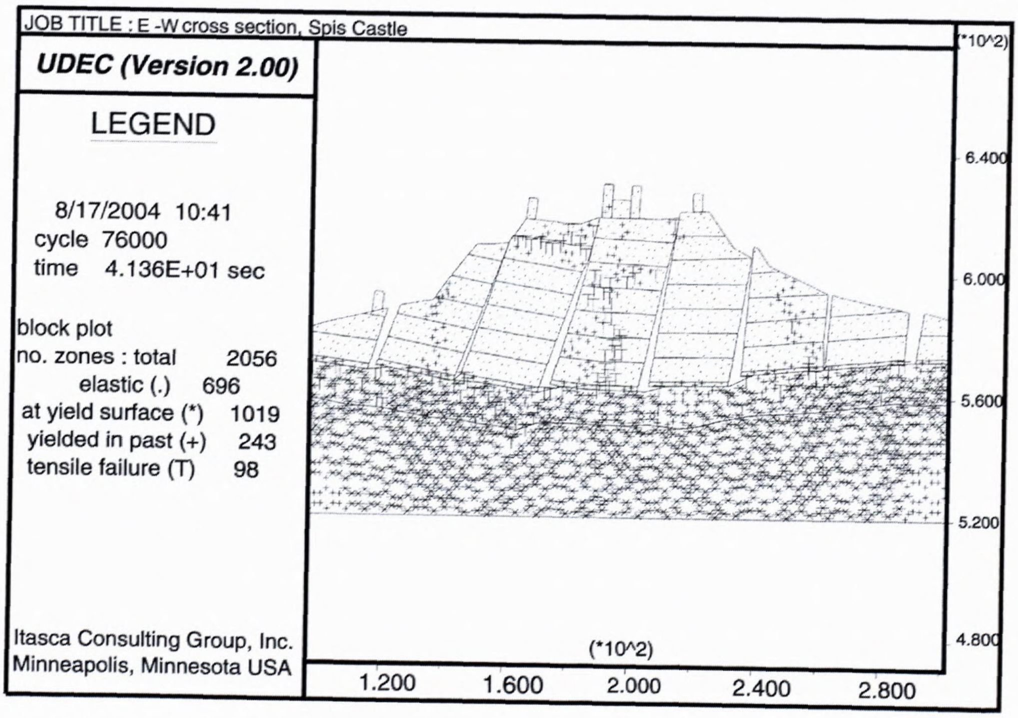


Fig. 5 Numerical analysis at Spis Castle - yielding zone and tensile fracture

Tab. 1 Physical and mechanical parameters of rocks use in numerical model (Baskova, Vlcko 2003)

Material	ρBulķ density (kg.m^{-3})	ρ_c – Uniaxial strenght (MPa)	E – Young´s modulus (MPa.10^3)	yPoisson´s ratiọ -
Travertine	*2500*	*63*	*56,6*	*0,19*
Contact zone (creep zone)	*1850*	*10*	*17,0*	*0,35*
Claystone	*2310*	*33*	*20,0*	*0,25*

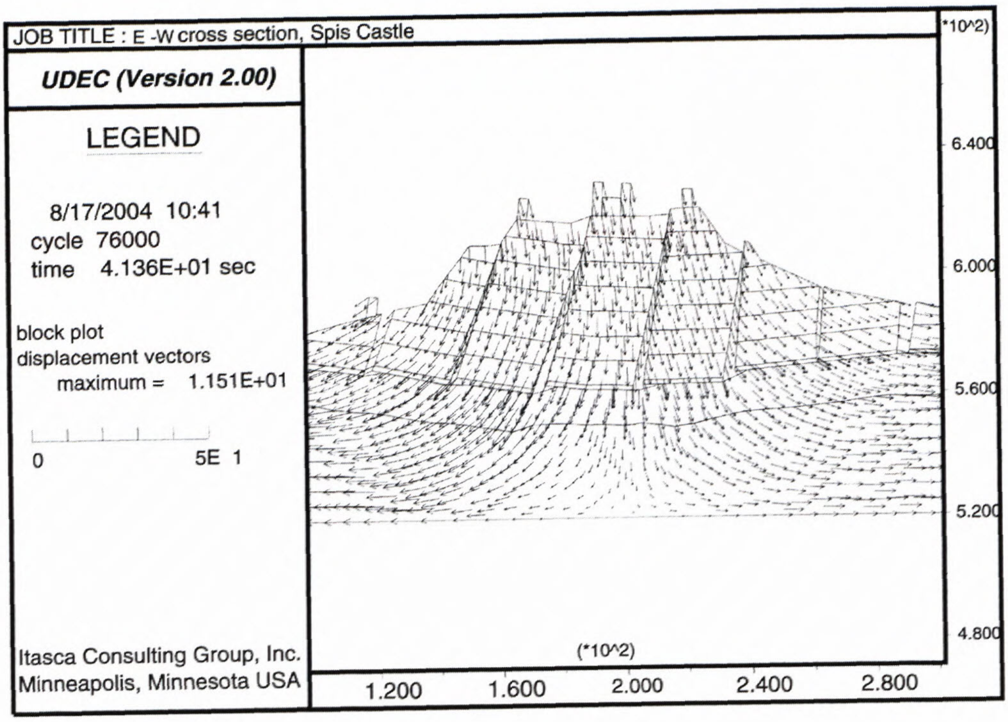


Fig. 6 Numerical analysis at Spis Castle – displacement vectors

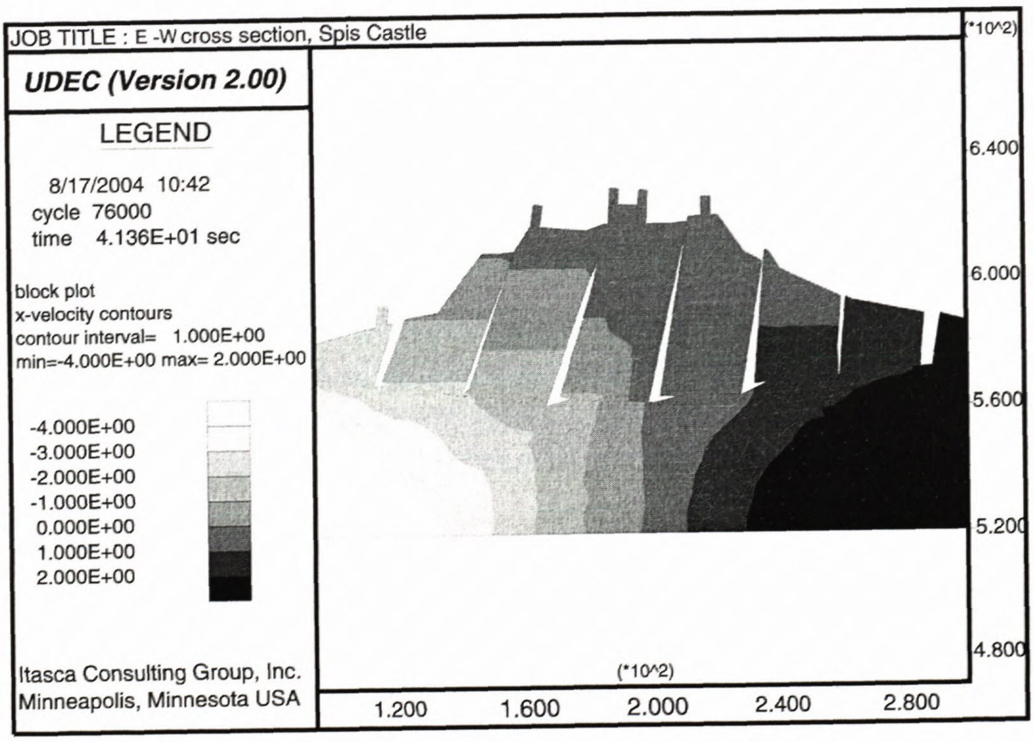


Fig. 7 Numerical analysis at Spis Castle – x- velocity contours (-4.0 mm.s^{-1} up to 2.0 mm.s^{-1})

Discussion

Discrete element method incorporates the main features required for slope failure mechanism analysis as it provides a realistic presentation of the rock mass under study and the use of deformable medium (travertine blocks) makes this method capable of reproducing the Spis castle rock deformation.

The results of the study confirmed the complexity of the phenomenon investigated and there are a number of details that emerge. Numerical analysis confirmed that the instability of travertine is related to significant shear strength reduction of the claystone formation. When the shear stress induced by the weight of travertine equals the diminishing shear strength (Fig. 4) and the strength of the claystone reaches the residual state, yielding zone and the

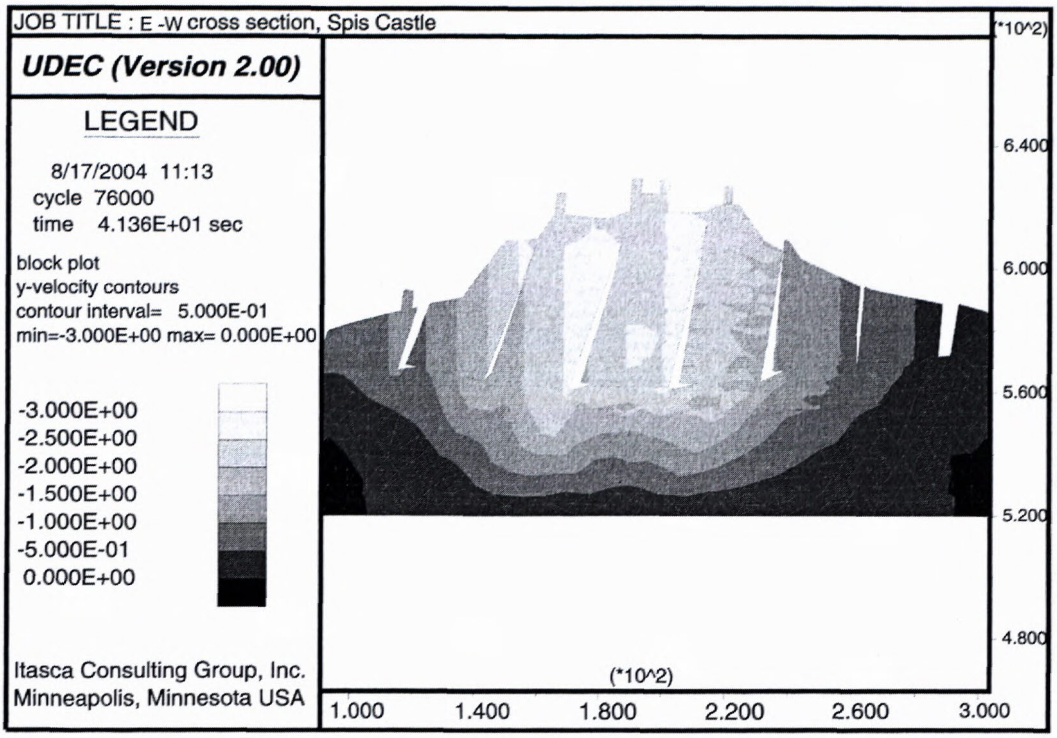


Fig. 8 Numerical analysis at Spis Castle – y - velocity contours (-3.0 $mm.s^{-1}$ up to 0.0 $mm.s^{-1}$)

failure surface start to develop and the travertine body is separating by subvertical persistent tensile fractures into several individualized blocks that starts to be unstable. At the western marginal part of the castle rock the cliffs are toppled up-slope while in the eastern part these are toppled down-slope. Along tensile fractures the strain is transmitted to the castle walls and inhibits their rupture, in some places even collapse (Fig. 5).

The slope failure mechanism is evident from the distribution of the displacement vectors (Fig. 6) as well as from the contours diagrams of velocity in x (Fig. 7) and y directions (Fig. 8).

Conclusion

To understand better landslide failure mechanism a numerical modelling can significantly contribute to the hazard/risk assessment for various purposes. The applicability in numerical modelling in rock slope engineering apart from material properties data almost entirely depends on the quality characteristics of the fracture system geometry, physical behaviour of individual fractures and the interaction between intersecting fractures.

The numerical modelling has a broad variety of applications in engineering geology (Greif et. al. 2001, 2002), rock and soil mechanics, structural engineering, etc. In case of Spis Castle, a monument under patrimony of UNESCO, the analysis confirmed the continual process of castle rock disintegration and the results we gained will be applied in design of stabilization and preservation works.

Acknowledgement

This paper was prepared as part of the framework of VEGA grants projects No. 1/9159/02 and 1/9160/02, IPL Project No. 101–2 OF and a bilateral project between Kyoto University, Faculty of Natural Sciences Jap/Slov/JSPS/40. The authors are thankful to the Ministry of the Environment of the Slovak Republic, Ministry of Education of the Slovak Republic, grant agency VEGA and the International Consortium on Landslides for their kind support.

References

Baskova, L., Vlcko, J. 2003: Numerical analysis of block movements at the Spis Castle. Geotechnical Measurements and Modelling - Natau, Fecker & Pimentel (Eds.) Karlsruhe, Swets & Zeitlinger, Lisse, ISBN 90 5809 603 3

Fussgänger, E. 1985: Poznatky z terénneho výskumu plazivých svahových pohybov travertínových blokov na Spišskom hrade. Mineralia Slovaca, 17, 1, p. 15-24

Greif, V., Sassa, K., Fukuoka, H. 2002: Bitchu-Matsuyama castle rock slope monitoring and failure mechanism analysis using distinct element method. International Symposium Landslide Risk Mitigation and Protection of Cultural and Natural Heritage, 21-25January 2002, Kyoto University, Kyoto, Japan, pp.329-338

Greif, V., Sassa, K., Fukuoka, H. 2001: Failure and triggering mechanism analysis of the Bitchu-Matsuyama castle rock using distinct element method. Annuals of the Disaster Prevention Research Institute Kyoto University, Vol. 44, pp. 7-14

Itasca, 1993: UDEC version 3.10–user manual. Itasca Consulting Group Inc., Minneapolis. Minnesota

Vlcko, J., Baliak, F., Malgot, J. 1993: The influence of slope movements on Spis Castle stability. Landslides – Seventh International Conference and Field Workshop: 305-312. Rotterdam: Balkema

Vlcko, J. 2002: Monitoring – an Effective Tool in Safeguarding the Historic Structures. International Symposium Landslides Risk Mitigation and Protection of Cultural and Natural Heritage: 267-278. Kyoto: Kyoto University

Permeability of fine-grained soils

IVAN DANANAJ and JANA FRANKOVSKÁ

Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava
e-mail: dananaj@fns.uniba.sk frankovska@gssr.sk

Abstract. In our study we tried to compare several methods of laboratory determination of coefficient of permeability, which is the principal property characterizing sealing properties of soils. We also tried to evaluate relationships of coefficient of permeability with other engineering geology parameters.
Permeability of 26 fine-grained Quaternary and Neogene soil samples from Western Slovakia was determined in triaxial apparatus and in oedometer by calculation from the time behavior consolidation using square root method and logarithmic method. Permeability was also estimated from grain size distribution by empirical formulas.

