1 C 66 b

GUDŠ

# SLOVAK GEOLOGICAL MAGAZINE

DIONÝZ ŠTÚR PUBLISHERS, BRATISLAVA

3-4/96

SLOVAK GEOLOGICAL MAGAZINE

ISSN 1335-96X

# *SLOVAK GEOLOGICAL MAGAZINE*

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

- **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**

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

**Editor in Chief:** JOZEF VOZÁR

**Editorial Board:**

| INTERNAL MEMBER | | EXTERNAL MEMBERS | |
|---|---|---|---|
| Vladimír **Bezák** | Peter **Kováč** | Dimitros **Papanikolaou** | Athens |
| Dušan **Bodiš** | Jaroslav **Lexa** | Franz **Neubauer** | Salzburg |
| Michal **Elečko** | Ján **Mello** | Jan **Veizer** | Bochum |
| Milan **Gargulák** | Milan **Polák** | Franco Paolo **Sassi** | Padova |
| Pavol **Grecula** | Michal **Potfaj** | Niek **Rengers** | Enschede |
| Vladimír **Hanzel** | Miloš **Rakús** | Géza **Császár** | Budapest |
| Jozef **Határ** | Dionýz **Vass** | Miloš **Suk** | Brno |
| Michal **Kaličiak** | Anna **Vozárová** | Zdeněk **Kukal** | Praha |
| Alena **Klukanová** | | | |

**Managing Editor**: J. HRTUSOVÁ
**Language review and translation:** K. JANÁKOVÁ
**Technical Editor:** G. ŠIPOŠOVÁ
**Address of the publisher:** GEOLOGICAL SURVEY OF SLOVAK REPUBLIC, MLYNSKÁ DOLINA 1, 817 04 BRATISLAVA, SLOVAKIA
**Typography:** G. ŠIPOŠOVÁ
**Printed at:** DUAD-Print Bratislava
**Price of single issue:** USD12
**Annual subscription rate:** USD 48 (4 issues) The price include the postage
© Edition of Geological Survey of Slov[illegible] Bratislava, SLOVAKIA

Ústredná geologická knižnica SR
ŠGÚDŠ



3902001018572

# SLOVAK GEOLOGICAL MAGAZINE

DIONÝZ ŠTÚR PUBLISHERS, BRATISLAVA

3-4/96

GEOLOGICKÁ SLUŽBA SLOVENSKEJ REPUBLIKY
INFORMAČNÉ STREDISKO
Bratislava

© Geological Survey of Slovak Republic, Bratislava 1996

SLOVAK GEOLOGICAL MAGAZINE

# Contents

SIMAN, P., MADARÁS, J., KOVÁČIK, M., SCHULMANN, K. & LEDRU, P.: Petrogenetic relationship between deformation and alteration on the example of the extension tectonics of the Veporicum crystalline basement (Central Western Carpathians) 175

MADARÁS, J., HÓK, J., SIMAN, P., BEZÁK, V., LEDRU, P. & LEXA, O.: Extension tectonics and exhumation of crystalline basement of the Veporicum unit (Central Western Carpathians) 179

BEZÁK, V., HURAI, V. & KRÁĽ, J.: A fluid inclusion analysis contribution to the study of tectono-metamorphic evolution of the Veporicum crystalline complex 185

LEXA, O., & BEZÁK, V.: Porphyric granitoids in the western part of the Slovenské rudohorie Mts.: Emplacement and deformation in shear zones 189

IVAN, P., HOVORKA, D. & MÉRES, Š.: Gabbroid rocks - a newly-found member of the leptyno-amphibolite complex of the Western Carpathians 199

MÉRES, Š. & HOVORKA, D.: Genetic relationship of greenschists and amphibolites in Veporicum of the Nízke Tatry Mts. 205

SIMAN, P., JOHAN, V., LEDRU, P., BEZÁK, V. & MADARÁS, J.: Deformation and p-T conditions estimated in "layered migmatites" from southern part of Veporicum crystalline basement (Western Carpathians; Slovakia) 209

KOVÁČIK, M.: Alpine metamorphism of Southern Veporicum - an evolution model and the problem of correlation with the Eastern Alps 215

PUTIŠ, M., MADARÁS, J., KORIKOVSKY, S. P., KOTOV, A. B. & FILOVÁ, I.: Ductile deformation and recrystallization of the Variscan magmatic complex in the hanging wall of Cretaceous thrust (Veporic unit, Central Western Carpathians) 221

IVAN, P.: Problems of geodynamic evolution and geological structure of the Paleozoic gemeric Unit (Inner Western Carpathians) as inferred by magmatic rock study 239

VOZÁROVÁ, A. & IVANIČKA, J.: Geodynamic position of acid volcanism of the Gelnica Group (Early Paleozoic, Southern Gemericum; Inner Western Carpathians) 245

VOZÁROVÁ, A.: Tectono-sedimentary Evolution of Late Paleozoic Basins based on Interpretation of Lithostratigraphic Data (Western Carpathians; Slovakia) 251

SOTÁK, J. & PLAŠIENKA, D.: Upper Triassic - Lower Jurassic sediments of the Lučatín Unit in the Northern Veporicum: facial diversity and tectonic stacking 273

PLAŠIENKA, D. & PROKEŠOVÁ, R.: Towards an evolutionary tectonic model of the Krížna cover nappe (Western Carpathians, Slovakia) 279

PLAŠIENKA, D. & SOTÁK, J.: Rauhwackized carbonate tectonic breccias in the West Carpathian nappe edifice: introductory remarks and preliminary results 287

POLÁK, M., HAVRILA, M., FILO, I. & PEVNÝ, J.: Gader Limestones - a new lithostratigraphic unit of the Hronicum in the Veľká Fatra Mts. and its extension in the Western Carpathians. 293

RAKÚS, M.: Jurassic of the innermost Western Carpathian zones - its importance and influence on the geodynamic evolution of the area 311

PLAŠIENKA, D.: Mid-Cretaceous (120-80 Ma) orogenic processes in the Central Western Carpathians: brief review and interpretation of data ____ 319

MICHALÍK, J., REHÁKOVÁ, D. & JABLONSKÝ, J.: Geodynamic setting of fluxoturbidites in West Carpathian Upper Jurassic and Lower Cretaceous sedimentary basins ____ 325

IVAN, P. & KRONOME, B.: Protolith and geodynamic setting of the HP/LT metamorphosed basic from the northern margin of the Bôrka nappe (meliatic Unit Inner Western Carpathians) ____ 331

HAVRILA, M. & OŽVOLDOVÁ, L.: Meliaticum in the Stratenská hornatina Hills ____ 335

SPIŠIAK, J.: Volcanism in the Mesozoic of the Outer and Central Western Carpathians ____ 341

SOTÁK, J., BEBEJ, J. & BIROŇ, A.: Detrital Analysis of the Paleogene flysch deposits of the Levoča Mts.: evidence for sources and paleogeography ____ 345

HUDÁČKOVÁ, N., KOVÁČ, M., SITÁR, V., PIPÍK, R., ZÁGORŠEK, K. & ZLINSKÁ, A.: Neogene tectono-sedimentary megacycles in the Western Carpathians basins, their biostratigraphy and paleoclimatology ____ 351

VASS, D., TÚNYI, I., MÁRTON, E.: Young Tertiary rotation of the megaunit Pelso and neighbour units of the West Carpathians. ____ 363

SZALAIOVÁ, V., ŠANTAVÝ, J.: Gravimetric map of the western part of Slovakia and its possible interpretations ____ 369

# Preface

*The Geodynamic Development of the Western Carpathians represents a topical national widely spectral geological project, the essence of which since the year 1991 has been the study of the individual development stages of the Variscan and Alpine orogen in the Western Carpathian region. In solution the Project had two time stages (1991-1993, 1994-1997), which in concrete shape are finished by presentation of latest knowledge, in form of particular reports, numerous thematical seminars, lectures at conferences at home and abroad, congresses and numerous publications.*

*The Project Geodynamic Development of the Western Carpathians included the activity of the wide geological community of Slovakia in relation to international projects (IGCP), associations of IUGS (INQUA, IAS, IAVCEI, CBGA) and IGC.*

*In solution of topical problems of the Project mainly the former Dionýz Štúr Institute of Geology (till the year 1995), now the Geological Survey of the Slovak Republic, the Geological Institute of the Slovak Academy of Sciences, the Natural Sciences Faculty of the Comenius University, also in cooperation with Geocomplex, a.s., the Geophysical Institute of the Slovak Academy of Sciences and VVNP - Research Oil Company for Exploration and Production, were mainly taking part.*

*The choice of latest knowledge presented in the frame of the Project Geodynamic Development of the Western Carpathians in the year 1996, i.e. in the last year of solution we present for the professional community in the Slovak Geological Magazine no. 3-4/96.*

*The results of the Project were lectured at the seminar and the corrections of the reviewers do not influence the author's rights.*

*M. Rakús, J. Vozár*

SLOVAK GEOLOGICAL MAGAZINE

# Petrogenetic relationship between deformation and alteration on the example of the extension tectonics of the Veporicum crystalline basement (Central Western Carpathians)

PAVOL SIMAN[1], JÁN MADARÁS[1], MARTIN KOVÁČIK[1], KAREL SCHULMANN[2] & PATRICK LEDRU[3]

[1] Geological Survey of Slovak republic, Mlynská dol. 1, 817 04 Bratislava, Slovakia
[2] Fac. of the Natural Sciences, Charles Univ., Albertov 6, 128 00 Prague, Czech rep.
[3] BRGM, BP 6009, 45060, Orléans, France

*Abstract:* The conditions of the deformation in the Veporicum crystalline basement are estimated at middle to upper greenschist facies or the lower part of amphibolite facies; according to these first results, max. T reached approximatelly ~ 450-500°C at P~ 3-4 kbar. The observations from the Permo-Mesozoic cover sediments suggest that deformation occurred in the greenschist facies conditions at a temperature estimated at 350°C (max. 450°C according to crystal plasticity of quartz in the eastern part ), or only at anchimetamorphism. Our observations suggest that the major paragenetic transformations reflect probably the strong Alpine overprint. We assume that only relics of higher metamorphosed rocks from the so-called "hybridic complex" in the southern part of the Veporicum basement could bear records of Late - Hercynian events.

*Key words:* Central Western Carpathians, Veporicum unit, crystalline basement, sedimentary cover, regional metamorphism, metamorphic alteration, paragenetic transformation.

## Introduction

The evolution of polyorogenic and polymetamorphic regions is perhaps one of the most discussed uestions in present petrological studies. The Western Carpathians as a part of the extensive Alpine - Carpathian orogenic belt comprise more or less conserved older units. These were, as relic structures, incorporated into the comprehensive framework during the Alpine orogeny.

The Veporicum is an internal part of the central domain of the Western Carpathians and it is an area which consisting of several, differently old tectonicaly approached units.

This short explanation is focused on a very simplified scheme of the metamorphic alterations in the Veporicum crystalline basement during its reworking into the present state.

## Localisation of deformation and petrogenetic implications in the basement

Several rocks types occur in the Veporicum crystalline basement, however, this paper discusses the phase relationships in some granitoids and gneisso-migmatitic rocks in the central and southern parts.

The primary rock-forming mineral assemblages are unstable, recrystallised and replaced due to heterogeneous deformation with grain - size reduction and generally with retrogression. (Fig. 1).

*K-feldspar* - porphyroblasts in granitoids (partly in "migmatites") are replaced, at first by myrmekitic structures probably associated with strain features. SIMPSON & WINTSCH (1989) showed that myrmekites may form only on the sides of K-feldspar facing the shortening direction. Subsequently they were replaced by perthitic zones associated with partial recrystallisation on the grain boundary. The frequently brittle behaviour of K-feldspars, (Fig. 2.b), without significant recrystallisation and with quartz-albite basic filling of microcracks suggests a low metamorphic grade.

*Plagioclase* - is mostly completely altered by processes of "reaction softening". This means sericitization, saussuritization and albitization due to sufficient amount of reaction fluids. Only brittle fracturing was observed with quartz filliing of microcracks, (Fig. 2.a,c). In some cases there was preserved the primary zonation of plagioclase with a basic core An ~ 30-35. Plagioclases are rarely recrystallised (in migmatites - metagranitoids) on the grain boundary or only brittle-ductile folded. We assume that retrogression of Plg indicates max. upper greenshist facies.

*Quartz* - it is characterised by low-temperature cataclastic flow and crystal-plasticity on the grain boundary, or only undulose exstinction. Higher-temperature plasticity - sliding may be considered specially in migmatitic rocks.

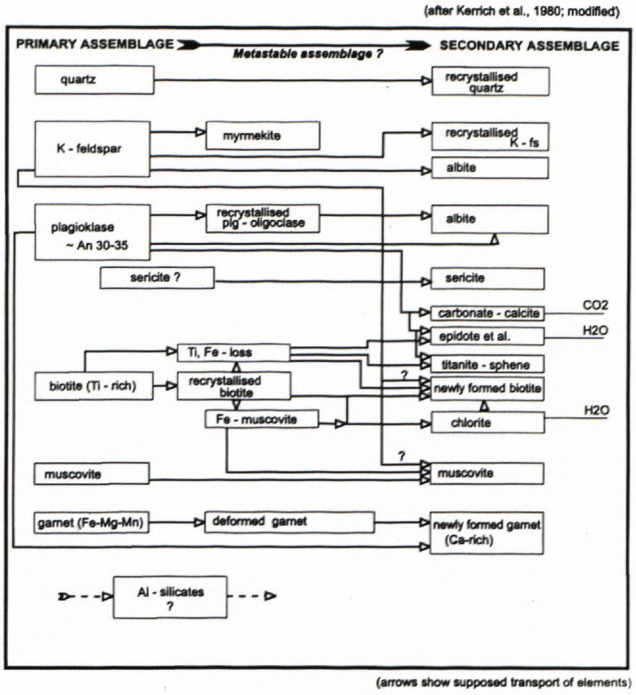



*Fig. 1 Simplified sketch of alterations during the Hercynian and the Alpine development of the Veporicum crystalline basement (esp. of hybridic complex); the Western Carpathians.*

*Biotite* - 3 generation were observed, especially in migmatitic and granitoid rocks. Biotite$_1$ is represented by relics ($L_1$?) of dark-brown grains with obvious exsolution of rutile/sagenite, titanite and with content of Ti ~ 2wt % till 3.5wt %. Biotite$_2$ has dark-brown to brown colour without exsolution and with content of Ti ~ up to 2.4 wt% defining the lineation ($L_2$ and/or $L_1$). Biotite$_3$ is represented by newly formed, relatively Ti-low (below 1 wt %), greenish grains in microcracks of garnets and plagioclases, ( Fig. 2.c,d).

In the main part of the deformed granitoids biotites have been altered - chloritised, baueritised/uralitised. EGGLETON & BANFIELD (1985 in SHELLEY, 1993) suggested a reaction for chloritization in a granite at 340°C.

*Muscovite, white mica* - they are recrystallised (post-deformational growth was also observe) into brittle-ductile folded porphyroblasts. Muscovite is characterised by phengitic composition, with the lower content of paragonite. It may have increased the pressure of metamorphism, contemporaneously decreasing the temperature, at the presence of a sufficient amount of fluids.

*Chlorite* - often defines the lineation ($L_3$) in the deformed granitoids. It originated by retrogression of biotite and as a newly formed radial aggregates in fractures.

Chlorite, sericite and epidote-zoisite group of minerals are the main bearers of deformational strain and retrograde processes in the deformed crystalline basement.

*Garnet* - has been found especially in "migmatitic" and gneissic rocks, as brittle deformed grains or only relics. Fractured garnet cores, often with slightly regressive zonation, are replaced and enveloped in the newly formed progresive growth-zoned almandine-spessartine garnets with relatively high content of grossularite ~33 to 40 wt %, according to a compilation of previous studies and our own observations.

## The cover sequences

The principal mineral assemblages of the sedimentary clastic and carbonatic cover rocks are simply described by the composition: Quartz - Sericite - Plagioclase - K-feldspar ± Muskovite, white mica, Tourmaline, Epidote-Zoisite group.

The bearer of deformation is the weak phase, represented by sericite, but also in some cases by altered and "softened" clasts of plagioclase. The deformational strain was born by quartz only in pure quartzite, where there are few weak phases. Quartz recrystallised on the grain boundary or in brittle-ductile conditions with grain size reduction. K-feldspar - clasts are only fractured.

## The conditions of the deformation

The deformation strongly depends on the viscous strength contrast between strong and weak phases, and on the relative amounts of the constituent phases. It is controlled by the quantity of the weak phase.

The conditions of the deformation in the Veporicum crystalline basement are estimated at middle to upper greenschist facies or the lower part of amphibolite facies; according to these first results, max. T reached approximatelly ~ 450-500°C at P~ 3-4 kbar. After evaluation of rheological properties of the crystalline rocks we are inclined to accept the "clast-matrix" type (HANDY, 1990) or in some mylonites the "IWL" equilibrated microstructure (HANDY, 1994).

The observations from the Permo-Mesozoic cover sediments suggest that deformation occurred in the greenschist facies conditions at a temperature estimated at 350°C (max. 450°C according to crystal plasticity of quartz in the eastern part - in the Rejdová area), or only at anchimetamorphism confirmed by illite crystallinity (PLAŠIENKA et al., 1989).

## Discussion

The newly formed mineral assemblages in the deformed Veporic granitoids are interpreted as the products of "Alpine dynamometamorphism", after ZOUBEK (1936). The first data on Alpine metamorphism of the South Ve-

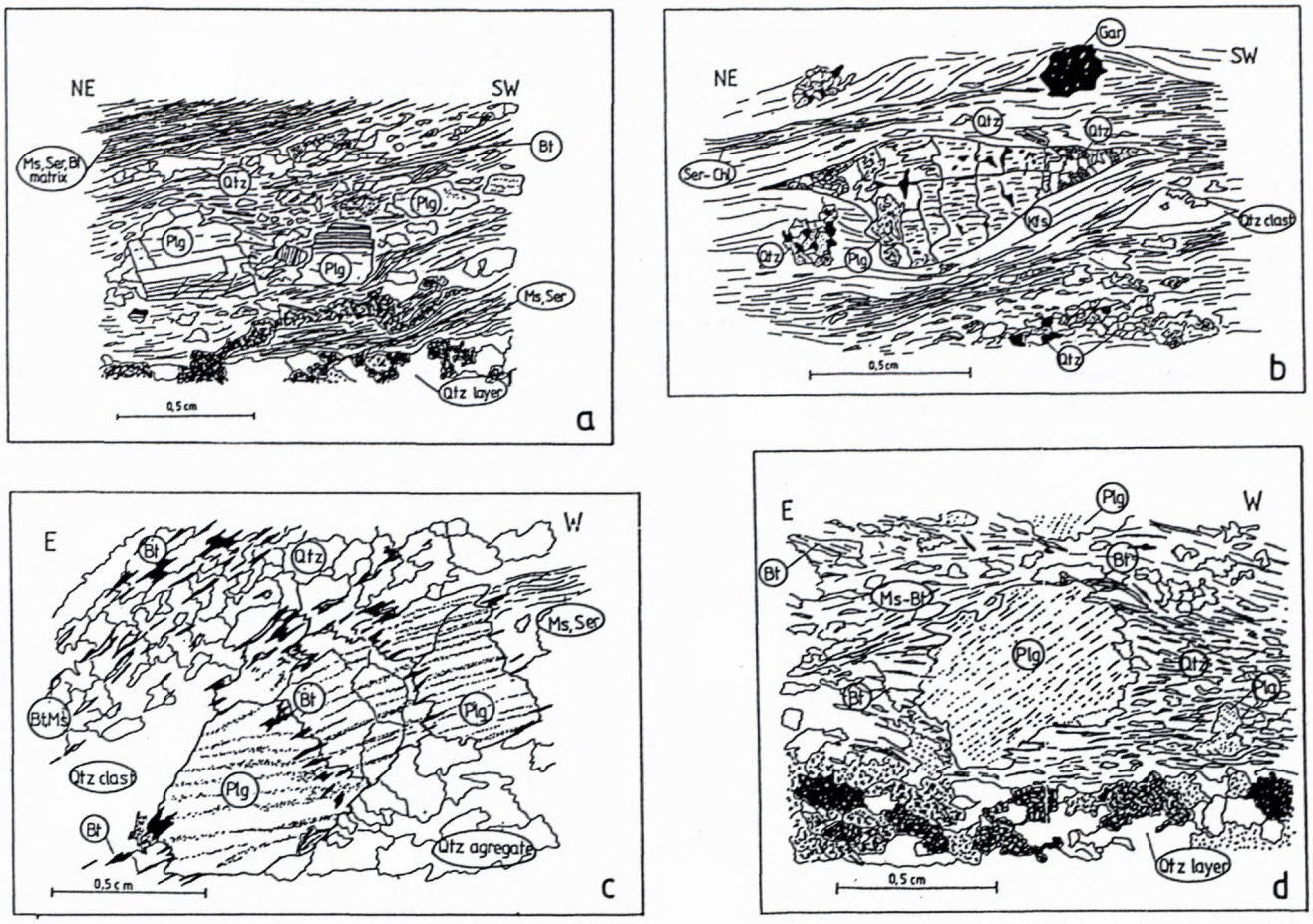



*Fig.2 Microdeformation of porphyric granite, blastomylonite. Drawing according to photographs from oriented thin section, XZ cut. A. Veprianska valley, upper part, Klenovec area. Extension deformation. Plg in brittle conditions, gaps with new formed Ab, Qtz, Ser, Bt. Sense of shear to the SW. B. Borový potok, near Klenovec village. Kfs clast, tails form new Qtz. Mylonitic foliation - matrix from Ser, Chl, Qtz. Shear criteria indicate a displacement towards NE. C. Karafová valley, near Muránska Zdychava village. Extension deformation, Plg clast in brittle condition, gaps with new formed Qtz, Bt. Mylonitic foliation - matrix form Qtz, Chl, Ser. Shear criteria show top to the the NE-E.*

poric Mesozoic cover reaching the biotite zone of the greenschist facies conditions, on the example of the Foederata Group (Foederata Unit), have been presented by VRÁNA (1966). Using the Kubler index measurements, this should correspond to temperatures of 300-350°C (PLAŠIENKA et al., l.c.). Mineral composition of the Alpine diaphtoritic basement rocks directly underlying the Foederata cover unit (kyanite, chloritoide, biotite and garnet) point to temperatures in excess of 400°C and pressure up to 8 kbar (VRÁNA 1980, MÉRES & HOVORKA 1991).

Recently, b° values of muscovites from the Lower Triassic South Veporic cover rocks determine surprisingly high pressures, up to 12 kbar (MAZZOLI et al. 1992). Generally, the Foederata Unit has been affected by medium to high pressure, low temperature Cretaceous dynamothermal metamorphism typical for collisional orogenic belts. The tectonic overburding during the peak pressure conditions probably did exceed 10-15 km (PLAŠIENKA 1993). Similarly, the South Veporic basement is presumed to have been plunged into the middle crustal level, coresponding to the depth down to 20 km (KOVÁČ et al. 1994). To the contrary, lower to middle pressure conditions 2.5-4 kbar and the temperatures between 350-430°C are estimated to have ocurred during the Alpine overprint in the central part of the South Veporic basement (KOVÁČIK & MALUSKI 1994). KORIKOVSKI et al. (1986) Veporicum determined conditions of regional metamorphism for southern at 400-450°C and 4-4.5 kbar and of contact metamorphism at 450-490°C and 1-1.5 kbar, which are relativelly consistent with data obtained by VOZÁROVÁ & KRIŠTÍN (1985, 1989) and KAMENICKÝ (1977).

Permian sandstones, as a cover of the North Veporic basement only, were anchimetamorphosed during Mid-

dle Cretaceous folding events at temperatures of up to 320°C (KORIKOVSKI et al.,1992) and the Foederata group sediments at 250 - 350°C (PLAŠIENKA et al, l.c.). The considerable Alpine recrystallisation, which took place during the Mediterranean phase, is in the case of the Southern Veporic domain attributed to a thick overburden of the Gemeric Unit, whereas the less affected Nothern Veporicum could have only been overlain by the higher superficial nappes (ANDRUSOV, 1968).

The Hercynian regional metamorphism reached temperatures of 500-540°C at the assumed pressure 4.2-7.2 kbar and at 470-360°C as later retrogression for Kraľova Hoľa crystalline complexes and Čierny Balog series, after KRIST et al. (1992). BEZÁK (1991) concluded that the main stage of the Hercynian metamorphism took place at 450-530°C and 4-5 kbar for Early Paleozoic complexes.

Our observations suggest that the major paragenetic transformations reflect probably the strong Alpine overprint. We assume that only relics of higher metamorphosed rocks from the so-called "hybridic complex" in the southern part of the Veporicum basement could bear records of Late - Hercynian events.

## References


ANDRUSOV, D. 1968: Grundriss der Tektonik der Nördlichen Karpaten. Vyd. SAV, Bratislava, 188p.

BEZÁK, V. 1991: Metamorphic conditions of the Veporic unit in the Western Carpathians. Geol. Carpathica, 42, 4, 219-222.

HANDY, M.R.1990: The solid-state flow of polymineralic rocks. J. Geophys. Research, 95, B6, 8647-8661.

HANDY, M.R. 1994: Flow laws for rocks containing two nonlinear viscous phases: a phenomenological approach. J. Struct. Geol., 16, 3, 287-301.

KAMENICKÝ, J. 1977: Contact metamorphism in the aureole of the Rimavica granite (West Carpathian Mts.). Miner. slovaca, 9, 3, 161-184.

KORIKOVSKI, S. P., JANÁK, M. & BORONIKHIN, V. A. 1986: Geotermometria i izmenenia mineraľnych rovnovesij pri perekristalizacii granat-sľudjannych slancev v kordieritovie rogoviki v oreole rochovsych granitov (Slovackoje Rudogorie, rajon Rochovce-Chyžné). Geol. Carpathica, 37, 5, 607-633. (in Rus., Engl. res.)

KORIKOVSKI, S.P., PUTIŠ, M. & BORONIKHIN, V. A. 1992: Anchimetamorphism of Permian sandstones of the Struženík group in the Nízke Tatry Mts. (Western Carpathians). Geol. carpath., (Bratislava), 43, 2, 97-104.

KRIST, E., KORIKOVSKIJ, S. P., PUTIŠ, M., JANÁK, M. & FARYAD, S. W. 1992: Geology and Petrology of Metamorphic Rocks of the West Carpathian Crystalline Complexes. Comenius Univ. Press, Bratislava, 342 p.

KOVÁČ, M.,, KRÁL, J., MÁRTON, E., PLAŠIENKA, D. & UHER, P. 1994: Alpine uplift history of the Central Western Carpathians:geochronological, paleomagnetic, sedimentary and structural data. Geol. Carpathica, 45, 2, 83-96.

KOVÁČIK, M. & MALUSKI, H. 1994: Alpine reactivation of the Eastern Veporic basement metamorphites (Western Carpathians). Romanian J. Tect. and Region. Geol., Special Abstract volume 75, Suppl. 1, ALCAPA II. - Geological evolution of the Alps-Carpathian-Panonian system, 27-28.

MÉRES, Š. & HOVORKA, D. 1991: Alpine metamorphic recrystallization of the pre-Carboniferous metapelites of the Kohút crystalline complex (the Western Carpathians). Mineralia slov., 23, 5-6, 435-442.

MAZZOLI, C., SASSI, R. & VOZÁROVÁ, A. 1992: The pressure character of the Alpine metamorphism in the Central and Inner Western Carpathians (Czecho-Slovakia). In VOZÁR J. (ed): The Paleozoic geodynamic domains - Western Carpathians, Eastern Alps, Dinarides. D.Štúr Inst. of Geol., Bratislava, 109-117.

PLAŠIENKA, D., JANÁK, M., HACURA, A. & VRBATOVIČ, P. 1989: Prvé údaje o kryštalinite illitu z alpínsky metamorfovaných hornín Veporika. Miner. slovaca, 21, 1, 42-51.

PLAŠIENKA, D. 1993: Structural pattern and partitioning of deformation in the Veporic Foederata cover unit (Central Western Carpathians). In: Rakús, M. - Vozár, J. (Eds.): Geodynamic model and deep structure of the Western Carpathians, GÚDŠ, Bratislava, 269-277.

SHELLEY, D. 1993: Igneous and metamorphic rocks under the Microscope. Chapman-Hall publ., London, 445 p.

SIMPSON, C. & WINTSCH, R. P. 1989: Evidence for deformation-induced K-feldspar replacement by myrmekite. J. Metam. Geol., 7, 261-275.

VOZÁROVÁ, A. & KRIŠTÍN, J. 1985: Zmeny v chemickom zložení granátov a biotitov v kontaktnej aureole alpínskych granitoidov v južnej časti Veporika (Západné Karpaty). Záp. Karpaty, Séria Miner., Petrol., Geoch., Metalogen., 10, Bratislava, 199-221. (In Slovak, Engl. res.)

VOZÁROVÁ, A. & KRIŠTÍN, J. 1989: Termodynamické podmienky premeny metasedimentov slatvinského súvrstvia v stykovej zóne gemerika a veporika. Záp. Karpaty, Séria Miner., Petrol., Geoch., Metalogen., 12, Bratislava, 143-175. (In Slovak, Engl. res.)

VRÁNA, S. 1966: Alpidishe metamorphose der Granitoide und der Foederata - serie im Mittelteil der Veporiden. Zbor. geol. vied, Rad Záp. Karpaty, Bratislava, 6, 29-84.

VRÁNA, S. 1980: Newly - formed garnets in metagranitoids of the Veporides in relation to the structure of the Central zone of the West Carpathians. Časopis pro miner. a geol., 25, 1, 41-54.

ZOUBEK, V. 1936: Poznámky o krystaliniku Západních Karpát. Věstník Stát. geol. úst. ČSR, XII., 6, Praha, 207-239. (In Czech)

SLOVAK GEOLOGICAL MAGAZINE

# Extension tectonics and exhumation of crystalline basement of the Veporicum unit (Central Western Carpathians)

JÁN MADARÁS[1], JOZEF HÓK[1], PAVOL SIMAN[1], VLADIMÍR BEZÁK[1], PATRICK LEDRU[2] & ONDREJ LEXA[3]

[1] Geological survey of Slovak republic, Mlynská dol. 1, 817 04 Bratislava, Slovakia
[2] BRGM, BP 6009, 45060, Orléans, France
[3] Charles University, Faculty of Natural Sciences, Department of Petrology, Albertov 6, 128 43 Praha 2, Czech republic

*Abstract:* Pre-Alpine crystalline units in the central part of the Western Carpathian range (Slovenské rudohorie Mts.) represents the domain of intensive Alpine overprinting. The Hercynian structural elements are preserved only in relics and they have been incorporated into the Alpine structural pattern. The Hercynian collisional structures - stacking of lithotectonic units - is a result of the Meso Hercynian tectonic stage. In the Late Hercynian evolutional stage the collision in the external zones was finished and crustal extension took place in more internal zones.

The intensive paleo-Alpine deformation had two main stages: thrusting in transpression regime and subsequent extensional unroofing.

After paleo-Alpine and neo-Alpine crustal thickening, inversion tectonic regime took place and exhumation of the crystalline basement followed.

*Key words:* Central Western Carpathians, Veporicum unit, tectonic stages, thrusting, extensional unroofing.

## Introduction

The effects of late orogenic extension are now well identified within collision-type orogens such as the Alps or the Variscan belt. The stacking of nappes resulting from the major lithospheric collision stage led to an unstable thickened crust which tended to re-equilibrate by means of erosion and extensional tectonics developed during vertical uplift and lateral expansion. Thus, the lithosphere accommodated both strain and displacement during collision and extension through its mechanical and thermal behaviour.

The geological evolution of the Veporicum unit is particularly interesting in this framework. The old orogenic crust, mainly composed of quartzo-feldspathic units, has been progressively exhumed, covered by detrital sequences, involved in collision and then re-exhumed.

The purpose of this study is to characterise the tectonic evolution of the Veporicum unit according to the strain partitioning within both the basement and cover sequence. Presented structures and metamorphism within this Alpine lithospheric slab show that the finite strain is mainly related to an Alpine major extensional tectonics. The existence of a possible Late Hercynian extensional tectonics, prior to Alpine collision and extension, is discussed in relation to several geological constrains.

## Geological framework

The Veporicum unit - one of the Alpine-formed units of the Western Carpathians - consists of crystalline rocks (basement) and an Upper Paleozoic - Mesozoic cover. Complicated inner structure of the Veporicum unit may be explained by the combined activity of several tectonic stages - pre-Alpine, paleo- and neo-Alpine.