The results showed that coefficients of permeability obtained from triaxial and oedometer tests are similar and comparable. Coefficient of permeability obtained by the square root method was very similar to triaxial coefficient of permeability and their relationship is linear. Logarithmic method showed greater differences in comparison with the triaxial test results. Coefficient of permeability showed very good correlation with consistency index, liquid limit, index of plasticity and volumetric moisture content. Coefficient of permeability from grain size distribution is not advisable for cohesive soils.

Key words: sealing properties, coefficient of permeability, triaxial tests, oedometer tests.

Introduction

Proposal for an EU Directive (1997) concerning the design of sanitary landfills prescribes an extra protection against the percolation of leachate using a geological barrier of clay (Baumann et al., 1997). Construction of a proper landfill is necessary for protection of soils and groundwater from the pollution migration. Sealing systems play an important role in landfill construction in creating a long-term protection against pollutant transport into the environment.

Slovak technical standard STN 83 8106 - Landfill sealing suggests parameters of materials suitable for landfill sealing (mineral, geomembrane, combined and others). Materials suitable for the mineral sealing are fine-grained sediments: clays and silts from low to high plasticity and sandy soils (silty sand and clayey sand). The standard suggests to built-in soils with fine-grained particles (< 0,06 mm) $\geq$ 20 to 30 %, $I_P \geq 7$ to 10 %, gravel content (> 2 mm) $\leq$ 30 %, maximum grain sizes 63 mm. It also recommends the use of bentonite or other smectite clays. Organic matter content must be lower than 5% (this is not relevant for stable organic matters, such as coal dust or slag, etc.) Clay activity should be within (0,5 - 1,0) interval. Homogeneity and suitability is required to be verified by laboratory tests: grain size, moisture content, Atterberg limits, maximum dry density (Proctor standard) and laboratory test of permeability.

Permeability is a primary factor governing the performance of sealing systems. Membranes made out of soils with sealing properties should have the desired effect. Coefficient of permeability is the most important property determining the suitability of natural sealants. According to the Slovak technical standard – Laboratory determination of soil permeability, materials are considered impermeable if their coefficient of permeability is below 10^{-8} m.s^{-1}. Jullien et al. (2002) state that the permeability of soils in the sealing systems has to remain below 10^{-9} m.s^{-1} under all circumstances.

Permeability is an inherent property of a solid material and by the definition it is a measure of the rate of fluid flow through a porous material under a unit hydraulic gradient. The coefficient of permeability is a constant of proportionality relating to the ease with which a fluid passes through a porous medium.

Accurate determination of the coefficient of permeability is very important. There are several methods for assessment of the coefficient of permeability. Generally, we recognize direct and indirect laboratory methods. Coefficient of permeability can be determined directly by field tests (Matys et al., 1990). Field tests are time-consuming and require more advanced equipment for determination of coefficient of permeability. Laboratory tests, using a permeameter or a triaxial apparatus, are the simpler and generally more available methods for direct and more accurate determination of coefficient of permeability, but on the other hand the tested specimen is only a limited part of soil mass. Calculation from the time behavior consolidation, estimation from the empirical formulas and geophysical tests are indirect methods. All methods cannot be used generally; each method is suitable for different types of soils.

Záleský (1995) conducted comparative tests of coefficient of permeability on a low plasticity clay (w_L = 32,1 %,

w_P = 18,3 %, w_{opt} = 15,5 %, ρ_s = 2730 kg.m^{-3} a $\rho_{d,max}$ = 1816 kg.m^{-3}). He provided tests on high dimensional permeameter (sample dimensions 2 x 2 m), modified field permeameters (with diameter 50 and 100 mm) and laboratory tests in a pressure chamber with falling head (sample height 50 mm) and from time behavior consolidation in oedometer (height 30 mm and diameter 100 mm). They got good correlation between all methods with coefficient of permeability between 8×10^{-10} m.s^{-1} and 3×10^{-10} m.s^{-1}, except the oedometer tests, which yielded almost one order higher permeability coefficient 4×10^{-9} m.s^{-1}.

Baumann et al. (1997) studied coefficient of permeability in oedometer on high plasticity clay Rodby Havn used as a sealing for landfill layers in Denmark. The diameter was 30 mm and height 20 mm. Resulting coefficient of permeability of 5×10^{-12} m.s^{-1} confirmed propriety of its use in sealing barriers.

Garbulewski et al. (1995) also used oedometer and triaxial tests to determine coefficient of permeability of high plasticity swelling clay. They used specially adapted oedometer, allowing monitoring of permeability changes with saturation of the sample. They observed rapid decrease of the coefficient of permeability in time, in the modified oedometer, (for t = 0, k = 1×10^{-7} m.s^{-1} and for t = 60 000 s, k = 1×10^{-11} m.s^{-1}). Triaxial tests showed relationship between coefficient of permeability and water content (for w = 15 % k = 1×10^{-12} m.s^{-1} and for w = 35 % k = 1×10^{-8} m.s^{-1}). Author did not correlate the results between oedometer and triaxial tests.

Švábik (2001) compared permeability of four high and intermediate plasticity clays from Devínska Nová Ves and Levice in triaxial apparatus and oedometer. He found a good correlation between the two methods (maximum difference was 5.10^{-12} m.s^{-1}).

In this paper we compare different methods of Permeability determination for fine-grained soils. Permeability was determined by test of permeability in triaxial apparatus, in oedometer (logarithmic and square-root method) and by using empirical formulas based on grain size distribution. Empirical methods were used only for comparative purposes, since they are not suitable for clays. Grain size distribution, plasticity and liquid limits, bulk density and specific density were determined to classify the samples. Other physical properties, such as porosity, clay activity, organic matter content, carbonate content, saturation degree, etc. were also estimated to characterize engineering properties of the samples.

Materials

Twenty-six samples from localities from western Slovakia around town Skalica (Skalica, Holíč, Vradište, Kátov, Kopčany), Nové Mesto nad Váhom (Turecký vrch) and Trnava were tested in laboratory to evaluate different laboratory and empirical methods of determining of coefficient of permeability. Samples are Quaternary and Neogene fine-grained sediments.

Area around Skalica is geologically constituted of Neogene sediments, mainly from Holíčske Súvrstvie formation composed predominantly by calcareous clays, claystones and siltstones. These are sediments of basin facies of culminating transgression. Genetically heterogeneous Quaternary sediments of different thickness represented mainly by fluvial, proluvial and eolian sediments cover almost whole area.

Area around Trnava is composed of Neogene and Quaternary sediments. Neogene sediments create pre-Quaternary sublayer, represented by Panonian (greenish and yellow brown calcareous clays with sand and fine gravel layers), Pontian (coarse to boulder gravels, sands with gravel admixtures and clayey layers) and Levantian (medium to coarse gravels, scarcely sands) sediments. Quaternary is composed mostly by eolian origin sediments – ochre-yellow, fine sandy loess and loess loams. Thickness of the loess cover reaches up to 26 m. Fluvial sediments create fillings of fluvial bottomland of streams and deluvial sediments (washed loess, having mostly clayey character and darker colored), on the valley slopes (Salai, 1984).

Turecký vrch area is represented by rock complexes from middle Triassic to Quaternary. Neogene in the Turecký vrch area protrudes only on few places, represented by basal conglomerates and sandstones of Egenburg-Otnang cycle. Quaternary sediments are represented by various types of Eolian sediments (Pleistocene) represented by light yellow to brown colored loess, loess silts and clays. These sediments are wide spread and up to 14 meters thick (Matejček, 2003).

Tested samples are classified as low to very high plasticity clays. One sample is classified as very high plasticity clay, 9 samples as high plasticity clay, 1 sample as sandy clay, 12 samples as medium plasticity clay and 3 samples as low plasticity clay. Table 1 shows the classification of particular samples.

Methods of determination of the coefficient of permeability

Tests in triaxial apparatus, calculation from the time behavior consolidation (Casagrande's and Taylor's methods) and estimate from the empirical formulas were employed in determining of the coefficient of permeability.

Determination by the permeability test in triaxial apparatus

Determination of coefficient of permeability in a permeameter or a triaxial apparatus is based on the Darcy's law (linear resistance law), which applies generally for steady water flow in soils. It is given as:

$$v = k.\, i \qquad (1)$$

and corresponding flow rate

$$q = k.\, i.\, A, \qquad (2)$$

where q is quantity (m^3) of fluid flow in a unit time t (s), k is coefficient of permeability (m.s^{-1}), $i = \frac{h}{l}$ expresses the hydraulic gradient, h is total head difference along the flow path of length or height of the tested sample l (m)

Table 1. List of samples and their classification.

No.	Probe	Depth (m)	Locality	Description	Class	Symbol	Consistency	Clay/Loess
3492	JV-12	2,5	Vradište	very high plasticity clay	F8	CV	stiff	Clay
3498	JV-13	5,4	Skalica	high plasticity clay	F8	CH	firm	Clay
3504	JV-2	2,6	Holíč	high plasticity clay	F8	CH	stiff	Clay
3512	JV-1	8,6	Kopčany	high plasticity clay	F8	CH	stiff	Clay
3513	JV-3	1,2	Holíč	high plasticity clay	F8	CH	stiff	Clay
3514	JV-3	1,4	Holíč	high plasticity clay	F8	CH	stiff	Clay
3517	JV-3	6,8	Holíč	intermediate plasticity clay	F6	CI	stiff	Clay
3523	JV-4	4,5	Holíč	high plasticity clay	F8	CH	stiff	Clay
3524	JV-4	6,2	Holíč	high plasticity clay	F8	CH	stiff	Clay
3525	JV-5	7,7	Holíč	intermediate plasticity clay	F6	CI	firm	Loess
3526	JV-5	11	Holíč	intermediate plasticity clay	F6	CI	firm	Clay
3527	JV-6	3,5	Kopčany	low plasticity clay	F6	CL	firm	Loess
3528	JV-6	3,3	Kopčany	intermediate plasticity clay	F6	CI	stiff	Loess
3529	JV-6	8,7	Kopčany	low plasticity clay	F6	CL	firm	Loess
3533	JV-7	8	Vradište	intermediate plasticity clay	F6	CI	firm	Clay
3535	JV-8	3,6	Kátov	high plasticity clay	F8	CH	firm	Clay
3540	JV-9	1,1	Skalica	sandy clay	F4	CS	firm	Clay
3711	VT-4	14,2	Turecký v.	intermediate plasticity clay	F6	CI	hard	Loess
3712	VT-4	16,7	Turecký v.	intermediate plasticity clay	F6	CI	hard	Clay
3713	VT-4	24,4	Turecký v.	intermediate plasticity clay	F6	CI	hard	Loess
3717	VT-4	25,5	Turecký v.	intermediate plasticity clay	F6	CI	stiff	Clay
3719	VT-1	2,9	Turecký v.	intermediate plasticity clay	F6	CI	hard	Loess
3726	VT-5a	13,7	Turecký v.	intermediate plasticity clay	F6	CI	hard	Clay
3783	T2	3,1	Trnava	low plasticity clay	F6	CL	hard	Loess
3784	T3	4,5	Trnava	intermediate plasticity clay	F6	CI	stiff	Loess
3785	T4	6,1	Trnava	high plasticity clay	F8	CH	stiff	Loess

and A is cross sectional area (m^2) Coefficient of permeability (Mucha, et al., 1987) is calculated after modification to:

$$k = \frac{q.l}{A.h.t}, \ (m.s^{-1}) \qquad (3)$$

Coefficient of permeability was determined in a triaxial cell apparatus by "Constant head permeability test", measuring the flow of water through the sample, according to the Manual of Soil Classification and Compaction Tests (Head, 1992) and Slovak technical standards. The triaxial test determination with a pore pressure apparatus gives substantial control over the hydraulic gradient h/l across the sample. Magnitude of the gradient was from 30 to 100. Measurements until steady values of coefficients of permeability k were obtained. Coefficient of permeability for temperature 10°C k_{10} was calculated according the Slovak technical standard STN 72 1020.

Determination from the time behavior consolidation in oedometer

Laboratory test of consolidation of soils in oedometer is a model test of one-dimensional consolidation (Lambe, 1969). A compressible water saturated specimen is loaded evenly, water is embossed into the porous plates on both sides. Consolidation is not just a hydraulic process. A certain immediate deformation occurs after the loading in the initial phase of the curve, which is generally explained by the soil framework structure deformation and compression of minor air bubbles. The so-called secondary consolidation, which reaches more important portion only for the clayey soils, occurs at the end phase after expected termination of the initial hydraulic consolidation and is explained by the long-term plastic flow of the soil.