The structure of the basement is heterogeneous and three basic types of complexes are distinguished here :
- high-grade metamorphic rocks of unknown age (Late Proterozoic? - Lower Paleozoic), mainly diaphtoresed;
- low-grade metamorphites of Lower Paleozoic age;
- Variscan granitoid complexes usually in overthrust position on metamorphic complexes and often strongly deformed - as much as to orthogneisses.

## Structures - finite strain and kinematics

Structural observations are based on the lithotectonic succession; structural data relate mainly to gneissic - migmatitic and granitic Variscan basement and the Permotriassic sedimentary cover.

Three types of linear structures have been identified in the basement. The first is restricted to highly metamorphosed rocks and the so-called hybridic complex (migmatites; deformed, hybridic granitoids). The second one is mostly visible in deep parts of granitic bodies, but also in the hybridic complex. The third type affects upper parts of granitic bodies near the discordance with the Permotriassic cover.

1.The oldest structural data were found in the relics of high-metamorphosed rocks (such as para- and ortho-

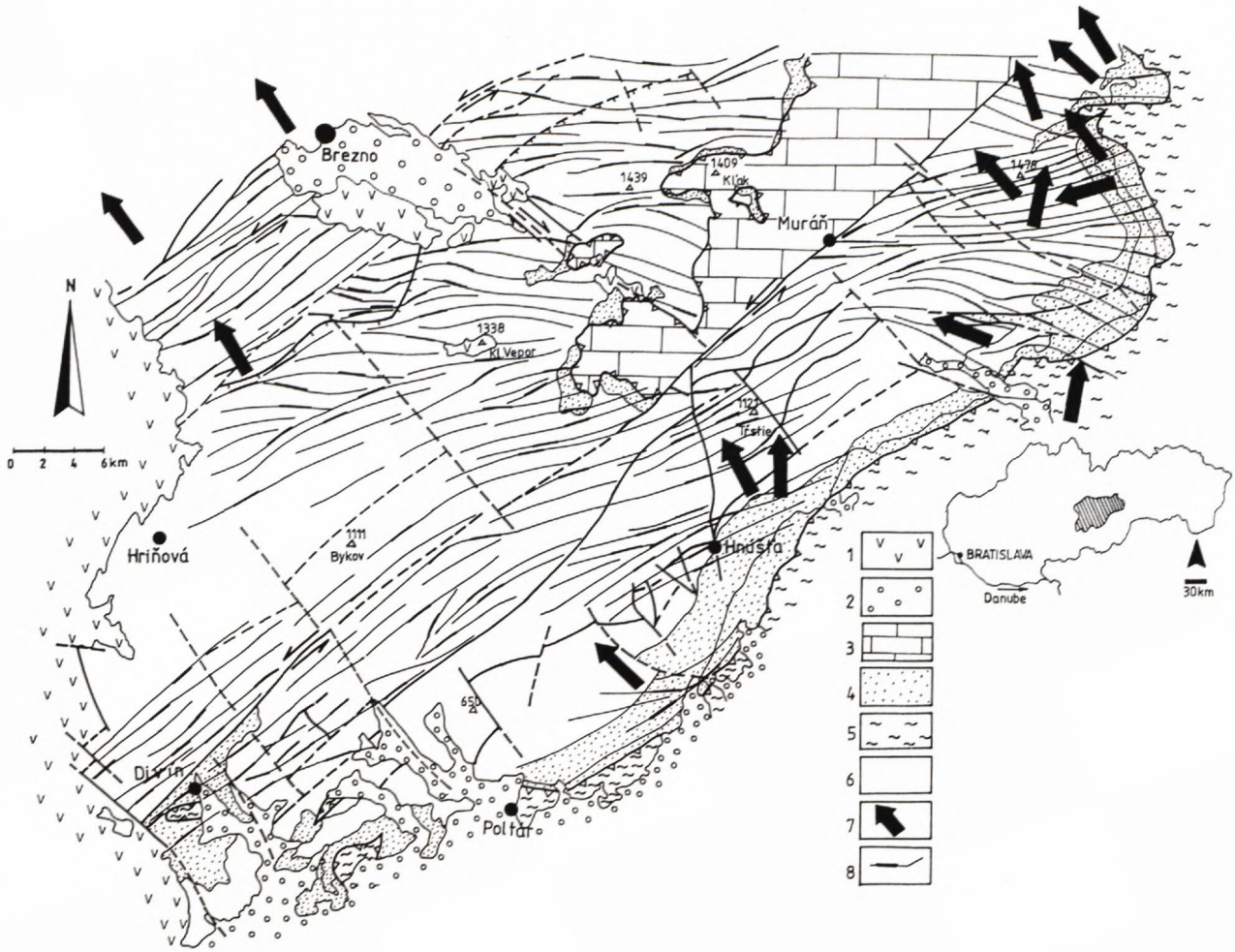



*Fig. 1 Structural scheme of the central part of the Veporicum unit. 1. Neovolcanics (Neogene), 2. Paleogene and Neogene sedimentary basins, 3. Silica (Muráň) nappe (Triassic - Lower Jurassic carbonates), 4. Markuška slice, Federáta unit - metasedimentary cover units of the Veporic basement (Lower?, Upper Carboniferous - Middle Triassic), 5 Gemericum unit (Early - Late Paleozoic metasediments), 6. Veporicum crystalline complexes (Early? - Late Paleozoic granitoids, metasediments). 7. sense of Paleo-Alpine compression, 8. Alpine mineral lineations ($L_3$) and trajectories of extension unroofing in ductile and brittle - ductile conditions.*

gneiss, layered migmatites, or hybridic granitoids) interpreted as host rocks of Hercynian granitoids. They occur in a narrow belt beneath the Hercynian granitoids, in their southern part.

The P-T definition and evolution of these relics seems to be very difficult due to a strong lower-temperature metamorphic and deformational overprint, which took place in greenschist facies conditions.

Foliation with the general strike of dip to NW (except folded zones) is regarded as the oldest one (in the whole Veporic unit). Re-orientation of migmatitic and metamorphic foliation planes resulted mainly from a syngenetic ductile deformation in high-temperature processes associated with partial melting.

Migmatites also exhibit a typical changeable of course strike and dip of axial planes of folds and B-axes of asymmetric folds, due to continuous high-plasticity conditions during the deformation. The local rotation of the mineral lineation $L_1$ (from NW-SE to NE-SW) as a later phenomenon indicates a highly inhomogeneous strain.

2. However, the dominant mineral lineation in deepest parts of hybridic complex is $L_2$ (Late Hercynian age?). While $L_1$ formed on metamorphic and migmatitic foliation planes, $L_2$ originated at ductile C-planes. Together with shear bands it reflects extension and normal tectonics and solid-state or lower-temperature processes, respectively. $L_2$ with NE-SW direction is slightly dipping to the E or/ and W. The B-axes of asymmetric folds are parallel with $L_2$. In XZ section there were found boudins of

gneissic xenoliths strongly thermally reworked. It indicates the sense of shear - top to the NE, the same as ductile deformed plagioclase porphyroblasts. Ductile shear zones ($318^0$ / $30^0$, $312^0$ / $60^0$ -sinistral and $20^0$ / $40^0$, $54^0$ / $30^0$, $10^0$ / $30^0$ -dextral) show the same sense of shear (NE). Biotite in $L_2$ is developed on S-planes, and on C-planes on a lower structural level. General trend of strike is NE-SW to ENE-WSW. There were observed lineations with biotite (partly rotated) in ductile shear zones.

The main complex of Variscan granitoids is developed on the hanging-wall of the migmatites and hybridic granitoid rocks. The Veporic granitoids are characterised as a complex of several different granitic bodies (porphyric, older S-type granite to granodiorite; isometric, younger I-type granodiorite to tonalite) with different Hercynian age (PETRÍK et al., 1994).

All varieties are more or less affected by strong solid-state deformation. Magmatic foliation is steeply dipping on the contact with the basement complex, however, in the uppermost parts of the present erosion base it is sub-horizontal. This trend is evident mainly in coarse-grained porphyric granites in the central part of the Vepor pluton. Magmatic foliation is sub-horizontal, parallel with mylonitic foliation, with a flat dip to NW or N.

Mineral lineations documents decreasing P-T conditions towards the top wall. Magmatic lineation $L_2$ is defined by biotite in the deepest parts of the granitic body, further on biotite occurs in stretching lineation and on the top the stretching lineation is marked by chlorite. All types are parallel. They formed at different levels in ductile (or post-magmatic) conditions.

3. Alpine stretching lineation $L_3$ (Fig. 1) is defined by elongated quartz; chlorite; sericite, occasionally biotite and a marked E-W trend with the sense of dip to the E. It is developed especially near the discordance with the cover, partly on C-planes and normal mylonite zones, such as brittle joint-like striae. Lineation is frequently rotated and it is a problem to distinguish it from $L_2$, because $L_3$ is defined by the same minerals as $L_2$ (with biotite, too). $L_3$ documents continual brittle/ductile extensional deformation with transition to transtensional regime with strike-slips. $L_3$ on the highest structural levels has the character of brittle striae on joint planes, brittle mylonite zones, locally with hydrothermal alteration. There were observed here only stretching grains of quartz, muscovite-phengite, epidote. Mylonitic foliation has a dip to S, SE, opposite to older magmatic and mylonitic foliations (c.f. SIEGL, 1982). In the XZ section, parallel with $L_2$ and $L_3$, there were found kinematic shear-sense indicators: brittle-ductile deformed porphyroblasts of K-feldspar, plagioclase; recrystallised tails with newly-formed albite, biotite, quartz; biotite book-shelf sliding; boudins of quartz - albite veins, quartz extensional veins.

Kinematic orientation of striations shows normal tectonic and horizontal wrenching in brittle -ductile conditions.

Folds and duplex structures were found as kinematic indicators of compression in granitoids. They are present in extremely deformed mylonitic zones, which are characterised by different material rheology. Their orientation indicates the sense of shear (nappe transport) to NW (Fig.1).

The feldspar study in two perpendicular cross-sections (XZ a YZ) shows a very small difference in deformation, the position of deformation ellipsoids in the flattening field. It is typical for extension and dome uplift of the crystalline basement (Fig. 1, 2).

Sedimentary cover sequences were the last complex studied. The crystalline basement (mainly granitoids) is discordantly overlain by a Late Paleozoic-Mesozoic (Permomesozoic) cover, which consist of schists, metaarcoses, quartzites, occasionally acid volcanites, metacar-

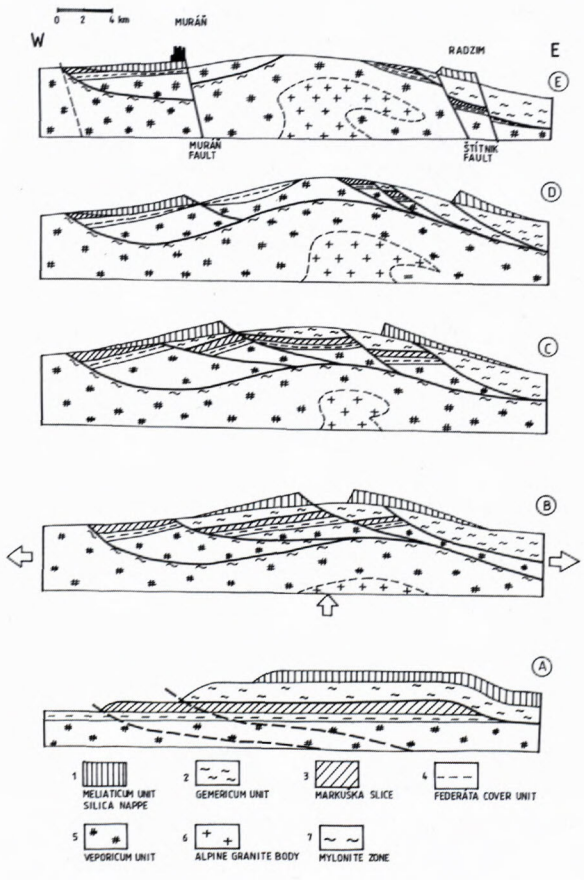



*Fig. 2 Model of the Alpine extension unroofing of the central part of the Veporicum unit, West Carpathians range. A.) situation after Paleo-Alpine compression stage - Upper Jurassic - Lower Cretaceous, B.) start of extension stage - Middle Cretaceous, C.), D.) continual extension, formation of listric faults and gravitational movements of nappes - Upper Cretaceous-Tertiary, E.) present time situation. The horizontal scale is real, vertical scale is variabil.*

bonates. There is a possibility for age correlation of the Permomesozoic sediments with the crystalline basement. Here there was observed only the third type of linear structures - stretching lineation $L_3$ and also the youngest striations. Clastic and carbonatic sediments were affected by ductile, brittle/ductile and brittle deformation. Their structural and tectonic development is well-known (PLAŠIENKA,1984;1993; PLAŠIENKA et al.,1989; HÓK et al.,1993).

## Conclusions

Pre-Alpine crystalline units in the central part of the Western Carpathian range (Slovenské rudohorie Mts.) represents the domain of intensive Alpine overprinting. The Variscan structural elements are preserved only in relics and they have been incorporated into the Alpine structural pattern. The Variscan collisional structures - stacking of lithotectonic units - is a result of the Meso Hercynian tectonic stage. In the Late Hercynian evolutional stage the collision in the external zones was finished and crustal extension took place in more internal zones (BEZÁK, 1991, 1994, PLAŠIENKA et al., 1993).

The intensive paleo-Alpine deformation had two main stages: thrusting in transpression regime and subsequent extensional unroofing (Fig.1,2).

The following tectonic regimes have been determined:

1. Compression and an overthrusting from SE to NW during the Late Kimerian stage of the Alpine orogeny (Late Jurassic to Early Cretaceous). Successively, the earliest stage of Alpine deformation is represented by duplex structures and folds with axial planes dipping to the SE.

2. Subsequent extension, top-to-the E. The second paleo-Alpine deformation is indicated by mineral stretching lineation, sub-parallel with B-axes of folds, by kink folds being product of the extensional tectonic regime, by numerous kinematic indicators, extension veins and by kinematics of normal faults. In the studied area all indicators point to the regime of ductile deformation close to transition to brittle conditions.

3. Transtensional deformation in brittle conditions. In the younger population of fault planes the compressive tensor changes its orientation from NE-SW to NW-SE. The rock mass movement continued in extensional regime, the direction being generally perpendicular to the Gemeric unit thrust (HÓK et al., 1993).

After paleo-Alpine and neo-Alpine crustal thickening, inversion tectonic regime took place and exhumation of the crystalline basement followed.

Extensional unroofing of the central part of the Slovenské rudohorie Mts. was presumably connected with the uplift of the Veporic crystalline unit. The uplift was accommodated by eastward extensional unroofing of the overlying units (Federáta, Markuška cover units, Gemeric unit, Meliata and Silica nappe). The middle Cretaceous age is determined by Ar-Ar, K-Ar, and FT dating - (c.f. KRÁĽ, 1977, BURCHART et al., 1987, MALUSKI et al., 1993, KOVÁČ et al., 1994). In the crystalline basement, the blasto-mylonitization of crystalline complexes and emplacement of the Rochovce granitic body is dated by different methods at 84-94 Ma (DALLMEYER et al., 1993, MALUSKI et al., 1993, HRAŠKO et al., 1995). There are different opinions on the peak P-T conditions reached during paleo-Alpine metamorphic event in the basement and sedimentary cover (low to medium grade c.f. VRÁNA, 1966, 1980, PLAŠIENKA et al., 1989, VOZÁROVÁ, 1990, SASSI & VOZÁROVÁ, 1992). Continuous uplift is documented by FT ages of apatite (53±7 - 89±10 Ma - KRÁĽ, 1977). Due to the extension, gravitational movements are recorded in the basement and Permomesozoic complexes of the Veporic and Gemeric units.

## References


BEZÁK V. 1991: Present knowledge of tectonogenesis of Veporicum (West Carpathians). Mineralia slov. (Bratislava), 23, 381-383.

BEZÁK V. 1994: Proposal of the new dividing of the West Carpathians crystalline based on the hercynian tectonic building reconstruction. Mineralia slov. (Bratislava), 26, 1-6. (In Slovak, English summary).

BURCHART J., CAMBEL B. & KRÁĽ J. 1987: Isochron reassessment of K-Ar dating from the West Carpathian crystalline complex. Geol. Zbor. Geol. Carpath. (Bratislava), 38, 2, 131-170.

DALLMEYER, R. D., NEUBAUER F. & PUTIŠ M. 1993b: $^{40}Ar/^{39}Ar$ mineral age controls for the pre-Alpine and Alpine tectonic evolution of nappe complexes in the Western Carpathians. In: PITOŇÁK P. and SPIŠIAK J. (Eds): Pre-Alpine events in the Western Carpathians' realm. Internat. conf. Excursion Guide, Stará Lesná, 13-20.

HÓK J., KOVÁČ P. & MADARÁS J. 1993: Extensional tectonic of the western part of the contact area between Veporicum and Gemericum (Western Carpathians). Mineralia Slov. (Bratislava), 25, 172-176. (In Slovak, English summary).

HRAŠKO Ľ, MICHALKO J., HATÁR, J., HÓK, J., VAASJOKI M., & KOTOV, A. B., 1995: Upper Cretaceous granite in Western Carpathian region. Terra abstracts, Abstract supplement N°.1, Terra nova, vol. 7, 307.

KOVÁČ M., KRÁĽ J., MÁRTON E., PLAŠIENKA D. & UHER P. 1994: Alpine uplift history of the Central Western Carpathians: Geochronological, paleomagnetic, sedimentary and structural data. Geol. Carpath. (Bratislava), 45, 83-96.

KRÁĽ J. 1977: Fission track ages of Apatites from some granitoid rocks in West Carpathians. Geol. Carpath. (Bratislava), 28, 2, 269-276.

MALUSKI H., RAJLICH P., & MATTE PH. 1993: $^{40}Ar$ - $^{39}Ar$ dating of the Inner Carpathians Variscan basement and Alpine mylonitic overprinting. Tectonophysics (Amsterdam), 223, 313-337.

PETRIK I., BROSKA I. & UHER P. 1994: Evolution of the Western Carpathian granite magmatism: age, source rock, geo-

tectonic setting and relation to the Variscan structure. Geol. Carpath. (Bratislava), 45,5, 283-291.

PLAŠIENKA D. 1984: Represents the Markuška nappe an interconnecting element between the Veporic and Gemeric units? Mineralia slov. (Bratislava), 16, 187-193. (In Slovak, English abstract).

PLAŠIENKA D. 1993: Structural patttern and partitioning of deformation in the Veporic Foederata cover unit (Central Western Carpathians). In: RAKÚS M. and VOZÁR J. (Eds): Geodynamic model and deep structure of the Western Carpathians. Conf., Symp., Sem., D. Štúr Inst. Geol., (Bratislava), 269-277.

PLAŠIENKA D., JANÁK M., HACURA A. & VRBATOVIČ P. 1989: First illite-crystalinity data from Alpine metamorphosed rocks of the Veporicum, Central West Carpathians. Mineralia Slov. (Bratislava), 21, 43-51. (In Slovak, English summary).

PLAŠIENKA D., BEZÁK V., JANÁK M. & UHER P. 1993: Record of the pre-Alpine orogenic processes in the Western Carpathians: a synopsis. PAEWCR conference, abstracts, Geol. Carpath. (Bratislava), 4,44, 266.

SASSI F. P. & VOZÁROVÁ A. 1992: Pressure character of the Variscan metamorphism in the Gemericum and Veporicum (West Carpathians, Czechoslovakia). Boll. Soc. geol. ital. (Roma), 111, 33-39.

SIEGL, K. 1982: Structure of the Vepor pluton (West Carpathians). Geol. Zbor. Geol. Carpath. (Bratislava), 33, 2, 171-175.

VOZÁROVÁ A. 1990: Development of metamorphism in the Gemeric/Veporic contact zone (Western Carpathians). Geol. Zbor. Geol. carpath., (Bratislava), 41, 475-502.

VRÁNA S. 1966: Alpidische Metamorphose der Granitoide und Foederata - serie im Mittelteil der Veporiden. Sbor. geol. Vied, Záp. Karpaty, 6, 29-84.

VRÁNA S. 1980: Newly - formed Alpine garnets in metagranitoids of the Veporides in relation to the structure of the Cental zone of the West Carpathians. Čas. pro min. a geol. (Praha), 25, 1, 41-54.

SLOVAK GEOLOGICAL MAGAZINE

# A fluid inclusion analysis contribution to the study of tectono-metamorphic evolution of the Veporicum crystalline complex

VLADIMÍR BEZÁK , VRATISLAV HURAI & JÁN KRÁĽ

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

*Abstract.* An analysis of the positon of quartz veins in Veporicum in space, and of their occurrence in the principal units (metamorphic rocks of the southern Veporicum, granitoids, metamorphic rocks of the northern Veporicum, Mesozoic cover) as well as the conditons of their formation, along with geochronological data, allowed to explain the formation of these veins in the context of the Hercynian and Alpine tectono-metamorpic development. On the basis of so far obtained data it may be stated that veins formed in granitoids in the Hercynian period (340-300 Ma), at temperatures of 450-500°C, and in the Alpine time (especially in the mylonite zones) at 300-380°C. These temperatures correspond to temperatures of Alpine vein formation in metamorphites of the northern and southern Veporicum and in the Mesozoic cover of Veporicum. Higher-temperature Alpine veins have not been found yet. The formation of Alpine veins is placed into the time of 140-80 Ma.

*Key words:* Western Carpathians, Veporicum, fluid inclusions,,geochronology, tectono-metamorphic events

The study of fluid inclusions in metamorphogenic quartz from crystalline complexes of Veporicum has been going on, with interruptions, for a longer time (e.g. HURAI 1983, HURAI et al. 1994). This method brought a number of interesting results, which must be considered when interpreting the tectonic and metamorphic evolution of the crystalline basement. In the first stage, data on metamorphic conditions were obtained, which, combined with geochronological data, characterised the metamorphic development and uplift of the complexes to higher levels. The results suggested two temperature ranges (HURAI 1983). The original interpretation, i.e. that both ranges belong to Alpine processes, met with a number of contradictions. Therefore, another solution was sought. This was contributed also by the progress the knowledge of tectonic development of Veporicum and by isotopic data. It has been proved that all veins contain also components coming from metasediments, even though they occur in granitoids, which was another point in favour of the nappe position of granitoids on metasediments (HURAI et al. 1994). A part of the Alpine-type veins, after analysing the tectonic position of their host complexes, had to be re-classified as Hercynian (HURAI et al. l.c.).

For the purpose of a confrontation of Hercynian and Alpine conditions, we analysed recently quartz samples from the cover Upper Paleozoic and Mesozoic from different parts of Veporicum-. The results indicated temperatures of the formation of Alpine veins ranging form 300 to 350°C. From other new data there are interesting the temperatures of quartz formation in schists of the Sinec complex - 370-380°C. These temperature are quite consistent with so far determined conditions of the crystallisation of Alpine veins in metamorphic rocks of the southern Veporicum and in Alpine mylonite zones of granitoids (HURAI et al. 1994).

This contribution is aimed at analysing the available data in direct relationships to the tectonic evolution.

The basic types of metamorphogenic quartz so far determined in Veporicum are the following:

1) veins of NE-SW direction parallel with the foliation of metamorphites, or in mylonite zones of granitoids with fluids indicating a temperature of 330°-380°C
2) filling of fissures in granitoids with crystallisation temperatures of 450°-500°C.

For the purpose of this analysis we distinguished the following basic types of host complexes:

a) metamorphites of the northern Veporicum (Krakľová Zone)
b) granitoids of the Kráľova hoľa Zone
c) metamorphites of the Kohút Zone
d) Upper Paleozoic and Mesozoic cover in all zones.

Tectonic relations of the se complexes are at present interpreted as an interaction of Hercynian and Alpine processes and their superposition is shown on Fig. 1. The granitoids are in thrust position, having originated already in the Hercynian tectonic stage. Age relationships (from published geochronological data) are shown as well as occurrences of the different quartz types.

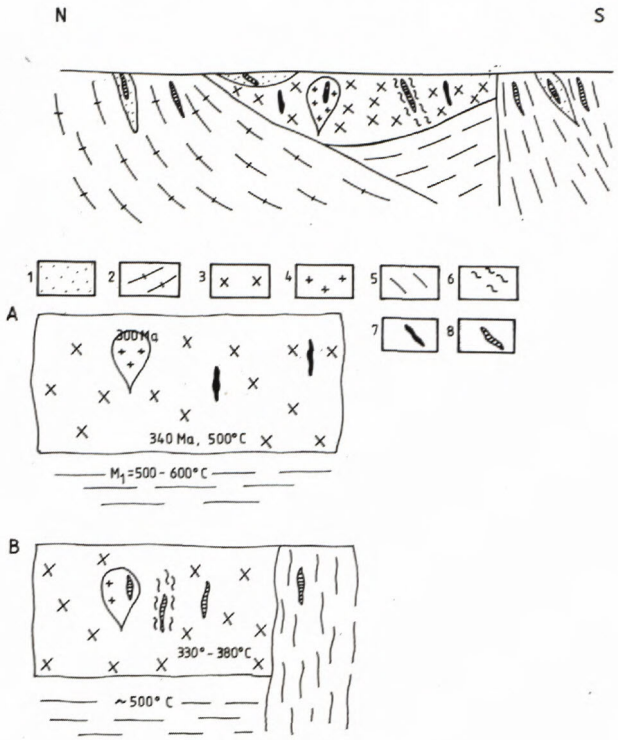



*Fig.1* ***Top****: Present distribution of low and high temperature quartz veins in the Veporikum.*
***Bottom:*** *Interpretation of the sequence in origin of the veins.*
***A - Hercynian stage:*** *1. Metamorphism, 2. cooling below 500°C in granitoids (340 Ma), 3. creation of veins in the temperature range between 450° and 500°C, 4. intrusions of the Sihla type granitoids (300 Ma), 5. part of veins formed at 330 - 380°C (?)*
***B - Alpine stage:*** *Metamorphism up to 500°C (in lower complexes), upper complexes 300 - 400°C (140 - 80 Ma), 2. creation of veins in the temperature range 330 - 380°C (in all complexes), 3. cooling below 300°C in all complexes (80 Ma)*
***Explanations:*** *1-Mesozoic cover,2 - North-Veporic metamorphites, 3-granitoids, 4 - Sihla type granitoids, 5 - South-Veporic metamorphites, 6 - mylonite zones, 7 - high-temperature veins (450 - 500°C), 8 - low temperature veins (330 - 380°C)*

From metamorphic rocks of the Kohút Zone, 8 samples have been analysed so far (micaschists of the Ostrá Complex, the Klenovec gneiss complex, Sinec Complex) and all quartz samples belong to the first - lower temperature - vein type. In granitoids there are low-temperature veins of the first type (especially in mylonite zones) - 6 samples - and higher-temperature filling of veins of the second type (6 samples). One lower-temperature vein has been analysed from metamorphites of the northern Veporicum. From cover sequences of all zones, 4 samples have been analysed, belonging all to lower-temperature veins with parameters as in metamorphic rocks (Fig. 1).

## Discussion

An analysis of the position of metamorphogenic quartz veins in space indicates that different-temperature quartz cannot have formed in the same period, but they are two tectono-metamorphic events. The fluid inclusions show also the temperature parameters of certain stages of their development and, together with geochronological data, they contribute to the reconstruction of the rate of uplift and of the cooling of the crystalline complexes.

Higher-temperature filling of fissures is associated exclusively with the granitoid complex. Accepting the nappe position of granitoids makes it impossible to interpret them as Alpine, as granitoids contain simultaneously also low-temperature veins and metamorphites, which were lower in position, only lower-temperature. Their formation is placed into the time after the thrusting of the migmatite-granite-gneiss complexes on low-metamorphosed sediments and after the intrusion of porphyric granites, which contain them, and, at the same time, after their cooling below 500°C (350-340 Ma, KRÁĽ et al.,1996), but before the intrusion of the Sihla granitoids (300 Ma, BIBIKOVA et al. 1990), which do not contain them, i.e. in the range of 340-300 Ma. The temperature conditions of the formation of Hercynian veins correspond to the Hercynian metamorphism of the metasediments (BEZÁK 1991).

The metamorphic rocks contain only low-temperature veins, formed at Alpine diaphtoritic processes connected with hydration, and not at progressive Hercynian metamorphism accompanied by dehydration. However, it cannot be excluded that higher-temperature veins have so far not been recorded by sampling. If they would exist, they would have formed also in the Hercynian stage, as the granites, or at the beginning of the Paleoalpine tectono-metamorphic development, as indicated by the analysis of latest Ar/Ar dating (KRÁĽ et al., 1996), and they would be associated only with the metamorphic complexes lowest in position. Paloealpine age of high-temperature veins in granites is out of question, as their immediate cover does not contain them.

The formation of Alpine metamorphogenic quartz took place in all complexes (veins in metamorphites, in mylonite zones of granitoids, in the Sihla granitoids, in Triassic metaquartzites) approximately at the same conditions (300-350°C). Slightly higher crystallisation temperatures (370-380°C) are indicated only by veins in the lower complexes of the Kohút Zone (Sinec).

The ages of the Alpine veins are limited by Ar/Ar, or K/Ar data, and the cooling of the crystalline complexes. According to newest data (KOVÁČIK et al. 1996, KRÁĽ et al., 1996), the age range of the assumed higher-temperature Alpine metamorphism (400-500°C), which affected the lower metamorphosed complexes (below the granitoids of the middle unit according to BEZÁK 1994) is so far not possible to prove, but we can say that it was not earlier than 140 Ma. The lower-temperature Alpine

metamorphic event (300-350°C), including also the formation of Alpine quartz veins, is supported by relatively reliable geochronological and geological evidence (in the cover). Its lower age boundary is dated at about 80 Ma (cooling below 300 °C in all Veporicum complexes).

## References


BEZÁK, V. 1991: Metamorphic conditions of the veporic unit in the Western Carpathians. Geologica carp., 42, 4, 219-222.

BEZÁK, V. 1994: Návrh nového členenia kryštalinika Západných Karpát na základe rekonštrukcie hercýnskej tektonickej stavby. Mineralia slov., 26, 1-6 (In Slovak, Engl. res.).

BIBIKOVA, E. V. KORIKOVSKY, S. P. PUTIŠ M., BROSKA I., GOLTZMAN Y.V. & ARAKALIANTS M. M., 1990: U-Pb, Rb-Sr and K-Ar dating of Sihla tonalites of Vepor pluton (Western Carpathian Mts.). Geol. Zb.-Geol. carpath., 41, 4, 427-436.

HURAI V., 1983: Genetická interpretácia plynokvapalných uzavrenín v kremeni zo žíl alpského typu veporického kryštalinika. Mineralia slov., 15, 3, 243-260 (In Slovak, Engl. res.).

HURAI V., SIMON K. & BEZÁK V., 1994: Hercýnsky vek niektorých trhlín s alpskou paragenézou minerálov v kryštaliniku veporika. Mineralia slov., 26, 355-361 (In Slovak, Engl. res.).

KOVÁČIK M., KRÁĽ J. & MALUSKI H., 1996: Alpínsky metamorfný a termochronologický vývoj juhoveporických predalpínskych metamorfitov. Mineralia slov., 28, 185-202 (In Slovak, Engl. res.).

KRÁĽ J., FRANK W. & BEZÁK V., 1996: $^{40}Ar/^{39}Ar$ spektrá z amfibolov amfibolických hornín veporika. Mineralia slov., 28, 501-513 (In Slovak, Engl. res.)

SLOVAK GEOLOGICAL MAGAZINE

# Porphyric granitoids in the western part of the Slovenské rudohorie Mts.: Emplacement and deformation in shear zones

ONDREJ LEXA[1] & VLADIMÍR BEZÁK[2]

[1]Charles University, Faculty of Natural Sciences, Department of Petrology, Albertov 6, 128 43 Praha 2, Czech republic
[2]Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava

*Abstract.* The paper is aimed at an analysis of the relationship of intrusion and deformation in porphyric granitoids of Veporicum. In the area under study, the following ductile deformation stages may be identified:

- Paleohercynian (at high temperature and leaving traces only in the hybrid complex)
- Mesohercynian (we registered especially a record of the transition from compressional to transpressional regime at higher greenschist facies conditions),
- Neohercynian transtensional and extensional stage (its structural record is relatively difficult to define due to the superimposed Alpine extension),
- Paleoalpine stage (represented especially by the inventory of transpressional, less compressional structures, while in the fundament there have been utilised Hercynian structures).

The subsequent deformational stages took place already in brittle conditions.

Intrusions of porphyric granitoids are associated probably with the end of the Mesohercynian stage, using for their ascent sinistral transpressional shear zones. The contemporary and subsequent deformations modified their structural position.

*Key words:* Slovenské rudohorie Mts., Veporicum, porphyric granitoids, intrusion system, deformation.