For each load increment the amount or (dial reading) that the sample has compressed at the end of a series of elapsed time in minutes is recorded as part of the data. A total time for a sample to consolidate under a load increment must be 24 hours or more (Bowles, 1992). There are several methods for taking time versus dial readings. Casagrande's and Taylor's methods are the most widely used. In the Casagrande's method, shown on Figure 1 the data are presented as a semi logarithmic plot of dial readings versus time (time on the log scale) in minutes and in the Taylor's method one uses a plot of dial reading versus $\sqrt{t}$ (in minutes). From such plots we obtain the dial reading corresponding to the end of primary consolidation (or the end of 100 percent consolidation) U or D_{100} . Time elapsed when this occurs is T. It is also necessary to obtain a dial reading at the beginning of the test. Data reduction for the Casagrande's method usually requires using a D_{50} (dial reading at U = 50 %) and corresponding time t_{50} (Figure Cassagrande's method). The time at U = 50 % is used to estimate the coefficient of consolidation c_v from the test. This value is used to estimate rate of settlement as follows:

$$c_v = \frac{0,049.(h_{50})^2}{t_{50}}, \ (m^2.s^{-1}) \qquad (4)$$

Slovak Geol. Mag., 10, 4 (2004, 305 – 312

Taylor's method presented on Figure 2 uses D_{90} (dial reading at U = 90 %) and corresponding time t_{90} to calculate the coefficient of consolidation (Figure Taylor's method) according to:

$$c_v = \frac{0{,}212.(h_{90})^2}{t_{90}}, \ (\mathrm{m^2.s^{-1}}) \qquad (5)$$

where h_{50} and h_{90} is height of the specimen at 50 and 90 % of the primary consolidation.

Since the coefficient of consolidation is defined:

$$c_V = \frac{k.E_{oed}}{\gamma_w}, \qquad (6)$$

where γ_w is water unit gravity, E_{oed} is oedometric modulus, c_v can be used for calculation of coefficient of permeability after modification to:

$$k = \frac{c_v.\gamma_w}{E_{oed}}, \ (\mathrm{m.s^{-1}}) \qquad (7)$$

Laboratory tests of consolidation of soils in oedometer were performed according to the Slovak technical standard STN 72 1027. Load of 400 kPa was used to determine oedometric modulus E_{oed}, coefficient of consolidation c_v and coefficient of permeability k for all samples. Loads of 100 kPa and 200 kPa were used for several samples as well. Coefficient of consolidation was evaluated by both Casagrande's and Taylor's method.

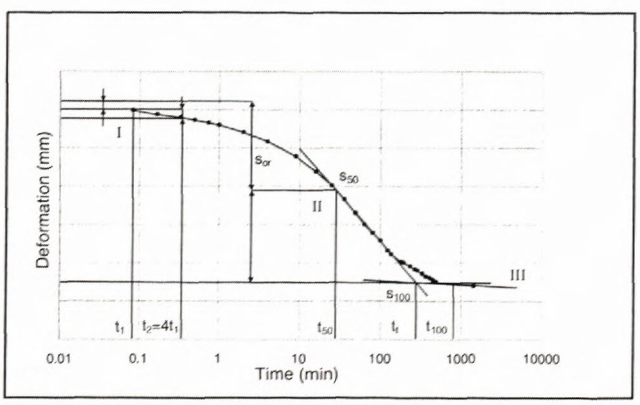


Figure 1. Casagrande's method diagram

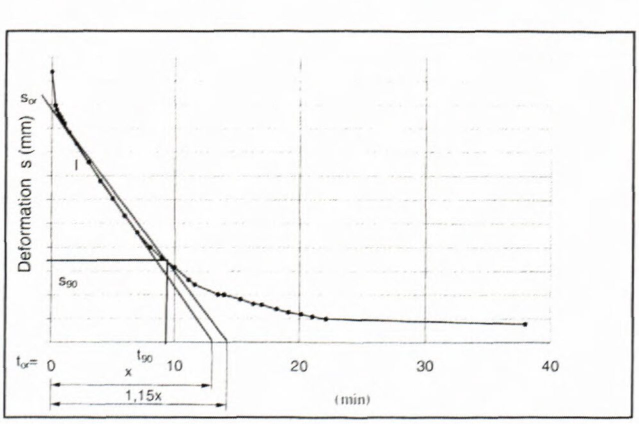


Figure 2. Taylor's method diagram

Determination from the Empirical equations

Grain size of soil is reflected in coefficient of permeability, because the permeability of the porous soil depends on the relative content of the grains of different sizes (Head, 1990). Different ways of coefficient of permeability determination from the grain size curve have been therefore developed. These are used for loose sedimentary soils, especially for non-cohesive sediments. They were used only for comparative purposes, even they are not suitable for fine-grained soils.

These methods are indirect, they are based on the size of particles, and it is therefore necessary to determine the grain size curve, which gives the amounts of particular grain size fractions. Several equations, which relate the permeability of soils and their grain size and other classification values, are used. Hazen's, Kozeny's and Carman's modification of the Kozeny's equation belong among the most known. Other are Jáky, Terzaghi, Orechová, American equation, Seelheim, Zieschang, Beyer, Zauerbrej, Zamarin, Schlichter, Krüger, Palagin, etc.

Empirical equations determined by Carman-Kozeny, Seelheim, Orechova and American formula were also used to determine to estimate coefficient of permeability for each soil.

Carman-Kozeny

Relates permeability with grain size, porosity, grain shape, surface area and water viscosity. The formula is intended only for clean sands, but it is sometimes extrapolated for finer soils to obtain an approximate indication of their permeability (Head, 1990):

$$k = \frac{\rho_w.g}{C.\eta_w.S^2}\frac{e^3}{1+e}; \quad C = 5.f \quad \text{or} \qquad (8)$$

$$k = \frac{1}{5}\frac{g.n^3}{\gamma.(1-n)^2}\left(\frac{d_e}{\alpha}\right)^2$$

(modified for spherical shape of grains), (9)

where e is void ratio, g is acceleration of free fall, ρ_w is water density, η_w is water viscosity, S is surface area, C is shape factor (5 for spherical shape), f is angularity factor (f range 1,1 – 1,4), n is porosity, γ is unit gravity d_e is effective grain diameter and α is pore shape factor.

Seelheim, American equation and Orechová relate coefficient of permeability just to the grain size distribution represented by grain size diameters d_{50}, d_{20} and d_{17}.

Seelheim

$$k = \frac{0{,}357.(d_{50})^2}{100},$$

valid for soils with grains (0,063 mm < 35 %) (10)

American equation

$$k = \frac{0{,}36.(d_{20})^{2.3}}{100},$$

valid for soils with (0.01 mm < d_{20} < 2.0 mm) (11)

Table 2. Coefficients of permeability

Sample No.	Coefficient of permeability k (m.s^{-1})										
		Oedometer						Empirical equations*			
	Triaxial	Taylor's square-root method			Casagrande's logarithmic m.			Orechová	American equation	Seelheim	Carman-Kozeny
	k_{10}	k_{100}	k_{200}	k_{400}	Lk_{100}	Lk_{200}	Lk_{400}				
3492	$1.24x10^{-11}$	$1.16x10^{-11}$	$1.96x10^{-11}$	$1.53x10^{-11}$	$8.73\ 10^{-11}$	$1.16x10^{-11}$	$1.72x10^{-11}$				
3498	$1.32x10^{-11}$		$3.74x10^{-11}$	$2.4x10^{-11}$		$4.88x10^{-11}$	$4.07x10^{-11}$			$1.87x10^{-8}$	$1.87x10^{-8}$
3504	$1.04x10^{-11}$		$1.66x10^{-10}$	$1.14x10^{-10}$		$1.21x10^{-10}$	$4.06x10^{-11}$			$1.52x10^{-7}$	$3.48x10^{-9}$
3512	$1.93x10^{-11}$			$3.59x10^{-11}$			$4.7x10^{-11}$	$2.95x10^{-8}$	$4.73x10^{-9}$	$4.31x10^{-7}$	$5.20x10^{-9}$
3513	$8.74x10^{-10}$	$2.73x10^{-9}$	$9.1x10^{-10}$		$3.6\ 10^{-10}$	$4.04x10^{-11}$				$7.21x10^{-8}$	$3.06x10^{-9}$
3514	$2.08x10^{-10}$	$4.71x10^{-10}$	$6.5x10^{-10}$		$2.49\ 10^{-10}$	$2.2x10^{-10}$				$2.19x10^{-7}$	$3.92x10^{-9}$
3517	$2.64x10^{-11}$		$1.17x10^{-10}$	$4.12x10^{-10}$		$2.42x10^{-10}$	$3.12x10^{-10}$	$3.79x10^{-8}$	$3.46x10^{-8}$	$3.99x10^{-6}$	$8.17x10^{-9}$
3523	$3.36x10^{-11}$	$2.40x10^{-11}$	$3.88x10^{-11}$	$3.55x10^{-11}$	$3.07\ 10^{-11}$	$2.97x10^{-11}$	$2.18x10^{-11}$			$1.02x10^{-8}$	$3.49x10^{-9}$
3524	$3.24x10^{-11}$		$1.17x10^{-10}$	$4.24x10^{-11}$		$6.93x10^{-11}$	$4.63x10^{-11}$			$7.37x10^{-9}$	$3.69x10^{-9}$
3525	$7.62x10^{-10}$	$8.02x10^{-10}$	$9.52x10^{-10}$	$5.33x10^{-10}$	$1.5\ 10^{-10}$	$5.32x10^{-10}$	$2.74x10^{-10}$	$1.63x10^{-8}$	$2.14x10^{-9}$	$1.90x10^{-6}$	$5.96x10^{-9}$
3526	$2.67x10^{-10}$	$4.43x10^{-10}$	$4.15x10^{-10}$	$2.96x10^{-10}$	$2.71\ 10^{-10}$	$2.34x10^{-10}$	$1.69x10^{-10}$	$2.53x10^{-8}$	$4.16x10^{-9}$	$1.27x10^{-6}$	$6.26x10^{-9}$
3527	$1.00x10^{-9}$		$7.01x10^{-10}$	$6.65x10^{-10}$		$1.35x10^{-10}$	$1.75x10^{-10}$	$2.15x10^{-8}$	$2.90x10^{-9}$	$9.49x10^{-7}$	$5.88x10^{-9}$
3528	$1.05x10^{-9}$		$2.01x10^{-9}$	$1.11x10^{-9}$		$3.18x10^{-10}$	$3.38x10^{-10}$	$2.14x10^{-8}$	$3.07x10^{-9}$	$1.34x10^{-6}$	$6.13x10^{-9}$
3529	$1.27x10^{-9}$	$1.3x10^{-9}$	$2.17x10^{-9}$	$1.3x10^{-9}$	$4.18\ 10^{-10}$	$6.42x10^{-10}$	$4.53x10^{-10}$	$2.22x10^{-8}$	$3.12x10^{-9}$	$1.37x10^{-6}$	$6.18x10^{-9}$
3533	$2.55x10^{-10}$	$3.21x10^{-10}$	$2.35x10^{-10}$	$2.35x10^{-10}$		$1.44x10^{-10}$	$5.75x10^{-11}$	$4.26x10^{-8}$	$6.51x10^{-9}$	$1.19x10^{-6}$	$6.26x10^{-9}$
3535	$8.91x10^{-11}$	$3.84x10^{-10}$	$1.05x10^{-10}$		$1.18\ 10^{-10}$	$9.07x10^{-11}$			$1.06x10^{-9}$	$2.24x10^{-6}$	$5.48x10^{-9}$
3540	$1.64x10^{-11}$	$4.26x10^{-11}$	$2.75x10^{-11}$		$6.09\ 10^{-11}$	$3.68x10^{-11}$				$4.37x10^{-6}$	$4.76x10^{-9}$
3711	$1.15x10^{-9}$		$3.76x10^{-9}$	$1.32x10^{-9}$		$3.69x10^{-11}$	$1.15x10^{-10}$		$1.97x10^{-9}$	$9.09x10^{-7}$	$5.45x10^{-9}$
3712	$1.74x10^{-10}$		$4x10^{-10}$	$2.09x10^{-10}$		$3.79x10^{-11}$	$7.09x10^{-11}$			$3.55x10^{-7}$	$3.88x10^{-9}$
3713	$7.89x10^{-11}$		$5.93x10^{-11}$	$8.93x10^{-11}$		$7.06x10^{-11}$	$6.43x10^{-11}$	$1.78x10^{8}$	$3.51x10^{-9}$	$1.03x10^{-6}$	$6.0x10^{-9}$
3717	$1.27x10^{-10}$		$2.15x10^{-11}$	$1.46x10^{-10}$		$7.13x10^{-11}$	$3.75x10^{-11}$			$2.58x10^{-7}$	$3.76x10^{-9}$
3719	$2.76x10^{-8}$			$8.72x10^{-9}$			$1.2x10^{-9}$	$8.27x10^{-8}$	$1.9x10^{-8}$	$1.59x10^{-6}$	$6.83x10^{-9}$
3726	$2.70x10^{-11}$			$2x10^{-11}$			$3.55x10^{-11}$		$2.12x10^{-9}$	$7.54x10^{-7}$	$5.17x10^{-9}$
3783	$8.90x10^{-9}$			$6.5x10^{-9}$			$4.07x10^{-10}$	$2.78x10^{-8}$		$2.42x10^{-7}$	$5.35x10^{-9}$
3784	$7.35x10^{-9}$			$6.2x10^{-9}$			$1.83x10^{-10}$	$4.15x10^{-8}$		$1.2x10^{-6}$	$7.79x10^{-9}$
3785	$1.45x10^{-9}$			$1.73x10^{-9}$			$3.38x10^{-10}$	$2.01x10^{-8}$		$7.75x10^{-7}$	$4.59x10^{-9}$

*not advisable for fine-grained soils

Orechová

$$k = \frac{640.(d_{17})^2}{86400},$$

valid for soils with grains (0,063 mm < 35 %) (12)

Tests Results

Obtained coefficients of permeability are shown in Table 2. Values of coefficient of permeability determined in triaxial test are within limits of $2{,}76\times10^{-8}$ m.s^{-1} to $1{,}04\times10^{-11}$ m.s^{-1}.