## Introduction

The so far published works concerning granitoids of the Veporicum were aimed mostly at the characterisation of individual varieties (from the best known we should mention the types Sihla, Hronček, Vepor, Ipeľ, Rimavica, Rochovce) and their petrographic-mineralogical investigation (ZOUBEK 1936, HOVORKA 1960, KAMENICKÝ 1977, KRIST 1979, 1981, KLINEC et al. 1980 etc.)

Most recently, the granitoids have been classified according to their geological setting, petrographic-geochemical characteristics and relative age succession by BEZÁK & HRAŠKO (1992). They distinguished four basic granitoid groups (hybrid, porphyric, Sihla, leucocratic) and they also showed their approximate extent in space.

Structural study of the Veporicum granitoids was carried out by SIEGEL (1982), who discovered a structural discordance of Hercynian foliation inclined predominantly to the north and the superimposed Alpine mylonite foliation inclined to the south. Deformed granitoids and their metamorphism have been studied especially by VRÁNA (1966), on the Hronček granite by PITOŇÁK & SPIŠIAK (1994) and in the Kohút Zone by HRAŠKO (in press).

The Hronček type granite was in the last time the subject of structural as well as petrologic studies. PETRÍK et al. (1995) interpreted this granite type as a system of intrusions in a Hercynian shear zone, showing the effects of Hercynian and superimposed Alpine deformations. Contrary to this, HÓK & HRAŠKO (1990) considered all deformation structures to be Alpine.

Recently there appeared works characterising the deformation structures in the granites from the viewpoint of the effects of the Alpine extension (HÓK et al., 1993 and others). Indirect evidence (analogy with the Hercynian development in other regions, Upper Paleozoic basins and volcanism, extensional Hercynian quartz veins, rapid exhumation of the granitoid) however points to a very probable late Hercynian extension. The separation of older structural records from the superimposed Alpine ones, however, has always been a big problem in Veporicum, due to their similarity in direction and metamorphism.

The aim of this work is a contribution to the solution of the above problem and filling the gap in the knowledge of the structural position of one of the most frequently occurring granitoid type in Veporicum - porphyric granite. At the same time, it is an attempt to explain its relationship to other granitoids, the mode of emplacement and the relationship to the subsequent deformations.

Porphyric granitoids occupy large monotonous structural areas in Veporicum and, on the other hand, they form smaller bodies among hybrid types. More suitable for the study of structural relationships is the second type, therefore, a region of this character was selected for the study. It is the area north of Klenovec, between Klenovecká and Tisovecká Rimava. Geological setting of the region is shown in Fig. 1.




*Fig.1. Geological map of the area northwards from Klenovec*
*1- overthrusts, 2 - faults of undifferentiated sense of movement, 3- normal faults, 4 - nappes of Gemericum and Silicikum, 5 - mica schists, 6 - hybrid complex (deformed granitoids, migmatites, enclaves of gneiss), 7 - porphyric granitoids, 8 - Mesozoic cover (Foederata group)*

Porphyric granitoids form in the area studied smaller, steeply inclined bodies among hybrid types, but in the northern part often also extensive sub-horizontal bodies. Moreover, Mesozoic cover occurs here too, serving as a marker for distinguishing Alpine structures.

## Geology

The area under study is built predominantly of the hybrid complex and porphyric granitoids. Metamorphic rocks of the Kohút Zone and cover sequences occur to a lesser extent.

The **hybrid complex** is the oldest "building stone" of the area. It consists of the remnants of high-metamorphic gneiss-migmatite rocks "sunken" in hybrid granitoids. Two types of these granitoids may be distinguished.

The first type is markedly oriented (foliation and lineation is defined by biotite, it is mostly parallel with the foliation of migmatites). They are high-grade metamor-

phosed granitoids, even with local manifestations of anatexis. The second type is more or less homogeneous, and foliation is only very badly observable. Its composition corresponds to granodiorite to tonalite (BEZÁK & HRAŠKO, 1992). It has been observed that migmatites and metamorphosed granitoids "float" as blocks in this granitoid type. They sometimes have even the character of a breccia.

A characteristic feature of the hybrid complex is sometimes strong potassium metasomatism. Its manifestation is especially the growth of new K-feldspars (orthoclase), which usually enclose the original mineral assemblages, especially plagioclase, biotite and quartz. It must be noted that metasomatism is strongest near the intrusions of porphyric granitoids.

The hybrid complex underwent also retrograde metamorphism. In places where the foliation planes are steep, the retrograde effects are connected only with steep shear zones and typical sub-horizontal foliation is not developed. Retrograde metamorphism resulted usually in microclinisation, sericitisation of K-feldspars, albitisation and saussuritisation of plagioclases with the formation of epidote, clinozoisite or tiny phengitic muscovite, and in chloritisation of biotites.

**Porphyric granitoids** are a well-defined granitoid type, with white and pink K-feldspar phenocrysts. From the viewpoint of structural position they may be divided into two groups. The first are porphyric granitoids associated with the hybrid complex. They occur here in the form of dikes, several meters to tens of meters thick, penetrating the hybrid complex. We shall deal later with the emplacement mechanism and geometry of the intrusions in greater detail. The second group comprises porphyric granitoids on the NW margin of the area under study, forming the immediate underlier of the uppermost Paelozoic and Mesozoic sediments. Even more evidently than in the hybrid complex, differences may be observed in the development of the sub-horizontal extensional foliation, which has penetrative character in the sub-horizontally placed porphyric granites, while in the steep intrusions and dikes it is almost impossible to observe. Retrograde alterations, being the same process, are similar as in the hybrid granites.

On the NW margin of the area under study, **envelope sediments** of the uppermost Paleozoic belonging to the Foederata Group are lying on the porphyric granitoids. The lower part consists of an arkose and quarzite formation. The quartzites occur here as non-rhythmically repeating intercalations (several cm to tens of meters thick) in the arkoses, the transitions being quite frequently gradual. Lower Triassic shales have been preserved locally. The whole Foederata Group is characterised by metamorphism in the lower greenschist facies, at a temperature of about 350°C. In the tectonic overlier, with a marked tectonic jump, there are lying predominantly carbonate formations of the **Muráň Nappe** of the Silicicum.

In the SE part of the area there are **garnet micaschists** of the Ostrá complex, with sporadic metamorphosed products, especially of basic volcanism. They are separated from the hybrid complex by faults assigned to the Muráň system. Detailed mapping showed that the contact of the granitised complex and the Ostrá complex is very complicated. It is formed by a shear zone, in which, at several places, these complexes are overlapping in a scale-like way. Small bodies of amphibole diorite and leucocratic granitoid are associated with this zone. They are affected only by brittle deformations and hydrothermal alterations.

## STRUCTURAL CONDITIONS

### Hybrid complex

The dominant foliation is defined by the banding of migmatites, crystallisation schistosity of biotite gneisses and granitoids. The whole complex is strongly folded, the general direction of fold axes being E-W. Locally, folds with SE vergency have been preserved. In these places the lineation with NW-SE direction is preserved as well.

The second group are foliation types defined by retrograde alterations. The original assemblage - Or + Bi + Plg + Q $\pm$ Gr is partly or totally substituted by the assemblage $Bi_2 + Q_2$ + Mus + Ab + Chl + Ser $\pm$ Ep. They are associated exclusively with shear zones of E-W and NE-SW direction, the width of which varies from several millimetres to a few hundreds of meters. These rocks were in the past described as a different rock type (various schist types, micaschists etc.). After detailed mapping, their connection with the shear zones has been clearly proved. In some profiles it was possible to observe gradual transitions from migmatites to these mylonites, or the presence of non-deformed domains in which original rocks have been preserved.

The lineation is also of two kinds. The first is lineation of biotite in migmatites and biotite gneisses. It varies about E-W direction and it is sub-horizontal, with the exception of the already mentioned older lineation of NW-SE direction. Their dispersion is minimal in zones where the hybrid complex is penetrated by porphyric granitoids and their direction is identical with lineation in porphyric granitoids. Linear elements are very intensively developed in the shear zones of NE-SW direction and the rocks have a marked pencil structure. The second group is lineation of chlorite and sericite, which partly or totally substitutes biotite lineation. Their directions are often consistent and only exceptionally it was possible to observe on one outcrop a discordance in the direction of biotite and chlorite-sericite lineation.

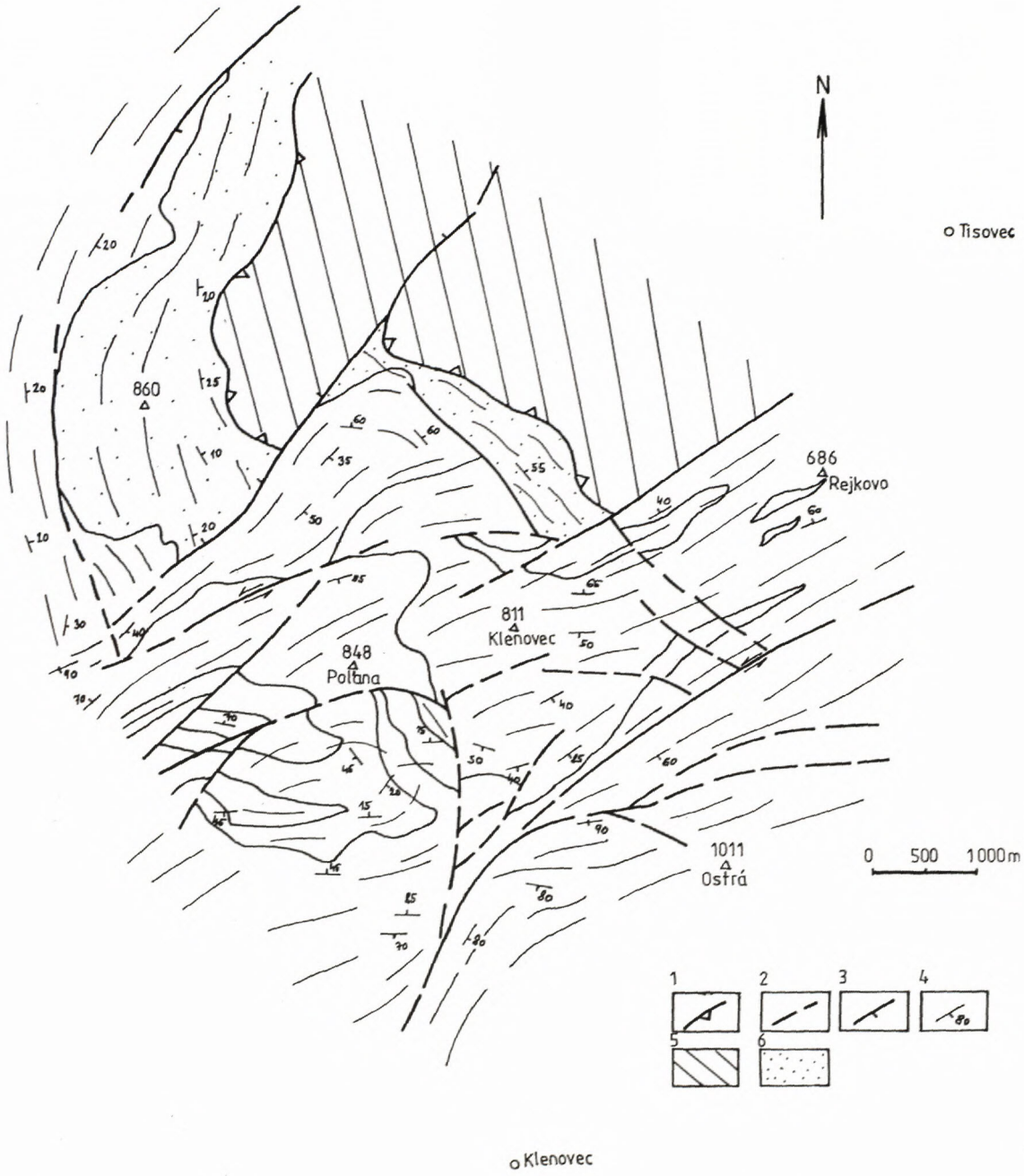



*Fig. 2. Foliation trajectories in crystalline and in cover of the Veporikum northwards from Klenovec*
*1 - overthrusts, 2 - faults (mostly strike-slip faults), 3 - normal faults, 4 - foliations, 5 - nappes of Gemerikum and Silicikum, 6 - Mesozoic cover*

## Porphyric granites

Similarly as in the hybrid complex, several types of foliation could be observed also in the porphyric granitoids. They are: 1) magmatic foliation connected with the deformation in the magmatic flow, defined by the preferential orientation of primary minerals (feldspar phenocrysts), their imbrication and also the presence of biotite schlieren or "fluvial textures"; 2) foliation generated by deformation in post-magmatic stage, defined by biotite lying in S-C structure, the presence of quartz ribbons etc., 3) foliation defined by retrograde alterations, especially into chlorite and sericite.

Mutual relationships of the foliation types in space are very varied and they were the main key to solving and understanding of the mechanisms of the emplace-

ment of porphyric granitoids. In the majority of cases the foliations are sub-parallel. Exceptionally it was possible to observe microscopically the opposite direction of motion on the planar structures. The map of foliation trajectories clearly shows the copying of the hybrid complex structures and their basically identical distribution in space. Differences occur only where there is a discordant contact between the porphyric granitoids and the hybrid complex. The position of retrograde alterations is wholly identical with the hybrid complex, these alterations are associated with identical shear zones. Slightly more monotonous are porphyric granitoids lying immediately below Upper Paleozoic and Mesozoic sequences, where all three foliation types are sub-horizontal and having the same direction.

As the investigated rocks are porphyric granitoids, besides the study of biotite, chlorite and sericite lineation it was possible to observe also lineation defined by the long axis of porphyric feldspar phenocrysts. The lineation of chlorite and sericite are, similarly as in the hybrid complex, connected with zones of retrograde alterations. Their direction is generally identical with biotite lineation. An important discovery were the results of the study of kinematic indicators. In the first group, characterised by relatively steep foliation of E-W direction and sub-horizontal lineation, the deformations of feldspars and biotites show a sinistral sense of movement. The shear zones with which the retrograde alterations were associated suggest dextral movement on the E-W zones and sinistral movement on the NE-SW zones. This fact has clearly genetically separated the biotite and chlorite-sericite lineation, identical in direction.

In the second group of porphyric granitoids, all three lineation types had the same direction and sense. These granitoids were emplaced at a higher level than the granites of the first group. An exception are transitional bodies between vertical and sub-horizontal ones. In view of the fact that they were directly connected with the sinistral regime in the shear zone of horizontal displacement, at their sub-horizontal emplacement they reveal once top to the east, other times top to the west movement, depending whether they were tipped to the north or to the south of the shear zone (Fig. 4).

## Upper Paleozoic-Mesozoic cover

Rocks belonging to this group occur on the NW margin of the area under study. Their structural setting is, in comparison with other rocks, simple and monotonous. Their metamorphism is reaching the lower part of the greenschist facies and their typical feature is the dominance of extensional structures (systematically top to the east, in contrast to the underlying granitoids). They are represented by foliation with a low angle, dipping to the E-NE. Lineation is formed exclusively of chlorite and sericite and it varies between E-W and NE-SW direction. This dispersion has been caused by the non-existence of an older preferential orientation of minerals (in contrast to rocks deformed in the Hercynian orogeny), allowing the rocks to react more sensitively to local changes of regional stress. In quartzites there are often preserved older folds (extensional foliation is cutting across these folds). As linear elements, the direction of which would be perpendicular to the axes of these folds, have not been preserved, it is not possible to form an opinion on their vergency and they provide only information on the existence of an older deformation.

## STRUCTURAL DEVELOPMENT OF THE TERRITORY AND MECHANISM OF INTRUSIONS OF PORHYRIC GRANITOIDS

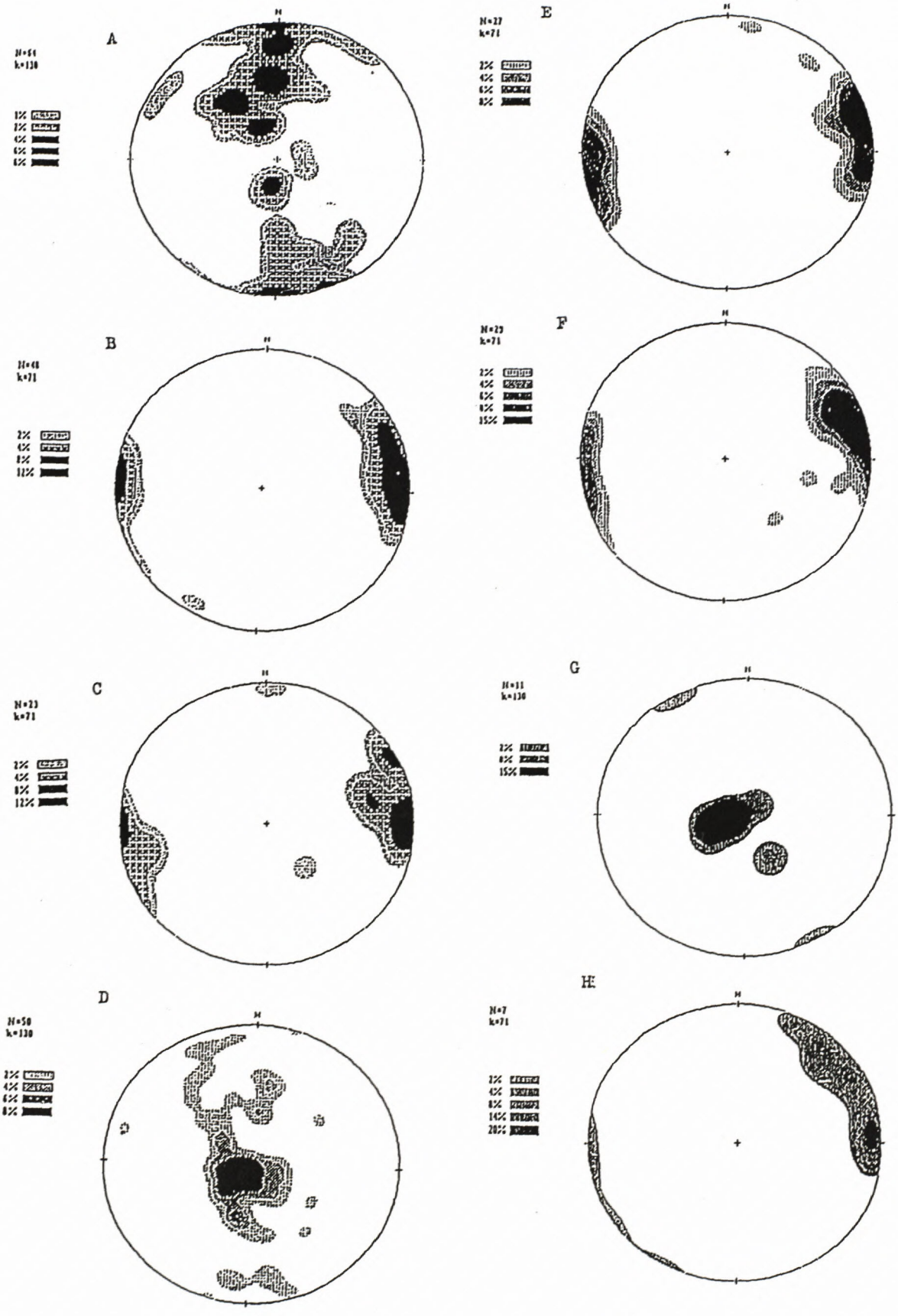
The oldest observed deformational stage are structures preserved in the remnants of a high-metamorphic cover complex and in older metamorphosed granitoids. It is mostly a considerably plastic deformation occurring in conditions near anatexis (BEZÁK 1991), probably at lower crust level. This stage includes the formation of hybrid granitoids. The formation of the dominant fold structures in the hybrid complex, with E-W fold axes, is connected with the progressing uplift of lower crust elements into mid-crustal levels and with thrust direction to S to SE.

Another deformation stage is connected with the intrusion of porphyric granitoids into the hybrid complex and their deformation in the magmatic stage. These intrusions are related to probably transpressional shear zones, having in present co-ordinates E-W direction and dipping mostly steeply to the north as well as to the south. E-W structures are a reflection of an older fold structure of the hybrid complex. The directions of superimposed shear zones are NE-SW. In zones of intensive shear, the structures of the hybrid complex have been rebuilt into this direction. The result of the overlapping of E-W and NE-SW structures is the typical S-shaped direction of the foliation.

Syntectonic emplacement of the porphyric granitoids is suggested especially due to the following phenomena:

- magmatic foliation in the marginal parts of porphyric granitoid intrusions are parallel to the margins of intrusions;
- the intensity of the development of magmatic foiation increases towards the margins of the intrusions;
- foliation in the surrounding rocks are more intensive towards the margins of the intrusions and they rotate from directions parallel with the margins of the intrusions.

With the gradual uplift and slight decrease of P-T conditions there is connected also the continual process of transition from deformation in magmatic state into deformation in post-magmatic stage. This is supported by the following evidence:


A
B
C
D
E
F
G
H

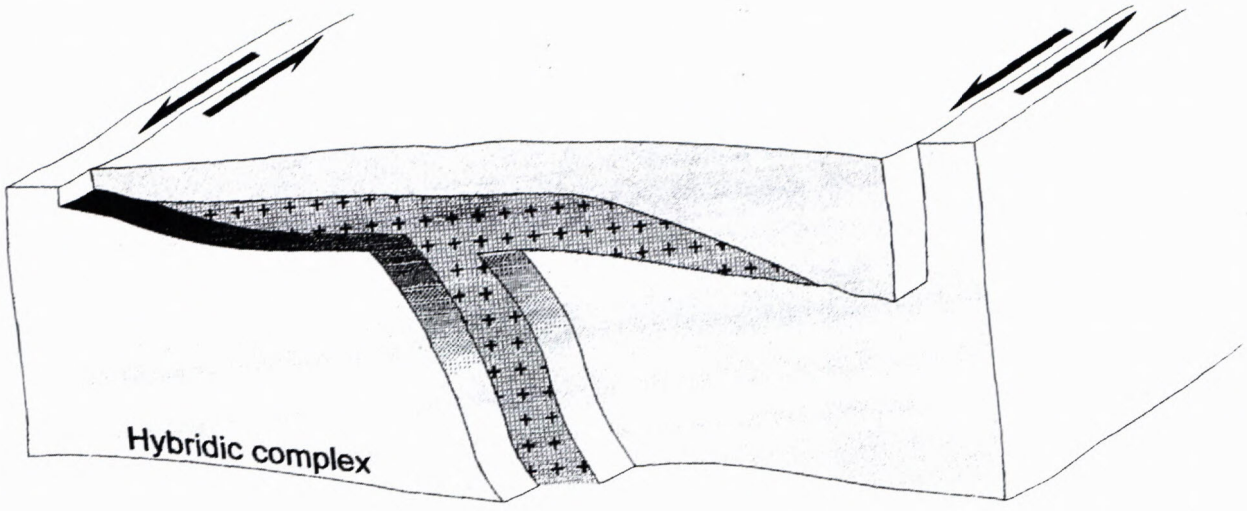



*Fig. 4. Blockdiagram showing opposite sense of shear on the base of granitoid intrusion involved by regional sinistral transtension. Apparent change of kinematics during the intrusion of laccoliths regime (top to the East, top to the West) depending on the position of the part of intruding body.*

- microscopic evidence of plastic deformation in magmatic plagioclases and biotites,
- a combination of grain-size reduction and marked elongation of fine-grained recrystallised aggregates into ribbon and spindle forms. The aggregates consist predominantly of feldspar and quartz, but also of new-crystallised muscovite or newly-formed biotite.

Metamorphic conditions of this deformation corresponded to the upper parts of the greenschist facies and they were similar to the metamorphic conditions of garnet micaschists (BEZÁK 1991).

With the above mentioned contact zone of the granitised complex and the Ostrá complex there are connected also the intrusions of leucocratic granites and amphibole diorites. This is evidence in favour of the important role of this zone in the Late Hercynian stage and they shift the foundation of the otherwise markedly Alpine line (Muráň fault system) at least to the Upper Paleozoic.

Structural manifestations of the Hercynian extension could not be unambiguously separated from the complex structural records, with the exception of sub-horizontally emplaced porphyric granites, where subsolidus and magmatic deformations are controlled by flattening, in some zones by shearing. This stage is indirectly indicated by the formation of Upper Paleozoic basins, volcanism, intrusions of leucocratic granitoids and strong hydrothermal activity.

Paleoalpine deformations resulted in the abundant development of sinistral transpressional shear zones in NE-SW direction. The compression was generally in N-S direction. E-W structures were rejuvenated again in this regime, acting as strike-slips. A typical feature of these shear zones is the with the deformation connected retrograde metamorphism in the lower greenschist facies. Compressional regime on E-W faults resulted in the formation of retrograde metamorphosed zones, several

*Fig. 3. Diagrams of structural elements*

*A. Foliation in the hybrid complex. Direction generally E-W, in shear zones rotated to NE-SW.*
*B. Biotite lineation in the hybrid complex. Generally E-W, parallel with fold axes direction. In shear zones rotated into NE-SW direction. Locally preserved N-S lineation.*
*C. Chlorite and sericite lineation in the hybrid complex. Sub-horizontal lineation is predominant, having E-W to ENE-WSW direction.*
*D. Foliation in porphyric granitoids. In dikes it has E-W direction, in shear zones it is rotated into NE-SW direction. In laccoliths it is sub-horizontal.*
*E. Biotite lineation in porphyric granitoids. It is parallel with preferential orientation of feldspar phenocrysts. Kinematic indicators show sinistral movement in vertical bodies, at higher levels (subhorizontal bodies) is the interpretation of kinematics not unambiguous.*
*F. Chlorite and sericite lineation in porphyric granites. It is parallel with older lineation may be observed locally.*
*G. Foliation in cover arkoses and quartzites.*
*E. Chlorite and sericite lineation in cover arkoses and quartzites.*

hundred meters wide, while the shear regime on NE-SW faults affected by the retrograde processes only several meters wide zones. A typical mineral assemblage is quartz + sericite + chlorite ± muscovite. In the crystalline complex, rocks affected by this deformation have usually the character of S-C mylonites, while the S-C structure is defined by the above mentioned mineral assemblage. This deformation stage is characterised by a transition from the transpressional regime into extension towards E to NE. In sub-horizontally emplaced porphyric granitoids in the uderlier of the cover, the extension resulted even in penetrative development of S-C mylonites, with the formation of the retrograde mineral assemblage quartz + sericite + chlorite. In the cover sequences the extension resulted in the dominant development of stretching lineation of chlorite and sericite, the indicators clearly and systematically indicating top to the east movement. At lower levels, where porphyric granitoids and the hybrid complex have vertical structure, extension resulted in further rejuvenation of E-W structures as dextral horizontal displacements. Sub-horizontal shear zones developed only sporadically.

In the Neoalpine stage the structural record of the continuation of the regime of extensive horizontal displacements are ambiguous (MARKO 1993). Tectonic development continued mostly in extensional regime connected with the development of Neogene basins, volcanism and downthrow of blocks on NW-SE and NE-SW faults.

## Conclusions

Porphyric granotids intruded within E-W sinistral, probably transpressional shear zones, using older structural predisposition. They formed dike swarms parallel with the direction of the shear zone. At a decrease of the lithostatic pressure at higher levels the dikes passed into laccoliths, or similar intrusive forms, while at subsolidus and post-magmatic conditions flattening took place in the middle and shearing on the margins (transition into extension). In this way, these bodies reached the surface already in the Pre-Alpine time (unroofing) and the Mesozoic cover sedimented on them.

As far as the age of the studied porphyric granitoids is concerned, they probably belong to the end of the Meso-Hercynian tectonic stage (360-340 Ma, BEZÁK et al. 1995). They must be older than the intrusions of the Sihla granitoids (300 Ma, BIBIKOVA et al. I. 1990) and also older that the cooling of this part of the middle Hercynian lithotectonic unit in the sense of BEZÁK (1994) below 500°C (350-340 Ma, KRÁĽ et al. 1996). This magmatic pulse is indirectly indicated by the ages of leucoratic granitoid facies of the middle unit in Veporicum - about 350 Ma (BIBIKOVA et al. 1988).

The dike intrusions have been subsequently deformed within NE-SW oriented sinistral shear zones, the foundation of which is probably Neohercynian. This is supported by synkinematic mineral assemblages, which are higher-temperature than Alpine ones, and by the relationship of the Permian intrusion to such zones (PETRÍK et al. 1995).

The Paleoalpine deformation resulted in deeper zones in the formation of NE-SW transpressional shear zones (horizontal displacements) with local E-W strike slips and, in higher zones, thrusting. In the next stage of development, extension with transportation towards E to NE occurred on rejuvenated sub-horizontal planes, at lower levels also on inherited vertical E-W discontinuities. The movement on them was, in contrast to the Hercynian deformation, dextral and took place at lower P-T conditions.

## References


BEZÁK V., 1991: Metamorphic conditions of the Veporic unit in the Western Carpathians. Geologica Carp. 42, 4, 219-222.

BEZÁK V. & HRAŠKO Ľ., 1992: Základné geologické členenie granitoidov západnej časti Slovenského rudohoria. Geol. práce, Správy, 95, 25-31 (In Slovak, Engl. res.).

BEZÁK V., 1994: Návrh nového členenia kryštalinika Západných Karpát na základe rekonštrukcie hercýnskej tektonickej stavby. Mineralia slov., 26, 1-6 (In Slovak, Engl. res.)

BEZÁK V., JANÁK M., KRÁĽ J., PETRÍK I., SPIŠIAK J. & VOZÁROVÁ A., 1995: Pre-Alpine evolution of the Western Carpathians. Europrobe, Stará Lesná.

BIBIKOVA E. V., CAMBEL B., KORIKOVSKY S. P., BROSKA, I., GRACHEVA T. V., MAKAROV, V. A. & ARAKELIANTS, M. M., 1988: U-Pb and K-Ar isotopic dating of Sinec (Rimavica) granites (Kohút zone of Veporides). Geol. zb. Geol. carp., 39, 2, 147-157.

BIBIKOVA E. V., KORIKOVSKY S. P., PUTIŠ M., BROSKA I., GOLTZMAN, Y. V. & ARAKELIANTS M. M., 1990: U-Pb, Rb-Sr, and K-Ar dating of Sihla tonalites of the Vepor pluton (Western Carpathians Mts.). Geol. Zbor. Geol. carpath., 41, 4, 427-436.

HÓK J., KOVÁČ P. & MADARÁS J., 1993: Extenzná tektonika západného úseku styčnej zóny gemerika a veporika. Mineralia slov., 25, 172-176 (In Slovak, Engl. res.).

HÓK J. & HRAŠKO L., 1990: Deformačná analýza západnej časti pohorelskej línie. Mineralia slov., 22, 69-80 (In Slovak).

HOVORKA D., 1960: Príspevok k petrografii veporidných granitoidov, Acta Geol. geogr. Univ. Com., Geol. 4, 255-262 (In Slovak, German res.)

KAMENICKÝ J., 1977: Contact imetamorphism in the aureola of the rimavica granite (West Carpathians Mts.). Mineralia slov., 9, 3, 161-184.

KLINEC A., MACEK J., DÁVIDOVÁ Š. & KAMENICKÝ J., 1980: Rochovský granit v styčnej zóne gemerid s veporidmi. Geol. práce, Správy 74, 103-112 (In Slovak, Engl. res.).

KRÁĽ J., FRANK W. & BEZÁK V., 1996: $^{40}Ar/^{39}Ar$ spektrá z amfibolu amfibolických hornín veporika. Mineralia slov., 28, 501-513 (In Slovak, Engl. res.)

KRIST E., 1979: Granitoid rocks of the southwestern part of the veporide crystalline complex. Geol. Zbor. Geol. carp., 30, 2, 157-179.

KRIST E., 1981: The problem of genesis of granitoids from then veporide crystalline complex from the point of view of K-feldspar, biotite and zircon investigation, Geol. Zbor. Geol. Carp., 32, 6, 671-678.

MARKO F., 1993: Kinematics of Muráň fault between Hrabušice and Tuhár village. In: RAKÚS - VOZÁR (ed:) Geodynamický model a hlbinná stavba Záp. Karpát. GÚDŠ Bratislava, 253-262.

PETRÍK I., BROSKA I., BEZÁK V. & UHER P., 1995: Granit typu Hrončok - hercýnsky granit A-typu v strižnej zóne. Mineralia slov., 27, 5, 351-364.

PITOŇÁK P. & SPIŠIAK J., 1994: Blastomylonity hrončockého granitu. Mineralia slov., 26, 171-176 (In Slovak, Engl. res.).

SIEGL K., 1982: Structure of the Vepor pluton (West Carpathians). Geol.zb.Geol.carp., 33, 2, 171-175.

VRÁNA S., 1966: Alpidische metamorphose der Granitoide und der Foederataserie im mittelteil der Veporiden. Zbor. Geol. Vied, rad ZK, 6, 29-84.