There were two groups of samples, with different origin: clays (16 samples) and loess and loess-like sediments (10 samples). Clayey samples are varying from intermediate to very high plasticity clays and loess and loess-like soils are characterized only as low and intermediate plasticity clays. Their comparison is presented in Figure 3. Values of coefficients of permeability determined by Taylor's method are labeled as k_{100}, k_{200} and k_{400}, according the load, at which they were measured. Similarly, the values from the Cassagrande's logarithmic method are labeled as Lk_{100}, Lk_{200} and Lk_{400}. Average coefficients of permeability were, as expected, lower for clays and the differences are most obvious for the triaxial test and Taylor's method at 400 kPa, where average value differs by one and a half of order. Higher permeability is caused by structure of loess and loess-like sediments, which controls their properties. Figure 4. shows the comparison of coefficient of permeability obtained by triaxial and oedometric Taylor's test for clays and loess and loess-like sediments separately. Generally Taylor's method gives higher values of coefficient of permeability for clays then triaxial test. Loess and loess-like sediment samples coefficient of permeability values mostly lay over the even line, which means this method gives lower values of coefficient of permeability then the triaxial method. Clays and loess and loess-like sediments also show differences in correlation of coefficient of permeability with other parameters. Clayey soils exhibit good correlation of coefficient of permeability with fraction % 0.5, 1 and 2 mm. For loess and loess-like sediments is characteristic good correlation of coefficient of permeability with fraction % 0.002, 0.005, 0.1, 0.25, 0.5, 1 and 2 mm, consistency index I_C, liquidity index I_L, bulk density ρ_n, specific gravity ρ_s, porosity n, void ratio e, degree of saturation S_r, volumetric moisture content w_o. Coefficient of permeability of loess and loess-like sediments seems to be more dependent on these properties in comparison with clays, because they characterize structure and state of the soil. Permeability of typical clays depends mainly on physical and chemical processes connected with mineralogical composition (clay minerals content). Plot of the Fraction < 0.002 mm content versus plasticity limit is shown on Figure 5. It shows the differences between clays and loess and loess-like sediments in clay activity expressed by the means of Activity index, the ratio of the plasticity limit and fraction < 0.002 mm ratio. Activity index, expressed by Skempton, serves for characterization of the clay behavior (Head, 1992). All of the loess and loess-like sediment samples belong to the group with intermediate clay activity. Clay samples are spread through the low, intermediate and high clay activity zone.

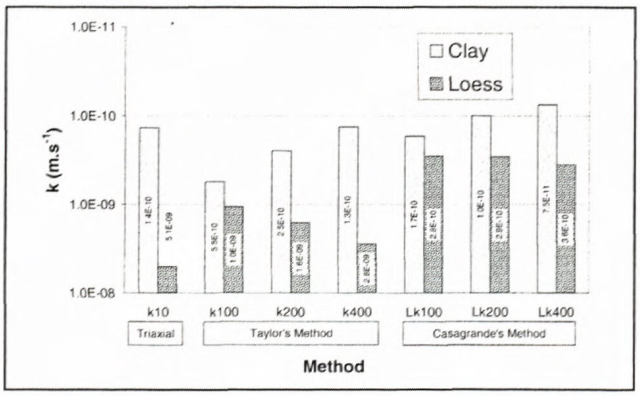


Figure 3. Coefficients of permeability for clays and loess and loess-like soils.

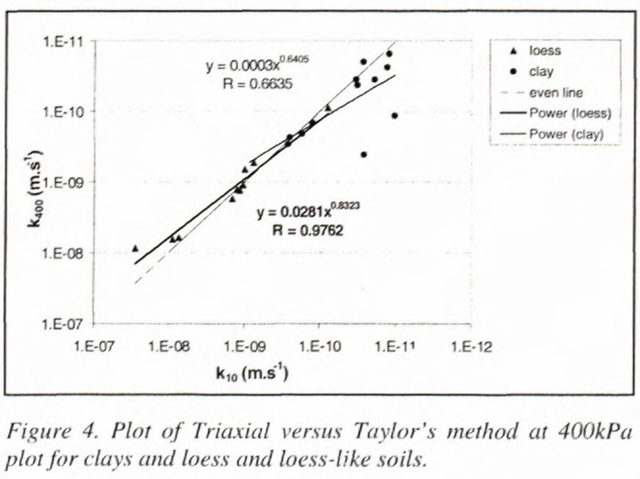


Figure 4. Plot of Triaxial versus Taylor's method at 400kPa plot for clays and loess and loess-like soils.

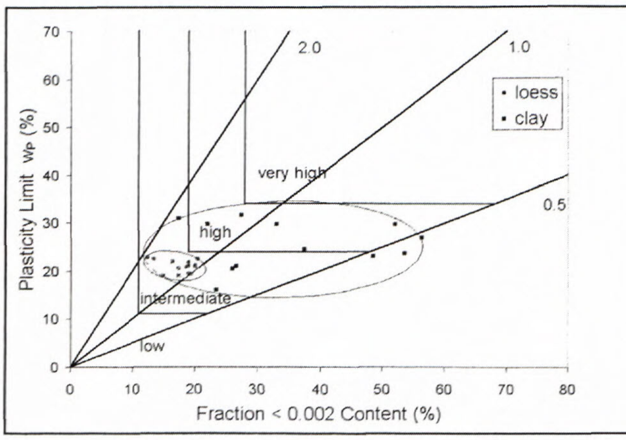


Figure 5. Activity comparison for clays and loess and loess-like soils.

It is obvious, from the Table 2 that the values obtained by triaxial and oedometer tests, especially Taylor's method are similar and for majority of samples the values of the coefficient of permeability from the triaxial test are lower then those from the Taylor's method. The Differences between coefficients of permeability from the triaxial test and Taylor's method are negligible. They differ only by decimals within one order. Greater difference was observed for samples 3504 and 3517, for which the Taylor's method yielded coefficient of permeability one order grater then the triaxial test ($k_{10} = 1.04\times10^{-11}$ m.s^{-1} / 2.64×10^{-11} m.s^{-1}, $k_{400} = 1.14\times10^{-10}$ m.s^{-1} / 4.12×10^{-10} m.s^{-1}). Sample 3719 (loess) show half of order difference, with lower oedometric test value ($k_{10} = 2.76\times10^{-8}$ m.s^{-1}, $k_{400} = 8.72\times10^{-9}$ m.s^{-1}).

Figure 6. shows plot of k_{10} from triaxial method and k from oedometer (Taylor's and Casagrande's method), for better resolution in log-log scale. The plot shows very good correlation between triaxial and oedometer tests with power relationship and Correlation coefficients R = 0.9975 for Taylor method and linear correlation with R = 0.8844 for Casagrande method. Correlation coefficients higher then 0.6084 represent significant relationship for number of cases n = 26. The significance of the correlation is expressed by a significance level. The two tailed significance level of 0.001 means that the correlation coefficient is significant at 99.9 %. Plot between Taylor's and Casagrande's method on Figure 7. shows power relationship with very good correlation R = 0.8459. For coefficient of permeability lower then 1.10^{-10} m.s^{-1} differences are very low and both oedometric methods give similar values with the triaxial test. For higher coefficients of permeability the differences between the Cassagrande's method and the triaxial method are getting higher with higher coefficient of permeability. Although the Correlation coefficient between the triaxial test and Casagrande's method shows significant relationship, values from Casagrande's test are lower then those from the triaxial test, which is good seen in the comparison with the even line (Fig. 6) and it means, the results are not on the safety side. This does not correspond with the Slovak technical standard STN 72 1027, which recommends to use logarithmic

Taylor's method if both methods could be used for evaluation. This points to the fact that Taylor's method is more accurate than Casagrande's method. Empirical equations showed two to three order higher values, Seelheim method even higher, which means, that empirical equations are not suitable for determination of coefficient of permeability for fine-grained soils.

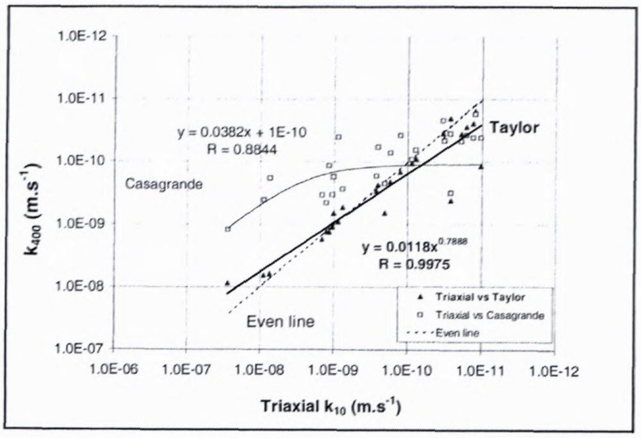


Figure 6. Plot of triaxial k_{10} versus Oedometer Casagrande's and Taylor's method.

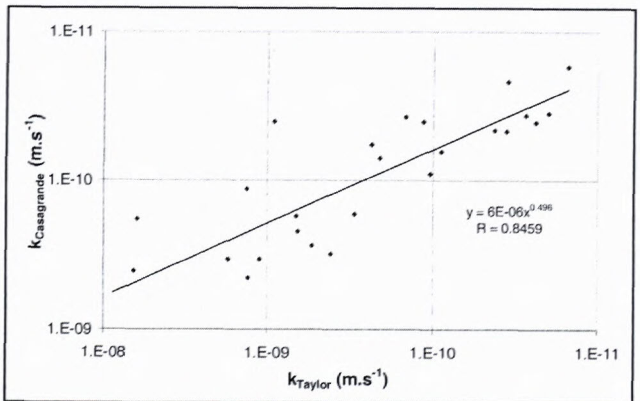


Figure 7. Plot of Taylor's versus Casagrande's method.

Comparison with other physical parameters revealed some interesting relationships. Coefficient of permeability from triaxial k_{10} shows very good linear correlation with consistency index I_C characterized by equation

$$k = I_C . 1^{-8} - 1^{-8}, \text{ (R = 0.7862)}, \qquad (13)$$

bulk density ρ_n (R = -0.7573) and degree of saturation S_r (R = -0.6656).

Coefficient of permeability with liquid limit w_L, equation

$$k = 0{,}1991 . w_L^{-5{,}4277}, \text{ (R = -0.6898)} \qquad (14)$$

and index of plasticity I_P

$$k = 8^{-6} . I_P^{-3{,}4338}, \text{ (R = -0.749)} \qquad (15)$$

show power relationship and relationship of coefficient of permeability and volumetric moisture content w_o is exponential, equation

$$k = 1^{-8} e^{-0{,}1264 . wo}, \text{ (R = -0.5307)}. \qquad (16)$$

Second order polynomial equation (R = 0.6413) characterizes relationship between k_{10} and void ratio e. Some of above-mentioned relationships are shown on Figure 8. and 9.

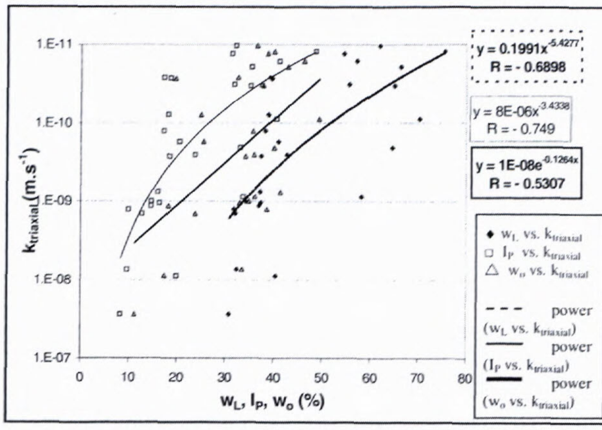


Figure 8. Plot of liquid limit w_L, plasticity index I_P and volumetric moisture content w_o versus triaxial k_{10}.

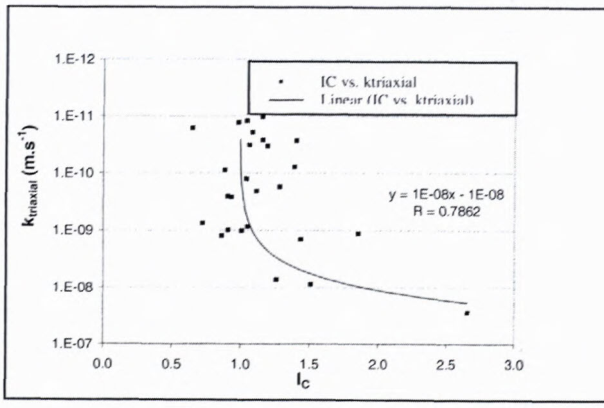


Figure 9. Plot of I_C versus triaxial k_{10}.

Conclusions

Following conclusions could be drawn from this investigation:

1. Oedometric determination of Coefficient of permeability yields very similar results to Triaxial permeability test. Both Taylor and Casagrande methods show close relationships to Triaxial test. Power relationship is characteristic for Taylor's method with Correlation coefficient R= 0.9975 and linear relationship characterizes Casagrande's method with R = 0.8844.

2. The best correlation between triaxial and oedometric determination of Coefficient of permeability was found for loads of 400 kPa (for k_{400} R = 0.9020 and for Lk_{400} R = 0.8844, number of cases 22) and 200 kPa (for k_{200} R = 0.8493 and for Lk_{200} R = 0.5380, number of cases 20), lower correlations were for loads of 100 kPa. (for k_{100} R = 0.7708 and for Lk_{100} R = 0.8176, number of cases 10).

3. Comparison of Taylor's square-root method and Casagrande's logarithmic method showed that Taylor's method gives values closer to those obtained from Triaxial test, the difference is negligible. Values from Casagrande's method are also close to triaxial method, but the differences are higher, especially for samples with coefficients of permeability higher then 1×10^{-10} m.s^{-1}. This is in contradiction to the STN 72 1027, which recommends the use of Casagrande's logarithmic method when both methods could be realized.

4. Methods of determination of Coefficient of permeability from the empirical equations (Carman-Kozeny and Seelheim) brought values more than two orders higher than those from Triaxial and oedometer tests. Since these methods are based only on the grain-size distribution, and partly on porosity or grain shape they do not express actual values of Coefficient of permeability. Empirical equations are suitable mainly for sands and gravels, but their use for fine-grained soils is not advisable, because mineralogical composition and behavior of clay mineral play very important role in these soils, however relationship between coefficient of permeability k_{10} and void ratio e is characterized by significant 2nd order polynomial relationship with $R = 0.6413$.