ZOUBEK V., 1936: Poznámky o krystaliniku Západních Karpat. Věst. SGÚ, XII, 212-227.

SLOVAK GEOLOGICAL MAGAZINE

# Gabbroid rocks - a newly-found member of the leptyno-amphibolite complex of the Western Carpathians

PETER IVAN[1], DUŠAN HOVORKA[2] & ŠTEFAN MÉRES[1]

[1]Department of Geochemistry, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava
[2]Department of Mineralogy and Petrology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava

*Abstract.* In the Veporic Unit of the Nízke Tatry Mts. gabbroids have been found. They bear primary magmatic minerals as well as primary fabric. Till now two varieties have been discerned: (1) troctolites, and (2) two-pyroxene gabbros. Based on cumulate texture and magmatic mineral compositions gabbroids might originate as a part of differenciated (leyered?) intrusion. Characteristics and mineral composition represent analogies of leptyno-amphibolite complex gabbroids from type-localities in the Massif Central (France). The autors consider discussed LAC gabbroids as reworked lower crustal complex of magmatic origin.

*Key words:* gabbroids, lithology, leptyno-amphibolite complex, Western Carpathians

## Introduction

An important part of the Western Carpathian pre-Alpine basement is built of the leptyno-amphibolite complex (LAC). LAC was distinguished on the basis of common occurrence of the following rock types: amphibolites, leptynites, garnet-pyroxene metabasites and metaperidotites (HOVORKA et al., 1992, 1994). LAC rocks in the Western Carpathians are, as far as their composition and metamorphism, comparable with type LAC rocks as defined by SANTELLIER et al. (1988). In the Western Carpathian LAC, gabbroids, occurring commonly on the type localities (e.g. French Massif Central), have so far not been found.

## Geology

The northern part of the studied Veporic Unit in the Nízke Tatry Mts. consists, according to the geological map (KLINEC et al., 1976; BIELY et al., 1992) of rocks of the Hron Complex (KLINEC, 1966): amphibolites, garnet-muscovite-biotite paragneisses, mica schist gneisses to micaschists. On the southern slopes of the Nízke Tatry Mts. (in the valleys Temná, Krivuľa and Koleso) we found also occurrences of gabbroids. In the majority of cases they are various types of metamorphosed gabbro derivatives. In the Koleso Valley, occurrences of well-preserved gabbroid bodies have been found, the size of which does not exceed a few tens of meters. Towards their surroundings they pass into intensively metamorphosed derivatives, especially amphibolites. Based on a preliminary study, we may state that they are spatially and genetically related to the leptyno-amphibolite complex (LAC).

## Petrography

Gabbroids of the Nízke Tatry Veporicum are medium-grained massive rocks of black-grey colour, with a brownish shade. They display preserved primary magmatic minerals and structures. Two petrographic types may be distinguished among them: (1) troctolites, (2) two-pyroxene gabbros.

Troctolite is composed predominantly of olivine and plagioclase, less abundant are from magmatogenic minerals orthopyroxene, clinopyroxene, ilmenite and chrom-spinelide. The rock has a preserved cumulate texture. The cumulate is formed of idiomorphic to hypidiomorphic olivine containing enclosed chrospinelide octahedrons. The intercumulus crystallised in the form of ophitically arranged plagioclase, along with a smaller quantity of ortho- and clinopyroxene.

Two-pyroxene gabbros have gabbroophitic texture. From magmatogenic minerals, there are represented plagioclases, ortho- and clinopyroxenes, in a lesser quantity olivines and ilmenite.

Troctolites and two-pyroxene gabbros bear sings of superimposed multi-stage metamorphic alterations. The predominant one was high-temperature hydration. It resulted in the formation of brown amphibole, from mafic magmatogenic silicates. The process took place in intergranulars and besides simple amphibole margins and grains, in the first stage of the process there formed also symplectites of clinopyroxene, amphibole and plagioclase. The subsequent metamorphic recrystallisation resulted in the troctolites and two-pyroxene gabbros in the formation of bluish-green and colourless amphibole, garnet, biotite, clinozoisite, chlorite, serpentine, iddingsite, white mica, titanite, magnetite and calcite.

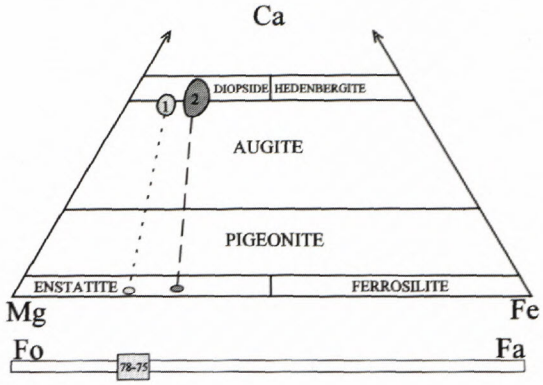



*Fig. 1. Classification diagram (MORIMOTO et al. 1988) for pyroxenes of gabbroic rocks from the Nízke Tatry Mts. (Veporic Unit). 1 - clinopyroxenes from troctolite, 2 - clinopyroxenes from two pyroxene gabbro.*

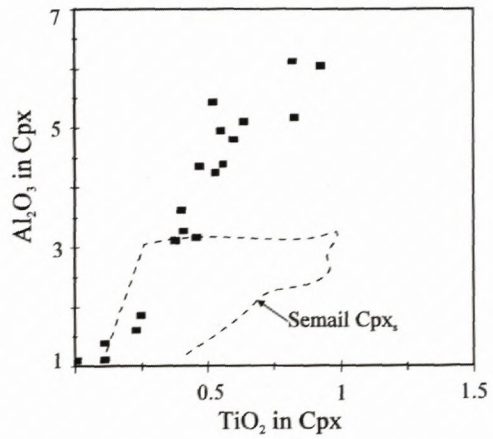



*Fig. 2. $Al_2O_3$ vs. $TiO_2$ diagram for gabbroic clinopyroxenes from the Nízke Tatry Mts. Dashed field - composition of Semail Ophiolite gabbroic rocks (taken from ELTHON; 1987).*

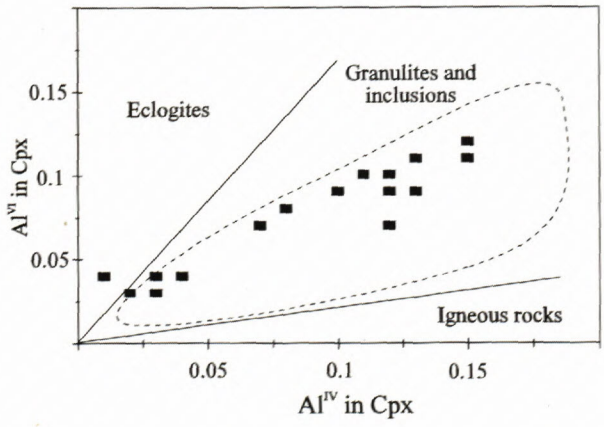



*Fig. 3. $Al^{VI}$ vs. $Al^{IV}$ diagram for clinopyroxenes of gabbroic rocks from Nízke Tatry Mts. Dashed field - composition of clinopyroxenes from basal gabbro of Tonsina Complex (DE BARI and COLEMAN, 1989). other fields by AOKI and KUSHIRO (1968).*

## Mineralogy

In this study of both gabbro types, there were studied the compositions of magmatogenic olivine, orthopyroxenes, clinopyroxenes, plagioclases, chromspinelids and from metamorphogenic minerals, the composition of brown amphiboles.

The composition of olivine varies in a narrow range ($Fo_{75-78}$, Fig. 1). Olivines with such composition are found in oceanic basic and ultrabasic cumulates ($Fo_{72-88}$, ELTHON et al., 1992), but also in tholeiite layered intrusions and ocean arc gabbros ($Fo_{90-40}$, and $Fo_{88-62}$, respectively; BEARD, 1986).

Clinopyroxene in MORIMOTO´s et al. classification (1988) is with its composition on the boundary of diopside and augite (Fig. 1). Clinopyroxenes of troctolites are more Mg-rich than clinopyroxenes of two-pyroxene gabbros. In comparison with cumulates and gabbros, they contain more Fe and Ca (HÉBERT et al. 1989). The Al contents in clinopyroxenes (Fig. 2) are also increased in comparison with oceanic or ophiolite analogues. Low-Al clinopyroxenes occurring in two-pyroxene gabbros along with high-Al clinopyroxenes are suggested to be the products of superimposed metamorphic processes. The $Al^{IV}$ vs. $Al^{VI}$ ratio in the studied clinopyroxenes is different from clinopyroxenes of common magmatites crystallising in low-pressure conditions (Fig. 3) and they rather resemble clinopyroxenes of granulites, high-pressure xenoliths or gabbros from the basal level of the ocean arc lower crust (DE BARI and COLEMAN, 1989).

Orthopyroxene composition corresponds to enstatite (Fig. 1) and the differences in Fe-contents between orthopyroxenes of troctolites and two-pyroxene gabbros are analogous to those of clinopyroxenes.

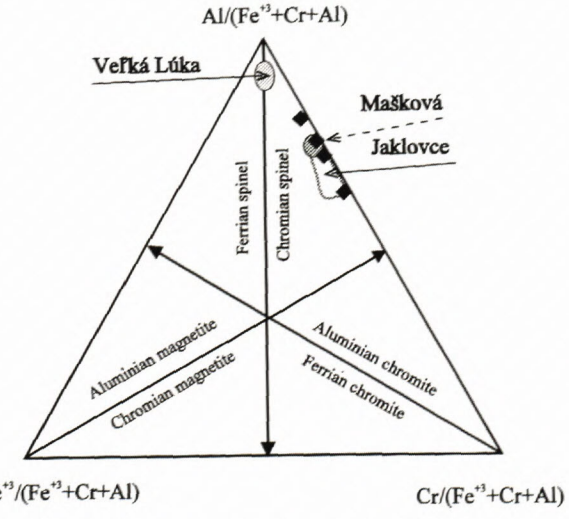



*Fig. 4. Spinel from troctolite in classification diagram by Stevens (in ROJKOVIČ, 1985) Fields for peridotite xenolith spinels (Mašková), ophiolitic peridotite spinels (Jaklovce) and deuteroperidotite spinels (Veľká lúka) are ploted for comparison (data by ROJKOVIČ, 1985).*

The composition of plagioclase from gabbroids varies in the range of $An_{62-65}$, in the two-pyroxene gabbro there has been also determined plagioclase with $An_{84}$. The ratio between plagioclase basicity and the contents of the Fo component in olivine, which in gabbros may reflect the geodynamic setting (BEARD, 1986), is similar to tholeiite layered intrusions.

Spinel in troctolites belongs to chromium spinels (Fig. 4). Its composition resembles spines of upper-mantle origin, but it is different from spinels of oceanic rocks (Fig. 5).

Brown amphiboles which are the products of the earliest stage of the metamorphic alteration correspond, according to their composition in LEAKE´s (1978) classification, to Ti-pargasite, Ti-pargasitic hornblende to pargasitic hornblende (Fig. 6). Amphiboles of analogous composition from gabbros have been described as products of high-temperature (900-1040°) hydration by OTTEN (1984).

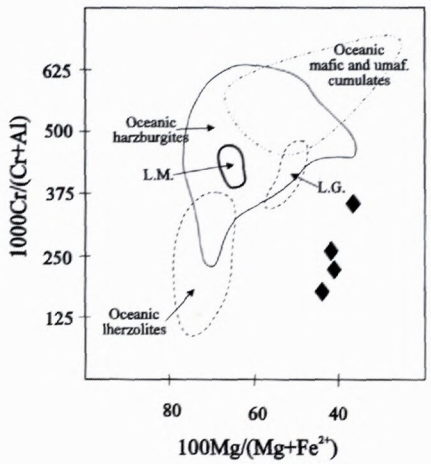



*Fig. 5.Composition of spinel in a Cr/(Cr+Al) vs. Mg/(Mg+$Fe^{2+}$) diagram for troctolite with comparison to oceanic rocks. Fields from HÉBERT et al. (1989). L.M. = Macquarie lherzolites, L.G. = Gorringe lherzolites.*

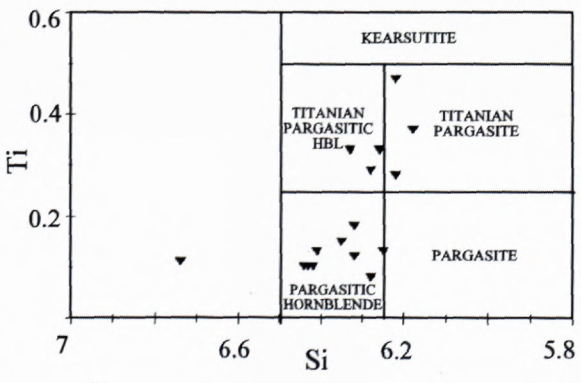



*Fig. 6. Brown amphiboles from gabbroic rocks of the Nízke Tatry Mts. in classification diagram by OTTEN (1984) based on the classification of amphiboles by LEAKE (1978).*

Tab. 1 Representative microprobe analyses of olivines from gabroids of the Veporic Unit (the Nízke Tatry Mts.) Structural formula calculated on the basis of 4-O

| Sample | VV-100 | VV-100 | VV-100 | VV-100 |
|---|---|---|---|---|
| Ol. N$^0$ | 77 | 81 | 95 | 100 |
| $SiO_2$ | 38.78 | 39.23 | 39.25 | 38.61 |
| $TiO_2$ | 0.08 | 0.01 | 0.00 | 0.00 |
| $Al_2O_3$ | 0.02 | 0.03 | 0.02 | 0.00 |
| $Cr_2O_3$ | 0.13 | 0.03 | 0.01 | 0.07 |
| FeO | 22.09 | 21.93 | 20.49 | 23.63 |
| MnO | 0.32 | 0.30 | 0.00 | 0.48 |
| MgO | 39.95 | 39.59 | 40.87 | 38.54 |
| CaO | 0.00 | 0.06 | 0.00 | 0.00 |
| $Na_2O$ | 0.03 | 0.00 | 0.02 | 0.00 |
| $K_2O$ | 0.00 | 0.05 | 0.03 | 0.01 |
| Total | 101.40 | 101.26 | 100.69 | 101.35 |
| Si | 0.99 | 1.01 | 1.00 | 1.00 |
| Ti | 0.00 | 0.00 | 0.00 | 0.00 |
| Cr | 0.00 | 0.00 | 0.00 | 0.00 |
| Fe | 0.47 | 0.47 | 0.44 | 0.51 |
| Mn | 0.01 | 0.01 | 0.00 | 0.01 |
| Mg | 1.53 | 1.51 | 1.56 | 1.48 |
| Total | 3.00 | 2.99 | 3.00 | 3.00 |
| Xmg | 0.77 | 0.76 | 0.78 | 0.74 |

Tab. 2 Representative microprobe analyses of clinopyroxenes from gabroids of the Veporic Unit (the Nízke Tatry Mts.) Structural formula calculated on the basis of 6-O

| Sample | VV-120 | VV-120 | VV-120 | VV-100 | VV-100 | VV-100 |
|---|---|---|---|---|---|---|
| Cpx N$^0$ | 2 | 23 | 25 | 90 | 96 | 98 |
| $SiO_2$ | 52.05 | 51.82 | 49.82 | 49.96 | 51.01 | 51.31 |
| $TiO_2$ | 0.25 | 0.40 | 0.52 | 0.93 | 0.55 | 0.53 |
| $Al_2O_3$ | 1.85 | 3.63 | 5.43 | 6.04 | 4.94 | 4.25 |
| $Cr_2O_3$ | 0.11 | 0.19 | 0.51 | 0.73 | 0.65 | 0.57 |
| FeO | 8.46 | 7.79 | 7.59 | 4.98 | 4.00 | 4.16 |
| MnO | 0.32 | 0.31 | 0.23 | 0.23 | 0.16 | 0.13 |
| MgO | 13.65 | 13.80 | 14.28 | 15.07 | 16.41 | 16.31 |
| CaO | 22.14 | 21.12 | 19.01 | 19.87 | 20.11 | 20.45 |
| $Na_2O$ | 0.43 | 0.69 | 0.93 | 1.17 | 1.14 | 0.98 |
| $K_2O$ | 0.10 | 0.09 | 0.14 | 0.09 | 0.01 | 0.09 |
| Total | 99.37 | 99.83 | 98.44 | 99.09 | 98.98 | 98.77 |
| Si | 1.95 | 1.92 | 1.87 | 1.85 | 1.88 | 1.90 |
| $Al^{IV}$ | 0.04 | 0.08 | 0.13 | 0.15 | 0.12 | 0.1 |
| Ti | 0.01 | 0.01 | 0.01 | 0.02 | 0.02 | 0.01 |
| $Al^{VI}$ | 0.04 | 0.08 | 0.11 | 0.11 | 0.09 | 0.09 |
| Al | 0.08 | 0.16 | 0.24 | 0.26 | 0.21 | 0.19 |
| Cr | 0.00 | 0.01 | 0.02 | 0.02 | 0.02 | 0.02 |
| Fe | 0.27 | 0.24 | 0.24 | 0.15 | 0.12 | 0.13 |
| Mn | 0.01 | 0.01 | 0.01 | 0.01 | 0.00 | 0.00 |
| Mg | 0.76 | 0.76 | 0.80 | 0.83 | 0.90 | 0.90 |
| Ca | 0.89 | 0.84 | 0.76 | 0.79 | 0.79 | 0.81 |
| Na | 0.03 | 0.05 | 0.07 | 0.08 | 0.08 | 0.07 |
| K | 0.00 | 0.00 | 0.01 | 0.00 | 0.00 | 0.00 |
| Xmg | 0.74 | 0.76 | 0.77 | 0.85 | 0.88 | 0.87 |