5. Coefficient of permeability showed some very high correlations with other parameters. Coefficient of permeability has linear relationship with consistency index I_C ($R = 0.7862$), bulk density ρ_n ($R = 0.7573$) and degree of saturation S_r ($R = 0.6656$). Coefficient of permeability with liquid limit w_L ($R = 0.6898$) and index of plasticity I_P ($R = 0.65696$) show power relationship and relationship of coefficient of permeability and volumetric moisture content w_o is exponential with $R = 0.6905$. These results confirm the dependence of permeability on the physical state of soil, which is characterized by liquid limit, consistency index and index of plasticity, water content in soil (degree of saturation and volumetric moisture content) and bulk density. Good correlation of the coefficient of permeability with liquid limit, consistency index and index of plasticity indirectly shows its relationship to the clay mineralogy.

6. Differences between clays and loess and loess-like sediments are best seen from triaxial test and oedometric Taylor's method results. Average value of coefficient of permeability obtained by triaxial test k_{10} is 1.37×10^{-10} m.s^{-1} for clays and 5.10×10^{-10} m.s^{-1} for loess and loess-like sediments. Taylor's method yielded average values of k_{400} 1.3×10^{-10} for clays and 2.8×10^{-9} m.s^{-1} for loess and loess-like sediments. This is the result of different structure and origin of loess soils and clays. Even though loess and loess-like soils are also fine-grained sediments containing clay minerals, they possess different properties, which was revealed by differences in permeability and other characteristics such as clay activity. The differences between the two groups in comparison of coefficient of permeability obtained by the triaxial test and oedometric Casagrande method hint that oedometric methods are suitable for clayey soils and could be used only as an informative method for loess and loess-like soils.

This laboratory investigation was an attempt to compare different methods of coefficient of permeability determination and it showed comparability of triaxial and oedometric Taylor's method of coefficient of permeability determination, especially for clay soils. Taylor's method is accurate, reliable alternative method for coefficient of permeability determination, which is in accordance with wide use of Taylor's method in USA (Bowles, 1992). Casagrande's logarithmic method yields lower values of coefficient of permeability.

References

STN 72 1020 Slovak Technical Standard - Laboratory determination of soil permeability. 1990.

STN 72 1027 Slovak Technical Standard - Laboratory determination of soil compressibility in oedometer. 1983.

STN 83 8106 Slovak Technical Standard - Waste disposal. Sealing of the landfills. Design, construction, control and technical requirements. 2004.

GeoFil - Coefficients of permeability, 1996. Software User's manual, Applied Software Consultants, Bratislava p. 27.

Bauman, J., Jørgensen, P., 1997. Are European landfills safe? Proceedings of the Fourteenth International Conference on Soil Mechanics and Foundation Engineering, Hamburg, Vo3. 1, p. 1875-1880.

Bowles, J. E. 1992. Engineering properties of soils and their measurement. International ed. Singapore: McGraw – Hill Book Co, 1992. 241 p. ISBN 0-07-112921-9

Garbulewski, K., Zakowicz, S, Wolski, W., 1995. Laboratory method for testing of the swelling permeability. Proceedings of the Eleventh European Conference on Soil Mechanics and Foundation Engineering, Copenhagen, Vol. 3. 1, p. 77-82.

Head, K.H., 1992. Manual of Soil Laboratory Testing. Vol. 2: Permeability, Shear Strength and Compressibility Tests, 2nd ed. Pentech Press, London UK, 747 p.

Jullien, A., Proust, Ch., Le Forestier, L., Baillif, P., 2002. Hydro-chemio-mechanical coupling effects on permeability and swelling behaviour of a Ca smectite soaked by Cu solutions. Applied Clay Science 21, p. 143-153.

Lambe, T.W., Whitman, R. V., 1969. Soil mechanics, John Wiley & Sons, Inc. New York, 553 p.

Matys, M., Ťavoda, O., Cuninka, M., 1990. Field tests of soils, Alfa, Bratislava, 1990, 303 p. ISBN 80-05-00647-0.

Mucha, I., Šestakov, V. M. 1987. Groundwater hydraulics, ALFA Bratislava 342 p.

Ondrášik, M., 2001. Engineering-geological map compilation Skalica-Holíč, Scale 1:10 000. Final report.

Salai, I., 1984. Trnava – additional water source Rakovice, Geological exploration.

Švábik, J., 2000. Laboratory investigation of sealing properties of material for waste dumps, thesis, Faculty of natural sciences, Comenius Unversity, Bratislava, Slovakia. 71 p.

Wang, J. A., Park, H.D., 2002. Fluid permeability of sedimentary rocks in a complete stress-strain process, Engineering Geology, Volume 63, Issues 3-4, p. 291-300.

Záleský, J., Harvey, A., Stevenson, K., 1995. Comparative tests of permeability of sealing material. Proceedings of Geothechnical problems of environment, Bratislava, Slovakia, p. 293-298.

Upper Jurassic and Lower Cretaceous scleractinian corals from the exotic pebbles - Pieniny Klippen Belt, Slovakian West Carpathians.

MILAN MIŠÍK[1] and ELŻBIETA MORYCOWA[2]

[1]Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina - G, SK-842 15 Bratislava, Slovakia
[2]Institute of Geological Sciences, Jagiellonian University, Oleandry 2a, PL-30-063 Kraków, Poland

Abstract: Totally 23 coral taxa from the exotic pebbles belonging to Upper Jurassic and Lower Cretaceous limestones were identified and compared with coral associations described from 29 states with the purpose to search for the area of their origin.

Key words: corals, Upper Jurassic, Lower Cretaceous, exotic pebbles, Pieniny Klippen Belt, West Carpathians.

Introduction

The Upper Jurassic and Lower Cretaceous scleractinian corals were identified from the exotic limestone pebbles from Upper Cretaceous (Albian-Senonian) conglomerates occurring in Slovakian Peri-Pieniny and Pieniny Klippen Belt, Western Carpathians. They devolopped originally in shallow and warm Tethyan environment.

The collection is composed of several fragmentary coral skeletons. Their dimensions are small, from 1 to several centimetres only. On the basis of about 40 thin-sections, 23 coral taxa were identified (Tab. 1); 13 species and 10 taxa on the generic level only. They represent 20 genera.

This small coral fauna, though poorly preserved and in fragments only, appears similar, though less diversified in species, to those known from the Upper Jurassic and Lower Cretaceous (Urgonian facies) shallow-water facies from the European Tethyan and epicontinental provinces. Some, but not numerous, species are also common with those known from East Europe (Crimea, Caucasus) and Asia, i.e. from Tibet, India, Japan (Tab. 2).

Consideration about the origin of exotic rocks from pebbles.

Described limestone pebbles with corals proceed from the Albian to Senonian polymictic conglomerates of the Pieniny and peri-Pieniny Klippen Belt; they are traditionally named Upohlav Conglomerates. More than hundred types of rocks, predominantly carbonates, were determined (their inventory was summarized by Mišík & Marschalko, 1988, p.100-102). An exotic character is clear in comparison with the rocks of internal adjacent zones - Tatric and Fatric Units, as well as with the neighbouring external one, i.e. Magura Unit, and they are exotic also in the relation to the rocks of the klippen in the Pieniny Klippen Belt.

Typical exotics are: a block of coal with Namurian sporomorphs, blocks of dark Paleozoic quartzose conglomarates, pelagic Triassic limestones with conodonts of Anisian, Ladinian, Carnian, Norian and Rhaetian age (cf. Mišík and Marschalko, 1986, fig. 1; conodonts are totally absent in the neighboring Tatric Zone), Ladinian-Carnian Wetterstein limestones with Dasycladaceae and foraminifers, shallow-water Upper Jurassic limestones with *Protopeneroplis striata, Mohlerina basiliensis*, Urgonian limestones of Barremian-Aptian age with Dasycladaceae (seven species never found in outcrops in the Western Carpathians - Soták & Mišík, 1993), with ophiolite detritus also absent in outcrops of Urgonian limestones (mainly chromian spinels, fragments of serpentinite and glaucophane grains - i.e.the material of subduction mélange and obducted ultrabasic rocks from the upper mantle under oceanic crust, evidenced also by pebbles of gabbro, basalts, andesites and metabasalts BABB with low and high pressure metamorphism). Granite pebbles are different from those of the Central Carpathians. Pebbles of acid volcanic rocks are also absent in the neighbouring zones.

As similar rocks are present in outcrops only in the innermost zones of the Western Carpathians, a contact of Meliata + Silica Units with Peri- pieniny Zone in the pre-Upper Cretaeeous time might be supposed ("Meliata – Pieniny or Meliata-Klape ocean"). In that case a large lateral shift of Central Carpathian Block from the East should take place.

Mišík & Marschalko (1988, fig. 7-9) discussed further possibilities: a long transport of pebbles from SW or S, a transport of lithified conglomeratic bodies by lateral shift from the East.

The direct transport of pebbles during the Albian to Senonian from the Meliata-Silica sedimentation area is excluded from the geological reasons. They cannot be derived from the frontal parts of prograding Silica and Choč nappes, because they arrived in the proximity of the future Klippen Balt only in Lower Turonian.

Localities of exotic-bearing deposits in Slovakia / Species	Vrtižer-n	Vrtižer-III	Nosice-II-f	Nosice-III-c	Chlmec-lom/IIc	Krivá-f	Krivá-i	Krivá-q	Zástranie-Ia	Divinka-g
Amphiaulastrea sp.							▲			
Mitrodendron sp.					▲					
Pleurophyllia sp.	▲					▲				
?*Pleurostylina* sp.				▲						
Aplosmilia semisulcata (Michelin, 1843)		▲								
Stylosmilia corallina Koby, 1881					▲	▲				
Stylosmilia sp.					▲	▲				
Pseudocoenia cf. *slovenica* Turnšek, 1972	▲									
Proaplophyllia sexradiata (Roniewicz, 1966)		▲								
Enallhelia cf. *differencia* Eliašova, 1981	▲									
Apocladophyllia sp.				▲						
Thecosmilia dichotoma Koby, 1884						▲				▲
Clausastrea saltensis Alloiteau, 1960							▲			
Felixigyra patruliusi Morycowa, 1971							▲			
Felixigyra sp.							▲			
Calamophylliopsis moreauana (Michelin, 1843)	▲					▲				
Calamophylliopsis stockesi (M. Edw. et H., 1851)					▲					
Mesomorpha excavata (d'Orbigny, 1849)									▲	
Fungiastraea sp.				▲						
?*Thamnoseris delorenzoi* Prever, 1909			▲							
Latomeandra sp.					▲					
Latiastrea sp.							▲			
Microsolena distefanoi (Prever, 1909)								▲		

Tabl. 1. Mentioned localities with scleractinian corals of exotic-bearing deposits (conglomerates) in Slovakian Pieniny Klippen Belt (Carpathians).

Plašienka (1996 and elswhere) suggested another solution – a large transport of Klape Nappe consisting mainly from Albian strata with conglomerates sliding upon the Middle Cretaceous clastic of Fatric and Tatric units (Poruba. Fm.). The exotic pebbles should proceed from the Veporic elevation (so-called Andrusov Mountains). Naturally, this theory cannot explain the presence of the same exotics in the Eastern Alps (Losenstein Fm.), in the Eastern Slovakia (Proč Conglomerates) and Carpathian Ukraine (Vulchovchik Conglomerates), because Klape Unit is absent there. Numerous rocks such as the huge quantity of dolomites, Urgonian limestones, Namurian coal is not possible to derive from the Meliata space and its frontal parts.

On the other hand, the previous hypothesis about an exotic Pieniny (or Andrusov) Cordillera emerging between Klape and Kysuca-Pieniny sedimentary zones is handicapped by absent evidencies of tectonic movements, metamorphism and volcanic activity during the Lower Cretaceous in the area of future Pieniny Klippen Belt.

The source area of mentioned exotics were probably scales of accreting wedge from the subduction mélange partly emerged as an exotic ridge. Directly on the emerged ridge, sintres and fresh-water limestones with Characeans were formed. Littoral fine-grained conglomerates from the margin were destroyed by continuing raising of the ridge (canibalism). They occur as blocks with pebbles dedolomitized under the hypergenetic conditions. A rich association of sporomorphs and leaves of terrestric plants proved the existence of that dry land. The documentation of these facts is in Mišík & Sýkora (1981).

The crucial question, from what direction the exotic pebbles were transported, can be answered only by detailed study of rocks as well as fossils found in pebbles. We are inclined to favorise the transport from SE. In the eastern part of the Klippen Belt there is frequent pyroclastic admixture in the Berriasian (Proč Conglomerates), as well as in Barremian-Aptian limestone pebbles. Abundant basic volcanism is known in those horizons in Pieniny and Rachov zones of Carpathian Ukraine. Volcanic admixture was found also in pebbles of Middle Liassic and Oxfordian. Volcanic rocks of the same age are known in Rachov Zone, also in Poiana Botizei and in Southern Carpathians. Dasyclad alga *Montiella elitzae* was found only in Georgia, Bulgaria and Romania (Masse & Bucur , 2002) it occurred in an exotic pebble in Slovakia. Foraminifera *Archaelveolina reicheli* was described from the Aptian of Italy and was present in a pebble of Upohlav conglomerates with Barremian fora-

Distribution \ Species	*Microsolena distefanoi* (Prever, 1909)	*Latiastrea* sp.	*Latomeandra* sp.	*Tamnoseris delorenzoi* Prever, 1909	*Fungiastraea* sp.	*Mesomorpha excavata* (d'Orbigny, 1849)	*Calamophylliopsis stockesi* (M. Edw. Et H., 1851)	*Calamophylliopsis moreauana* (Michelin, 1843)	*Felixigyra* sp.	*Felixigyra patruliusi* Morycowa, 1971	*Clausastrea saltensis* Alloiteau, 1960	*Thecosmilia dichotoma* Koby, 1884	*Apocladophyllia* sp.	*Enallhelia* cf. *differencia* Eliašova, 1981	*Proaplophyllia sexradiata* (Roniewicz, 1966)	*Pseudocoenia* cf. *slovenica* Turnšek, 1972	*Stylosmilia* sp.	*Stylosmilia corallina* Koby, 1881	*Aplosmilia semisulcata* (Michelin, 1843)	*?Pleurostylina* sp.	*Pleurophyllia* sp.	*Mitrodendron* sp.	*Amphiaulastrea* sp.
Portugal							▲					▲		△	▲	△			▲				
Spain	▲						▲	▲								△		▲					
Italy	▲						▲																
France				▲		▲	▲	▲		▲	▲							▲	▲				
England							▲																
Switzerland							▲	▲				▲						▲					
Germany				▲		▲	▲			▲		▲						▲					
Austria	▲									▲													
Slovakia																							
Czech Rep.												▲		△		△		▲	▲				
Poland	▲					▲	▲	▲			▲	▲			▲			▲					
Ukraine	▲						▲				▲	▲											
Romania							▲	▲		▲				△	▲			▲	▲				
Hungary	▲															△							
Slovenia	▲						▲			▲	▲	▲			▲	△		▲	▲				
Serbia						▲	▲				△							▲					
Croatia															△			▲					
Greece	▲									▲	▲	△											
Georgia	▲					▲	▲				▲							▲					
Turkmenistan	▲																						
Azerbajdjan	▲																	▲					
Iran																△			△				
Tibet								▲										△					
Japan								△															
Algeria	▲									▲													
Tunisia											▲												
Mexico	▲									▲	▲												
Texas	▲																						
Callovian																|			|				
Oxfordian							|	|				|			|	|		|	|				
Kimmeridgian							|	|				|		|	|	|		|	|				
Tithonian/Portl.							|					|		|				|	|				
Beriasian																							
Valanginian	|																						
Hauterivian	:					|																	
Barremian	|					|				|	|											
Aptian	|					|				|	|	:										
Albianan	|			|						|												
Cenomanian	|			|		|																

Tabl. 2. Geographic and stratigraphic distribution of the Jurassic and Cretaceous scleractinian corals in he Slovakian Pieniny Klippen Belt.

▲ – species identified as certain., Δ and --- : species described as affinis, conformis or doubtful determination.

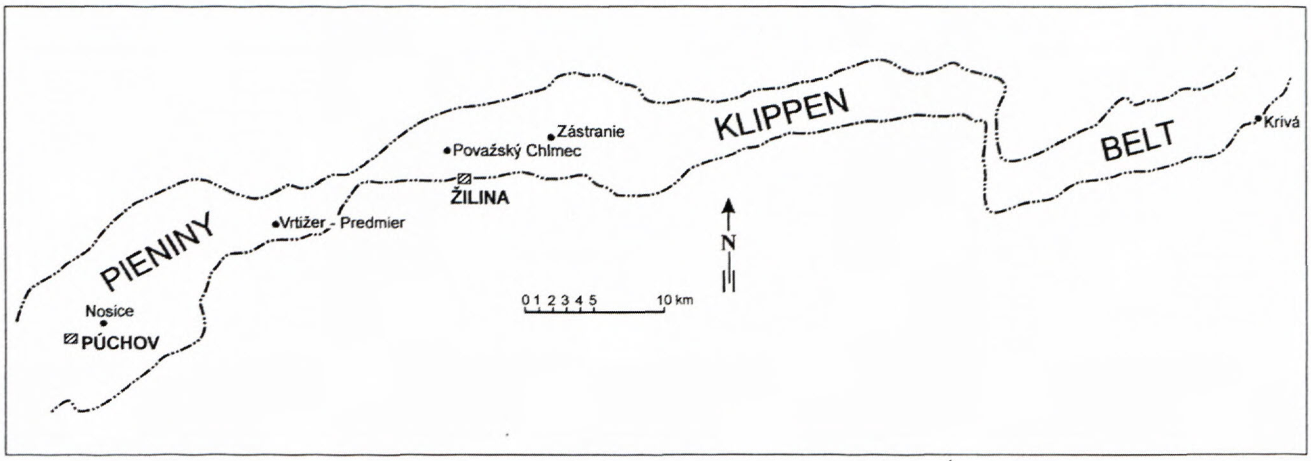


Fig. 1. Topographic map showing the localities (black spots) from which the analysed material was collected.

minifers (Mišík & Sýkora, 1981, p.36). Indication of the source area of exotics can be expected mainly from the detailed study of foraminifers from exotics not realized up till now. We hoped to gain some indications also from the study of corals from the pebbles presented here, but more data from some countries are needed for comparison.

On the other hand some hints might be expected also from the negative conclusions, such as the total absence of Carboniferous and Permian fusulinids, Liassic limestones with *Lithiotis*, *Orbitopsella praecursor*, *Paleodasycladus mediterraneus* etc. among the exotic pebbles, so abundant in the territory of Italia and former Yugoslavia.

Appendix

Description of thin sections of exotic limestones with scleractinian corals (see Fig. 1)

Nosice-II-f (loc. 11, thin section No. 6651). Klape Unit, Albian conglomerates. Probably Urgonian facies (Barremian-Aptian). Previously determined *Microsolena* sp. Unsorted biomicrudite. It contains corals, hydrozoans, bivalvian fragments, brachiopods, coralline algae (including *Lithothamnium* sp.), *Ethelia alba* (Pfender), textularid and encrusting foraminifers including *Kosktinobullina socialis* Cherchi et Schroeder, ostracods, echinoderm plates, spines of echinids.

Recently from the exotic limestones (biomicrite, biointramicrite) from these conglomerate one coral species has been identified, ?*Thamnoseris delorenzoi* Prever. This species is known to now from Early-Mid Cretaceous (Upper Aptian-Lower Cenomanian).

Nosice-III-c (loc. 12 , thin section No. 6661). Klape Unit, Albian- Cenomanian conglomerates. There are corals, thick-shelled bivalvians with original, calcite structure bored by boring algae, some *Bacinella irregularis* Radoičić, *Ethelia alba* (Pfender), ostracods, foraminifers encrusting corals, tubes of serpulid worms, rotalid foraminifers. Admixture of clastic silt quartz (up to 0.15 mm), one grain of chromian spinel and a tiny fragment of serpentinite. The limestones are probably Barremian-Aptian (?).

Vrtižer (loc. 29, thin section No.6336), now Vrtižer-Predmier SE from Považská Teplá. Klape Unit, age of the conglomerate is Senonian. Previously were determined *Stylosmilia* sp., *Calamophylliopsis* sp., *Pleurophyllia* sp. (aff. *minuscula* Kon.). Associated with *Cladocoropsis mirabilis* Felix (partly silicified), *Codiaceae*, echinoderm plates, encrusting foraminifers, problematic algae and bivalvian fragments.

Some scleractinian corals from the same location (Vrtižer-n, No 6983) have been identified, as i.a., *Calamophylliopsis moreauana* (Michelin), *Pseudocoenia* cf. *slovenica* Turnšek and *Enallhelia* cf. *differencia* Eliašova. *Pleurophyllia* sp. and *Stylosmilia* sp. also occur there.

From other thin sections from the exotic limestones (micrite, pelsparite) coming from Vrtižer (Vrtižer-III) the following Late Jurassic scleractinian corals have been identified: *Aplosmilia semisulcata* (Michelin) and *Proaplophyllia* sexradiata (Roniewicz).

The whole Vrtižer coral assemblage indicates Late Jurassic age, more precisely Oxfordian-Tithonian.

Považský Chlmec-c (loc.37, thin section No. 6825). Small quarry, Kysuca-Pieniny Unit, age of the conglomerate - Coniacian. Previously determined *Calamophylliopsis* cf. *stokesi* (Milne Edwards et Haime), photo in Mišík & Sýkora (1981, tab.VI, fig.4). Supposed age according to the coral taxon is Upper Oxfordian - Kimmeridgian. Thin section: Biopelmicrite to biolithite. Corals are partly silicified by the aggregates of quartzine, abundant *Tubiphytes obscurus* Maslov, *Bacinella irregularis* Radoičić, *Aeolisaccus* sp., nubecularid foraminifers , *Koskinobullina socialis* Cherchi et Schroeder, rarely rhaxa (spicules of silicisponges) filled by calcite, single fragments of serpulid tubes,ostracodes, spines of echinids, plate of crinoid, fragment of dasyclad alga, ?*Pseudocyclammina*, fragment of bryozoan. Without terrigenous admixture.

Recently from the Chlmec exotic limestones (biointrasparite; Chlmec-lom/IIc, No 6981) the following coral taxa have been identified: *Mitrodendron* sp., *Stylosmilia corallina* Koby, *Stylosmilia* sp., *Calamophylliopsis stockesi* (M. Edwards et Haime) and *Latomeandra* sp. These coral faunas additionally confirm the Early Jurassic age of the exotic limestones in which they occur.

Zástranie-I-a (loc.42). Kysuca-Pieniny Unit, Coniacian conglomerates. Previously determined *Mesomorpha excavata* (d'Orb.) – occurring from the Hauterivian to Aptian. It is figured in Mišík& Sýkora (1981, tab.X, fig.3). Description of thin section: Urgonian facies Upper Barremian-Lower Aptian. Biosparite to biosparrudite. Abundant *Palorbitolina lenticularis* (Blumenbach), colonial corals; thick bivalvian shells bored by algae *Paleachlya*, rare *Textularia* sp., miliolid, *Ethelia alba* (Pfender) and echinoderm plate.

Divinka-g (loc.35), Kysuca-Pieniny Unit, Coniacian conglomerates. Previously determined *Thecosmilia* cf. *dichotoma* Koby. In association *Clypeina jurassica* Favre was found. Evidently Kinmeridgian-Tithonian. Lately other specimens of *Thecosmilia dichotoma* Koby have been found there (thin section No 7603).

Krivá-f-railway (loc.55). Klape Unit, Cenomanian-Turonian conglomerates. Light grey biohermal limestone. In the thin sections abundant recrystallized corals, rare *Bacinella irregularis* Radoičić and a gastropod. The preliminary determination of corals (*Calamophylliopsis* sp., *Complexastraea* sp. and *Thecosmilia* sp., mentioned in Misik& Sykora 1981) has now been made more precise: *Calamophylliopsis moreauana* (Michelin), *Thecosmilia dichotoma* Koby. Moreover *Pleurophyllia* sp., *Stylosmilia corallina* Koby and *Stylosmilia* sp. have been identified. The corals indicate Late Jurassic age.

Krivá-i the dark grey exotic limestones (micrite, pelmicrite) with corallum fragments. The following taxa have been distinguished: *Amphiaulastrea* sp., *Clausastrea saltensis* Alloiteau, *Felixigyra patruliusi* Morycowa, *Felixigyra* sp. and *Latiastraea* sp. These taxa are known from Lower Cretaceous, more exactly from Barremian-Aptian.

Krivá-q (the same locality No. 55). Previously determined *Microsolena distefanoi* (Prever), stratigraphic span Barremian to Cenomanian. It is probably Urgonian facies (Barremian-Aptian; Mišik, 1990, p. 34). Coral limestone biomicrudite to biolithite. Only coral skeleton in the thin section, partly silicified.

References

Bassoullet, J.-P., Fourcade, E. & Peybernes, B., 1985: Paléogéographie des grands foraminifères benthic des marges néo-tethysienne au Jurassique et au Crétacé inférieur. *Bull. Soc. Géol. France*, 8, t.I, 5, 699-713.

Mišík, M., 1990: Urgonian facies in the West Carpathians. *Knihovnička Zemniho plynu a nafty*, sv. 9a. Biostratigrafické a sedimentologické studie v mezozoiku Českého masivu Západnich Karpat, 25-54.

Mišík, M., M. & Marschalko, R., 1988: Exotic conglomerates in flysch sequences: examples from the West Carpathians. In: Rakús, M., Dercourt, J., Nairn, A.R.M. (eds.): Evolution of the Northern Margin of Tethys. *Mém. Soc. Géol. France*, N.S., 154, 95-113.

Mišík M. & Sýkora M., 1981: Pieninský exotický chrbát rekonštruovaný z valúnov karbonátových hornín kriedových zlepencov bradlového pásma a manínskej jednotky. Der pieninische exotische Rücken, rekonstruiert aus Geröllen karbonatischer Gesteine kretazischen Konglomerate der Klippenzone und der Manín-Einheit. *Západné Karpaty, sér.geológia*, 7, 7-111.

Morycowa, E. & Mišík, M., in press: Late Jurassic shallow-water scleractinian corals from the Pieniny Klippen Belt (Western Carpathians, Slovakia). *Geol. Carpath.*

Plašienka, D., 1996: Kryptické chrbty, alebo kolízne orogénne pásma? *Miner. Slov.*, 28, 75-79.

Soták, J. & Mišík, M., 1993: Jurassic and Lower Certaceous dasycladalean algae from the Western Carpathians. In: F. Barattolo et al. (eds.): Studies on Fossil Benthic Algae. *Boll. Soc. Paleont. Ital.*, sp.Vol., 1, 383-404.

Slovak Geol. Mag., 10, 4 (2004), 313 – 321

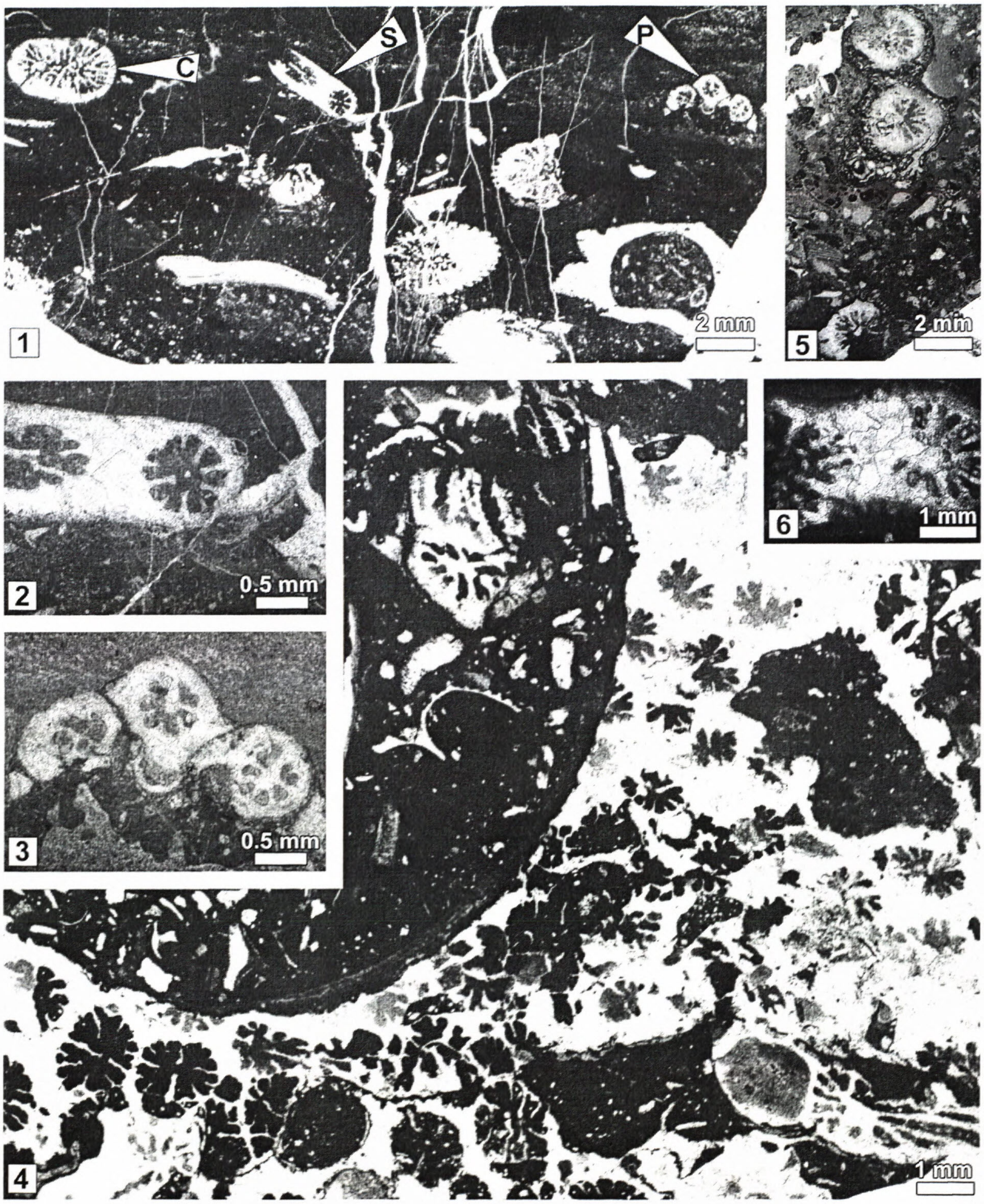
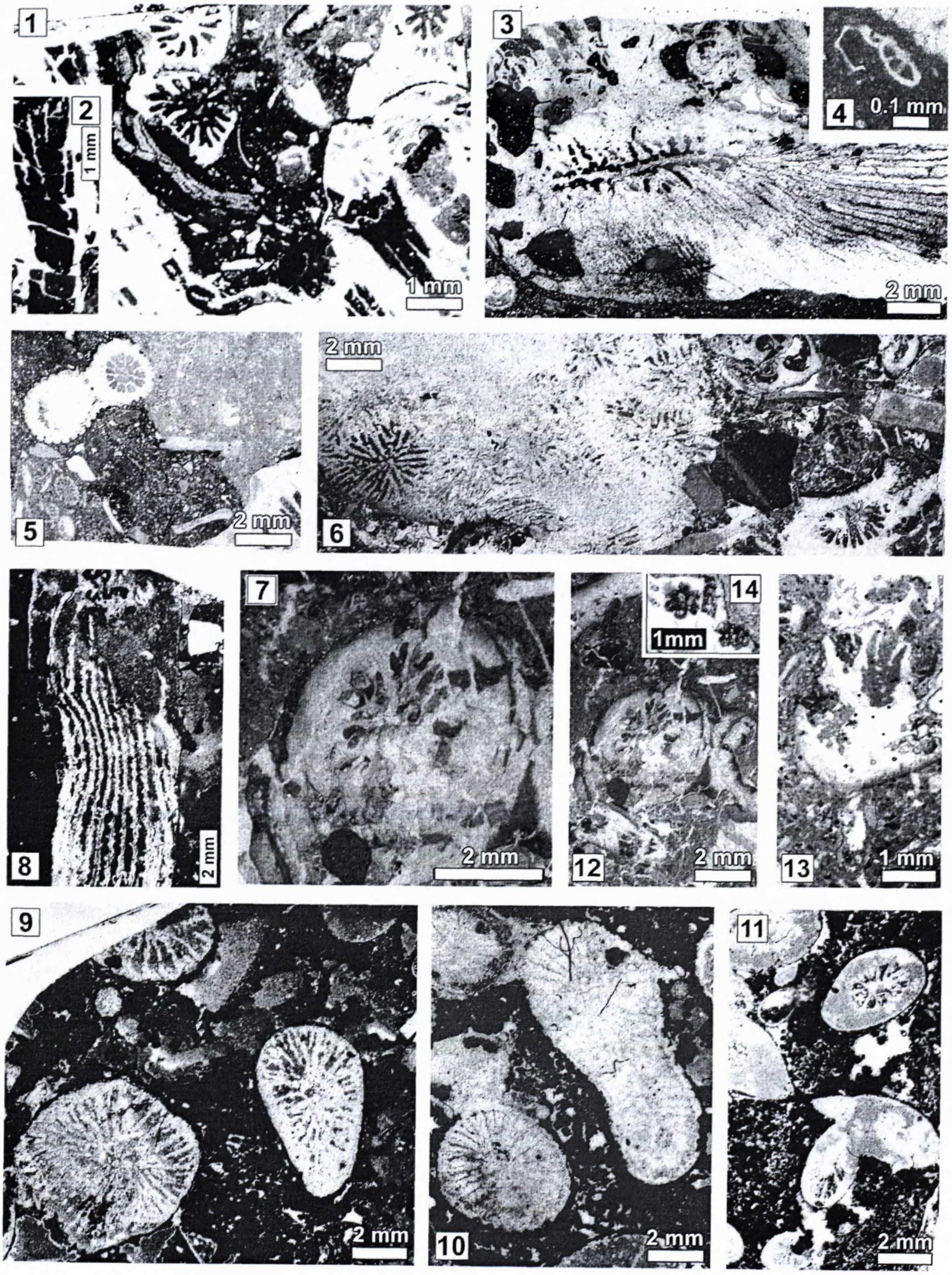


Fig. 2: 1. Fragments of scleractinian corals in micritic limestone from Krivá-f conglomerate; C- *Calamophylliopsis moreauana* (Michelin), E- *Stylosmilia* sp., P- *Pleurophyllia* sp.; 2- enlarged corallite branch (S) from Fig. 2:1 showing hexameral septal symmetry and small styliform columella; 3- enlarged fragment of three corallites marked in Fig. 2:1 as P. Note very small diameter of corallites and bilateral symmetry of their septa, 4- *Pleurostylina* sp., Nosice-III-c, fragment of cerioid colony in transverse section. Note the fragment of *Apocladophyllia* branch in the micrite (at the top of the picture); 5- *Stylosmilia corallina* Koby, Krivá-f, transverse section; 6- transverse section of *Calamophylliopsis* fragment from the limestone pebble from Krivá-f.

Fig. 3: 1, 2 – *Apocladophyllia* sp, Nosice-III-c, transverse section of corallites (in 1) and longitudinal one (in 2); 3 – *Aplosmilia semisulcata* (Michelin), Vrtižer-III, transverse, slightly oblique section of corallite; 4 – *Globotruncana*-like form occurring in the conglomerate matrix near *A. semisulcata*; 5 – *Proaplophyllia sexradiata* (Roniewicz) in same limestone pebble; 6 – *Latiastrea* sp., Krivá-i, transverse section of colony. Note in lower right-hand corner a corallite representing *Amphiaulastrea* genus; 7 – *Mitrodendron* sp., Chlmec-lom/IIc, transverse section of corallite; 8 – *Calamophylliopsis stockesi* M. Edwards & Haime,



same site, one corallite fragment in longitudinal section; 9 – *Latomeandra* sp., same site, transverse thin section of several corallites, 10 – *Calamophylliopsis stockesi*, same site, transverse section of corallites; 11– *Stylosmilia corallina* Koby, same site, corallites in transverse section; 12 – one corallite of *Mitrodendron* sp. (same section as in 7) with small branch fragment of *Stylosmilia* sp.. *Enallhelia* cf. *differencia* Eliašova, Vrtižer-n, longitudinal-oblique section of the fragment of branching colony.

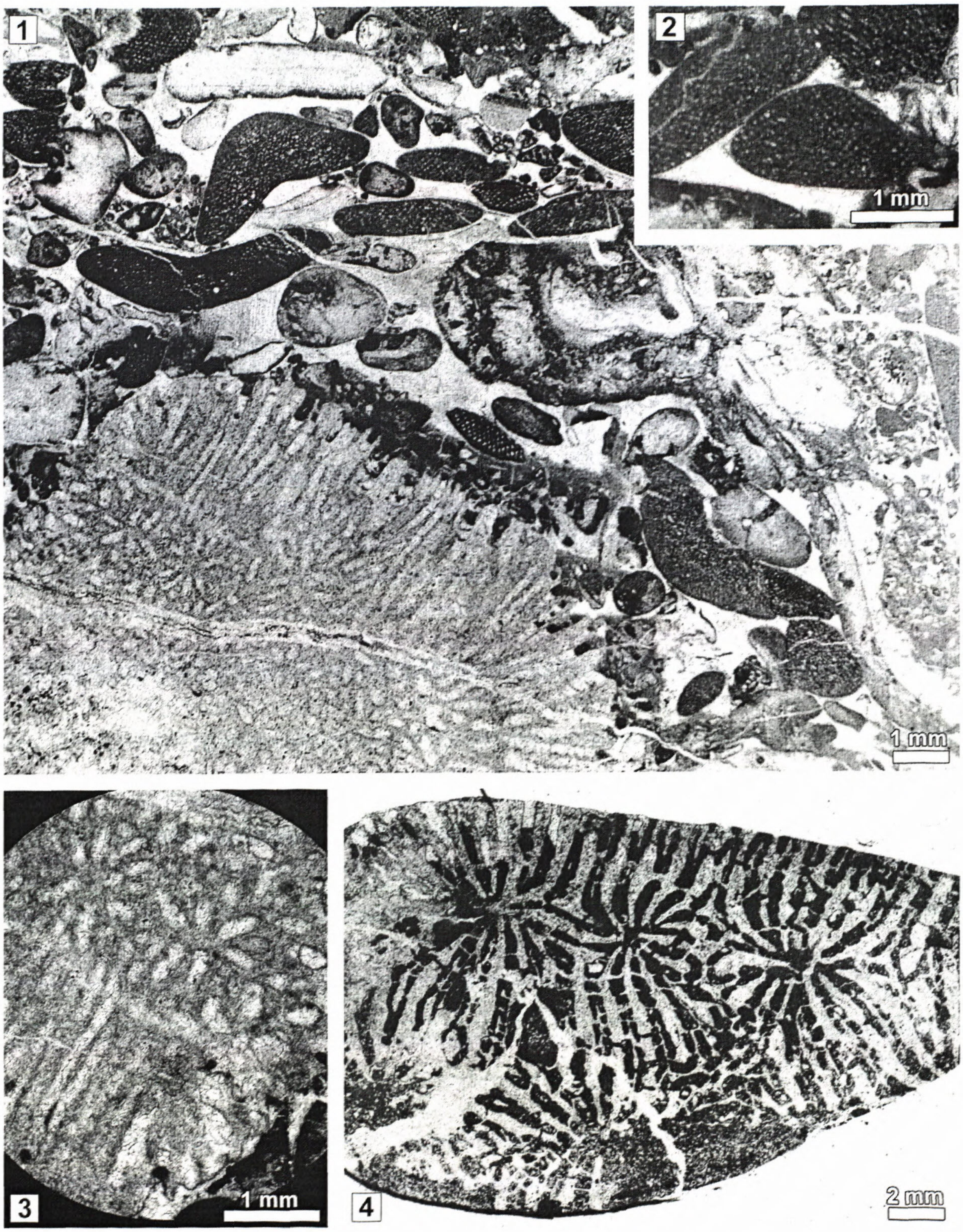


Fig. 4: 1 – 3. Biointrasparite with abundant bentic foraminiferids (such as *Orbitolina* sp.) and small thamnasterioid-subcerioid coral colony *Mesomorpha excavata* (d'Orbigny), Zástranie-Ia: 2 – some orbitolinids from thin section, a part of which is presented in 4:1; 3 – enlarged fragment of coral colony from Fig. 4:1; 4 – transverse thin section of *Clausastrea saltensis* Alloiteau, Krivá-i.

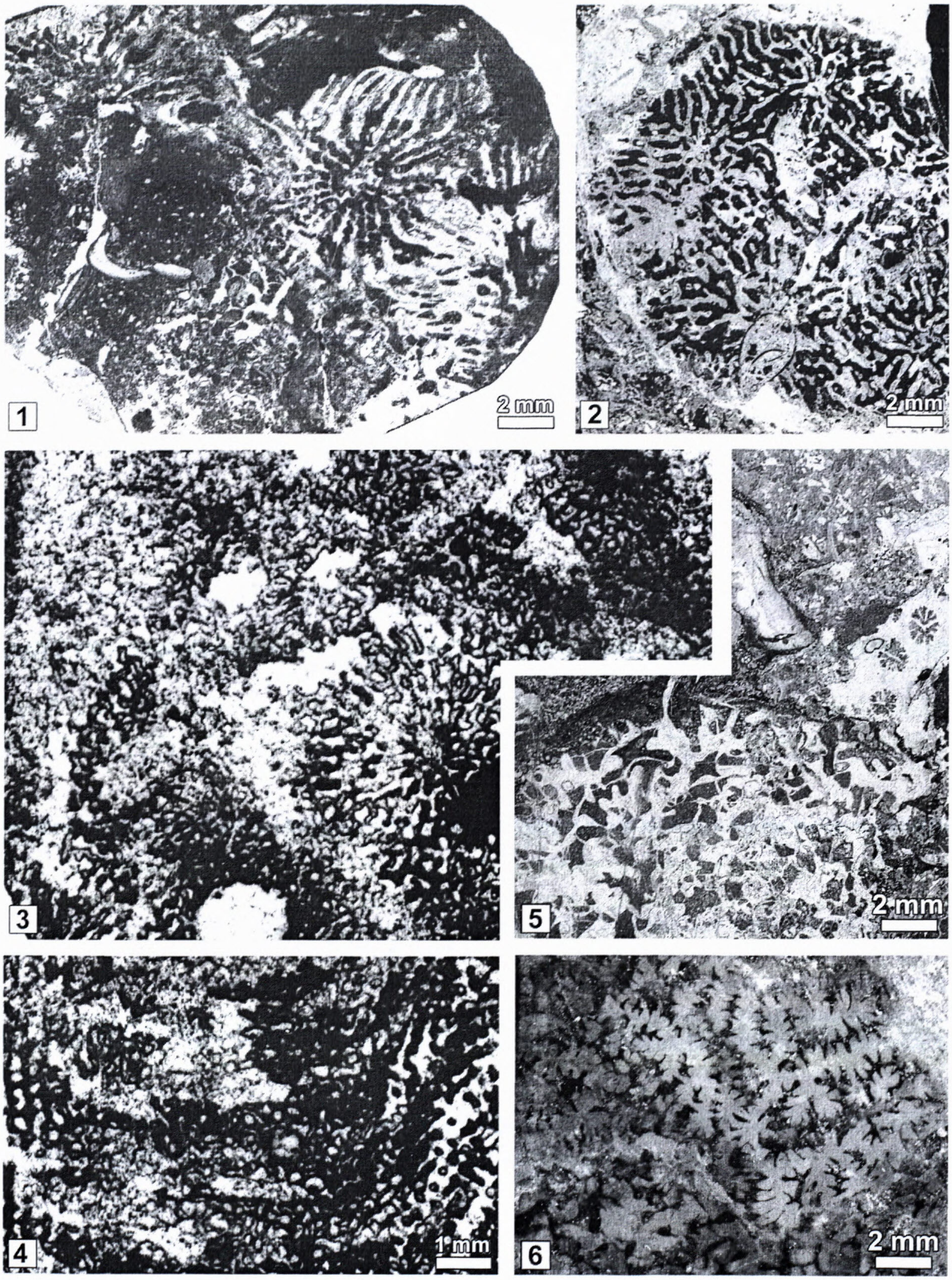


Fig. 5: 1– *Fungiastraea* sp., Nosice-IIIc; transverse section of a fragment of a colony; 2 – *Thamnoseris delorenzoi* Prever, Nosice-II f, transverse thin section of the small colony; 3, 4 – *Microsolena distefanoi* (Prever), Krivá-q: 3 – transverse section, 4 – longitudinal section of colony fragment; 5 – *Felixigyra* sp. and small portion of the stylinid colony; 6 – *Felixigyra patruliusi* Morycowa, Krivá-i, transverse thin section of the fragment of meandroid-hydnophoroid colony.

Comments to the papers:

Depositional systems of the Northern Vienna Basin

by I. BARÁTH, I. HLAVATÝ, M. KOVÁČ and N. HUDÁČKOVÁ
(Slovak Geol. Magazine 9/4, 2003, 237 – 239)

and

Miocene depositional systems and sequence stratigraphy of the Vienna Basin

by M. KOVÁČ, I. BARÁTH, M. HARZHAUSER, I. HLAVATÝ and N. HUDÁČKOVÁ
(Cour. Forsch.-Inst. Senckenberg 246, 2004, 187 – 212.

The authors of both papers applying the sedimentologic and biostratigraphic analyses and by the interpretation of well-logs and seismic lines using the seismic stratigraphy methods present a very complex model of the Vienna Basin Neogene evolution and the distribution of sedimentary facies inside the basin. The slack handling with the lithostratigraphic terminology spoils the really excellent image of both papers.

First of all the authors do not hold on one of the basic rule of the lithostratigraphic subdivision. The member as a low rank lithostratigraphic unit "is a subdivision of a formation and must be a part of a formation" (Cox and Sumbler in Doyle and Bennett, 1998, p. 18.). In both mentioned papers the members are described as independent units. For example the Štefanov Member (a delta) was "flooded and covered by the Lužice basinal clays" (Baráth et al. 2003, p. 237). Basinal clays and/or marls are dominant lithotypes of the Lužice Formation. The offshore Lužice Formation itself is described as a lithostratigraphic unit having their own coarse clastics even of brackisch environment (Kováč et al. 2004, p. 192). From such kind of description a reader is assured the coarse clastics as Štefanov, Brezová, Chropov, Winterberg members contemporaneous with the Lužice Formation are not members of that formation, even they are not framed by any formation.

According to the priority law the formal name Brezová Member (in sense of Buday 1955) is void, because Kodym and Matějka (1923) described the member as Podbranč Conglomerate. The formal name of Štefanov Member is controversial and would be omitted. That name was introduced into literature by an unhappy way. Buday in a paper published in 1955 described the Štefanov Sand, Early Helvetian (= Ottnangian) in age and Štefanov Member (multicoloured clay with sand/sandstone intercalations), Late Helvetian (= Karpatian) in age. Later on Buday abandoned the Štefanov Sand and referred to Štefanov Member Karpatian in age (Buday in Andrusov and Samuel 1985). By my opinion the valid formal name of the controversial Štefanov Sand (and/or Member), Ottnangian in age is Hodonín Sand commonly used by unformal way in many manuscripts of the oil geologists and formally introduced by Jířiček and Seifert (1990).

The names of lithostratigraphic units as Láb Ostracoda Member or Kúty Anhydrite Member are unformal and formal ones have replaced them: Láb Member, Kúty Member (Vass 2002).

The nouns usually names of villages as Láb, Studienka, Aderklaa could not be used in formal names of two different lithostratigraphic units. In both papers the rule is neglected in cases as Láb Ostracoda Member (a deltaic-lagoonal member, Karpatian in age) and Láb Member (a sand sheet, Badenian in age), Studienka Sand (littoral deposits, Middle Badenian in age) and Studienka Clay Formation of the Late Badenian, Aderklaa Formation of Late Karpatian and Aderklaa Conglomerate of Early Badenian (both units are in the Austrian part of Vienna Basin)

The deposits described by Bartek (1989) as Záhorie Formation, latter on redefined as Záhorie Member (Vass 2002) in the chronostratigraphic scale correspond to Pannonian, zone E, in sense of Papp, (1951). The Záhorie Member could not be attributed to the Early Pannonian as it is done in both papers.

The Devínska Nová Ves Member was defined as a set of olistostromes, eventually the debris aprons, locally redeposited by a short fluvial transport forming alluvial cones (Vass et al. 1988). The pure alluvial origin attributed to the member by Kováč et al. 2004 is dubious.

The Čáry Formation was described by Bartek (1989) and not by Kováč et al. (1998) as is mentioned in Kováč et al.(2004).

The freedom without any restriction in the lithostratigraphic terminology is the way to a hell of chaos. To avoid the misunderstanding and to hamper the anarchy in West Carpathian´s lithostratigraphy a national Slovak commission for stratigraphy must be created, or better to say resurrected as soon as possible. The Slovak universities, the both geological institutes of Slovak Academy of Sciences and State D. Štúr Geological Institute are predestined to create such a commission a competent and inventional successor of the famous Slovak lithostratigraphic tradition expressed by three volumes of Slovak Stratigraphic Dictionary of D. Andrusov and O. Samuel eds. (1983, 1985 and 1988).

Dionýz Vass

Instructions for authors

Slovak Geological Magazine – periodical of the Geological Survey of Slovak Republic is quarterly presenting the results of investigation and researches in wide range of topics: regional geology and geological maps, lithology and stratigraphy, petrology and mineralogy, paleontology, geochemistry and isotope geology, geophysics and deep structure, geology of deposits and metallogeny, tectonics and structural geology, hydrogeology and geothermal energy, environmental geochemistry, engineering geology and geotechnology, geological factors of the environment, petroarcheology.

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

General instructions

The Editorial Board of the Geological Survey of Slovak Republic – Dionýz Štúr Publishers accepts manuscripts in correct English. The papers that do not have sufficient accuracy in language level will be submitted back for language correction.

The manuscript should be addressed to the Chief Editor or the Managing Editor.

Contact address:

Geological Survey of Slovak Republic – Dionýz Štúr Publishers, Mlynská dolina 1, 817 04 Bratislava, Slovak Republic
e-mail addresses: hok@gssr.sk
siposova@gssr.sk
http://www:gssr.sk

The Editorial Board accepts or refuses a manuscript with regard to the reviewer's opinion. The author is informed of the refusal within 14 days from the decision of the Editorial Board. Accepted manuscript is prepared for publication in an appropriate issue of the Magazine. The author(s) and the publishers enter a contract establishing the rights and duties of both parties during editorial preparation and printing, until the time of publishing of the paper.

Text layout

The manuscript should be arranged as follows: TITLE OF THE PAPER, FULL NAME OF THE AUTHOR(S); NUMBER OF SUPPLEMENTS (in brackets below the title, e.g. 5 figs., 4 tabs.), ABSTRACT (max. 30 lines presenting principal results) – KEY WORDS – INTRODUCTION – TEXT – CONCLUSION – ACKNOWLEDGEMENTS – APPENDIX – REFERENCES – TABLE AND FIGURE CAPTIONS – TABLES – FIGURES. The editorial board recommends to show a localisation scheme at the beginning of the article.

The title should be as short as possible, but informative, compendious and concise. In a footnote on the first page, name of the author(s), as well as his (their) professional or private address.

The text of the paper should be logically divided. For the purpose of typography, the author may use a hierarchic division of chapters and sub-chapters, using numbers with their titles. The editorial board reserves the right to adjust the type according to generally accepted rules even if the author has not done this.

Names of cited authors in the text are written without first names or initials (e.g. Štúr, 1868), the names of co-authors are divided (e.g. Andrusov & Bystricky, 1973). The name(s) is followed by a comma before the publication year. If there are more authors, the first one, or the first two only are cited, adding et al. and publication year.

Mathematical and physical symbols of units, such as %, ‰, °C should be preceded by a space, e.g. 60 %, 105 °C etc. Abbreviations of the units such as second, litre etc. should be written with a gap. Only SI units are accepted. Points of the compass may be substituted by the abbreviations E, W, NW, SSE etc. Brackets (parentheses) are to be indicated as should be printed, i.e. square brackets, parentheses or compound. Dashes should be typed as double hyphens.

If a manuscript is typed, 2 copies are required, including figures. The author should mark those parts of a text that should be printed in different type with a vertical line on the left side of the manuscript. Paragraphs are marked with 1 tab space from the left margin, or by a typographic symbol. Words to be emphasized, physical symbols and Greek letters to be set in other type (e.g. *italics*) should be marked. Greek letters have to be written in the margin in full (e.g. *sigma*). Hyphens should be carefully distinguished from dashes.

Tables and figures

Tables will be accepted in a size of up to A4, numbered in the same way as in a text.

Tables should be typed on separate sheets of the same size as text, with normal type. The author is asked to mark in the text where the table should be inserted. Short explanations attached to a table should be included on the same sheet. If the text is longer, it should be typed on a separate sheet.

Figures should be presented in black-and-white, in exceptional cases also in colour which must be paid approx. 100 EUR per 1 side A 4. Figures are to be presented by the author simultaneously with the text of the paper, in two copies, or on a diskette + one hard copy. Graphs, sketches, profiles and maps must be always drawn separately. High-quality copies are accepted as well. Captions should be typed outside the figure. The graphic supplements should be numbered on the reverse side, along with the orientation of the figures. Large-size supplements are accepted only exceptionally. Photographs intended for publishing should be sharp, contrast, on shiny paper. High quality colour photographs will only be accepted depending on the judgement of the technical editors.

If a picture is delivered in a digital form, the following formats will be accepted: *.cdr, *.dxf, *.bmp, *.tiff, *.wpg, *.fga., *.jpg *.gif, *.pcx. Other formats are to be consulted with the editors.

References

Should be listed in alphabetical and chronological order **according to annotation in the text** and consist of all references cited.

Standard form is as follows: 1. Family name and initials of author(s), 2. Publication year, 3. Title of paper, 4. Editor(s), 5. Title of proceedings, 6. Publishers or Publishing house and place of publishing, 7. Unpublished report – manuscript should be denoted MS. Unpublished paper can appear as personal communications only. 8. Page range

Quotations of papers published in non-Latin alphabet or in languages other than English, French, Italian, Spain or German ought to be translated into English with an indication of the original language in parentheses, e.g.: (in Slovak).

Example:

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

Beránek, B., Leško, B. & Mayerová, M., 1979: Interpretation of seismic measurements along the trans-Carpathian profile K III. In: Babuška, V. & Plančár, J. (Eds.): *Geodynamic investigations in Czecho-Slovakia*. Bratislava: VEDA, p. 201-205.

Lucido, O., 1993: A new theory of the Earth's continental crust: The colloidal origin. *Geol. Carpathica*, vol. 44, no. 2, p. 67-74.

Pitoňák, P. & Spišiak, J., 1989: Mineralogy, petrology and geochemistry of the main rock types of the crystalline complex of the Nízke Tatry Mts. MS – Archiv GS SR, Bratislava, 232 p. (in Slovak).

Proofs

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

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

Final remarks

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

1. Editorial Board reserves the right to publish preferentially invited manuscript and to assemble thematic volumes,
2. Sessions of Editorial Board – four times a year and closing dates for individual volumes will be on every 31[th] day of March, June, September and December.
3. To refer to one Magazine please use the following abbreviations: *Slovak Geol. Mag.*, vol. xx, no. xx. Bratislava: D. Štúr. Publ. ISSN 1335-096X.

Indexed/Abstracted in: Chemical Abstracts, Ulrich's International Periodical