Tab. 3 Representative microprobe analyses of orthopyroxenes from gabbroids of the Veporic Unit (the Nízke Tatry Mts.). Structural formula calculated on the basis of 6-O.

| Sample | VV-100 | VV-100 | VV-120 | VV-120 |
|---|---|---|---|---|
| Opx No | 108 | 106 | 26 | 30 |
| $SiO_2$ | 55.16 | 54.60 | 52.37 | 51.97 |
| $TiO_2$ | 0.12 | 0.17 | 0.11 | 0.12 |
| $Al_2O_3$ | 1.13 | 1.23 | 0.66 | 0.77 |
| $Cr_2O_3$ | 0.03 | 0.05 | 0.03 | 0.10 |
| FeO | 15.32 | 15.77 | 25.89 | 25.35 |
| MnO | 0.37 | 0.34 | 0.89 | 1.32 |
| MgO | 27.12 | 27.55 | 19.98 | 20.22 |
| CaO | 1.00 | 0.51 | 0.40 | 0.60 |
| $Na_2O$ | 0.08 | 0.04 | 0.01 | 0.00 |
| $K_2O$ | 0.00 | 0.02 | 0.00 | 0.02 |
| Total | 100.33 | 100.28 | 100.34 | 100.47 |
| $Si^{IV}$ | 1.98 | 1.96 | 1.98 | 1.96 |
| $Al^{IV}$ | 0.02 | 0.04 | 0.02 | 0.03 |
| $Al^{VI}$ | 0.03 | 0.02 | 0.01 | 0.00 |
| Ti | 0.00 | 0.00 | 0.00 | 0.00 |
| Fe | 0.46 | 0.47 | 0.82 | 0.80 |
| Mn | 0.01 | 0.01 | 0.03 | 0.04 |
| Mg | 1.45 | 1.48 | 1.13 | 1.14 |
| Ca | 0.04 | 0.02 | 0.02 | 0.02 |
| Na | 0.01 | 0.00 | 0.00 | 0.00 |
| K | 0.00 | 0.00 | 0.00 | 0.00 |
| Xmg | 0.76 | 0.76 | 0.58 | 0.59 |

Tab. 4 Representative microprobe analyses of plagioclases from the gabroids of the Veporic Unit (the Nízke Tatry Mts.) Structural formula calculated on the basis of 8-O

| Sample | VV-100 | VV-100 | VV-120 | VV-120 |
|---|---|---|---|---|
| Opx No | 108 | 106 | 26 | 30 |
| $SiO_2$ | 55.16 | 54.60 | 52.37 | 51.97 |
| $TiO_2$ | 0.12 | 0.17 | 0.11 | 0.12 |
| $Al_2O_3$ | 1.13 | 1.23 | 0.66 | 0.77 |
| $Cr_2O_3$ | 0.03 | 0.05 | 0.03 | 0.10 |
| FeO | 15.32 | 15.77 | 25.89 | 25.35 |
| MnO | 0.37 | 0.34 | 0.89 | 1.32 |
| MgO | 27.12 | 27.55 | 19.98 | 20.22 |
| CaO | 1.00 | 0.51 | 0.40 | 0.60 |
| $Na_2O$ | 0.08 | 0.04 | 0.01 | 0.00 |
| $K_2O$ | 0.00 | 0.02 | 0.00 | 0.02 |
| Total | 100.33 | 100.28 | 100.34 | 100.47 |
| $Si^{IV}$ | 1.98 | 1.96 | 1.98 | 1.96 |
| $Al^{IV}$ | 0.02 | 0.04 | 0.02 | 0.03 |
| $Al^{VI}$ | 0.03 | 0.02 | 0.01 | 0.00 |
| Ti | 0.00 | 0.00 | 0.00 | 0.00 |
| Fe | 0.46 | 0.47 | 0.82 | 0.80 |
| Mn | 0.01 | 0.01 | 0.03 | 0.04 |
| Mg | 1.45 | 1.48 | 1.13 | 1.14 |
| Ca | 0.04 | 0.02 | 0.02 | 0.02 |
| Na | 0.01 | 0.00 | 0.00 | 0.00 |
| K | 0.00 | 0.00 | 0.00 | 0.00 |
| Xmg | 0.76 | 0.76 | 0.58 | 0.59 |

## Discussion

The cumulate texture of the gabbroids and differences in the mineral composition indicate that these rocks originally represented a component of a differentiated (layered?) intrusion. Data on chemical composition of the rock are not available yet. In spite of this, it we may assume that the studied gabbroids are in their composition different from analogous oceanic rocks. They probably crystallised at higher pressures than oceanic gabbroids from magma with low water content and hydrous minerals were formed in the sub-solidus stage of the incorporation of the fluid at relatively high temperatures. Further metamorphic stages are superimposed on this alteration. The petrographic characteristics and mineral composition of gabbroids from the vicinity of Hel'pa are analogous to gabbros of the leptyno-amphibolite complexes of type localities in French Massif Central (c. f. PIN & LANCELOT, 1982; BRIAND et al., 1991). They are a part of the LAC forming the northern part of the Veporic Unit. The crystallisation at high pressures, high-temperature hydration and multi-stage regression support our interpretation of the LAC as a reworked lower crustal complex of magmatic origin.

Tab. 5 Representative microprobe analyses of spinels from the gabroids of the Veporic Unit (the Nízke Tatry Mts.) Structural formula calculated of the basis of 3 cations. $Fe^{+3}$ calculated from spinel stechiometry.

| Sample | VV-100 | VV-100 | VV-100 | VV-100 |
|---|---|---|---|---|
| Sp. $N^0$ | 78 | 93 | 101 | 105 |
| $TiO_2$ | 0.01 | 0.03 | 0.00 | 0.07 |
| $Al_2O_3$ | 43.77 | 48.94 | 45.74 | 36.47 |
| $Cr_2O_3$ | 22.93 | 16.11 | 19.82 | 30.03 |
| $Fe_2O_3$ | 0.00 | 0.28 | 0.00 | 0.26 |
| FeO | 23.30 | 23.68 | 23.80 | 24.83 |
| MnO | 0.24 | 0.20 | 0.28 | 0.35 |
| MgO | 9.54 | 10.32 | 9.60 | 8.34 |
| CaO | 0.11 | 0.00 | 0.00 | 0.07 |
| Total | 99.90 | 99.57 | 99.24 | 100.42 |
| Ti | 0.00 | 0.00 | 0.00 | 0.00 |
| Al | 1.49 | 1.63 | 1.55 | 1.28 |
| Cr | 0.52 | 0.36 | 0.45 | 0.71 |
| $Fe^{+3}$ | 0.00 | 0.01 | 0.00 | 0.01 |
| $Fe^{+2}$ | 0.56 | 0.56 | 0.57 | 0.62 |
| Mn | 0.01 | 0.00 | 0.01 | 0.01 |
| Mg | 0.41 | 0.44 | 0.41 | 0.37 |
| Ca | 0.00 | 0.00 | 0.00 | 0.00 |

## Conclusions

1) For the first time, gabbroids which are a rock member of a leptyno-amphibolite complex, have been found in the pre-Alpine basement of the Western Carpathians.

Tab. 6 Representative microprobe analyses of amphiboles from the gabroids of the Veporic Unit (the Nízke Tatry Mts.) Structural formula calculated on the basis of 23-O

| Sample | VV-100 | VV-100 | VV-100 | VV-120 | VV-120 | VV-120 |
|---|---|---|---|---|---|---|
| Hbl No | 92 | 104 | 111 | 2 | 21 | 12 |
| $SiO_2$ | 43.41 | 44.00 | 44.29 | 42.57 | 43.93 | 44.01 |
| $TiO_2$ | 4.37 | 3.09 | 2.72 | 1.59 | 1.17 | 0.95 |
| $Al_2O_3$ | 13.24 | 12.89 | 13.25 | 14.06 | 13.40 | 13.49 |
| $Cr_2O_3$ | 0.13 | 0.05 | 0.19 | 0.09 | 0.77 | 0.53 |
| FeO | 7.28 | 7.28 | 6.08 | 13.70 | 11.47 | 12.31 |
| MnO | 0.14 | 0.14 | 0.04 | 0.32 | 0.20 | 0.28 |
| MgO | 14.62 | 14.98 | 16.58 | 10.90 | 12.56 | 12.31 |
| CaO | 11.50 | 11.67 | 12.00 | 11.15 | 11.52 | 11.36 |
| $Na_2O$ | 3.12 | 3.08 | 3.08 | 2.19 | 2.15 | 2.16 |
| $K_2O$ | 0.39 | 0.51 | 0.46 | 0.71 | 0.60 | 0.48 |
| Total | 98.20 | 97.69 | 98.69 | 97.28 | 97.77 | 97.88 |
| $Si^{IV}$ | 6.22 | 6.33 | 6.28 | 6.32 | 6.41 | 6.43 |
| $Al^{IV}$ | 1.78 | 1.67 | 1.72 | 1.68 | 1.59 | 1.57 |
| T site | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 | 8.00 |
| $Al^{VI}$ | 0.45 | 0.52 | 0.49 | 0.78 | 0.72 | 0.76 |
| Ti | 0.47 | 0.33 | 0.29 | 0.18 | 0.13 | 0.10 |
| Cr | 0.01 | 0.01 | 0.02 | 0.01 | 0.09 | 0.06 |
| Mg | 3.12 | 3.21 | 3.50 | 2.41 | 2.73 | 2.68 |
| Fe | 0.87 | 0.88 | 0.70 | 1.62 | 1.33 | 1.40 |
| Mn | 0.02 | 0.02 | 0.00 | 0.00 | 0.00 | 0.00 |
| Ca | 0.05 | 0.04 | 0.00 | 0.00 | 0.00 | 0.00 |
| M1,2,3 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 | 5.00 |
| Fe | 0.00 | 0.00 | 0.02 | 0.08 | 0.07 | 0.11 |
| Mn | 0.00 | 0.00 | 0.00 | 0.04 | 0.02 | 0.03 |
| Ca | 1.77 | 1.80 | 1.82 | 1.77 | 1.80 | 1.78 |
| Na | 0.23 | 0.20 | 0.15 | 0.11 | 0.10 | 0.08 |
| M4 site | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 | 2.00 |
| Na | 0.63 | 0.66 | 0.70 | 0.52 | 0.51 | 0.53 |
| K | 0.07 | 0.09 | 0.08 | 0.13 | 0.11 | 0.09 |
| A site | 0.65 | 0.72 | 0.78 | 0.65 | 0.62 | 0.62 |
| Xmg | 0.78 | 0.79 | 0.83 | 0.59 | 0.66 | 0.64 |

2) Two petrographic gabbroid types have been distinguished: troctolites and two-pyroxene gabbros.

3) Based on the composition of magmatogenic minerals, the gabbroids are not analogues of ophiolite gabbros, they are similar to gabbros of layered tholeiite intrusions which crystallised at elevated pressure.

4) The gabbroid rocks underwent high-temperature hydration, with the formation of Ti-rich amphiboles and subsequent multi-stage retrograde alteration

## References


BEARD, J. S. 1986: Characteristic mineralogy of arc-related cumulate gabbros: Implications for the tectonic setting of gabbroic plutons and for andesite genesis. Geology, 14, 848-851.

BIELY, A., BEŇUŠKA, P., BEZÁK, V., BUJNOVSKÝ, A., HALOUZKA, R., IVANIČKA, J., KOHÚT, M., KLINEC, A., LUKÁČIK, E., MAGLAY, J., MIKO, O., PULEC, M., PUTIŠ, M. & VOZÁR, J. 1992: Geological map of Nízke Tatry Mts. 1 : 50 000. Geol. úst. D. Štúra, Bratislava.

BRIAND, B., PIBOULE, M., SANTALLIER, D. & BOUCHARDON, J. L. 1991: Geochemistry and tectonic implications of two Ordovician bimodal igneous complexes, southern French Massif Central. J. geol. Soc., 148, 959-971.

DE BARI, S. M. & COLEMAN, R. G. 1989: Examination of deep levels of an island arc: Evidence from the Tonsina ultramafic-mafic assemblage, Tonsina, Alaska. J. geophys. Res., 94, 4373-4391.

ELTHON, D. 1987: Petrology of gabbroic rocks from the Mid-Cayman Rise spreading center. J. geophys. Res., 92, 658-682.

ELTHON, D., STEWARD, M. & ROSS, D. K. 1992: Compositional trends of minerals in oceanic cumulates. J. geophys. Res., Solid Earth, 97, 15189-15200.

HÉBERT, R. SERRU, G. & HÉKINIAN, R. 1989: Mineral chemistry of ultramafic tectonites and ultramafic to gabbroic cumulates from major oceanic basins and Northern Appenine ophiolites (Italy) - A comparison. Chemical Geology, 77, 183-207.

HOVORKA, D, MÉRES, Š. & IVAN, P., 1992: Pre-Alpine Western Carpathian Mts. Basement Complexes: Geochemistry, Petrology, Geodynamic Setting. Terra Nova 4, Abstract supl. N$^{O}$ 2, 32.

HOVORKA, D., MÉRES, Š. & IVAN, P. 1994: Pre-Alpine Western Carpathians Basement Complexes: Lithology and Geodynamic Setting. Mitt. Österr. Geol. Ges., 86, 33-44 (Wien)

KLINEC, A. 1966: K problémom stavby a vzniku veporského kryštalinika. Sbor. geol. Vied, Západ. Karpaty, 6, 7-28.

KLINEC, A. et al. 1976: Geological map of Slovenské rudohorie and Nízke Tatry Mts. 1 : 50 000. Geol. úst. D. Štúra, Bratislava.

LEAKE, B. E. 1978: Nomenclature of amphiboles. Miner. Mag., 42, 533-563.

MORIMOTO, N., FABRIES, J., FERGUSON, A. K., GINZBURG, I. V., ROSS, M., SEIFERT, F. A., ZUSSMAN, J., AOKI, K. & GOTTARDI, G. 1988: Nomenklature of Pyroxenes. Min. Petrol., 39, 1, 55-76.

OTTEN, M. T. 1984: The origin of brown hornblende in the Artjället gabbro and dolerites. Contr. Mineral., Petrology, 86, 189-199.

PIN, CH. & LANCELOT, J. 1982: U-Pb dating of an Early Paleozoic bimodal magmatism in the French Massif Central and its further metamorphic evolution. Contr. Mineral. Petrology, 79, 1-12.

ROJKOVIČ, I. 1985: Ore mineralization of ultramafic bodies of the Western Carpathians. Veda, Bratislava, 1-116.

SANTALLIER, D., BRIAND, B. MÉNOT, R. P. & PIBOULE, M. 1988: Les complexes leptyno-amphibolitiques (C. L. A.): revue critique et suggestions pour un meilleur emploi ce terme. Bull. Soc. Géol. France, 8, 3-12.

SLOVAK GEOLOGICAL MAGAZINE

# Genetic relationship of greenschists and amphibolites in Veporicum of the Nízke Tatry Mts.

ŠTEFAN MÉRES[1] & DUŠAN HOVORKA[2]

[1]Faculty of Natural Sciences, Comenius University, Department of Geochemistry, Mlynská dolina, 842 15 Bratislava
[2]Faculty of Natural Sciences, Comenius University, Department of Mineralogy and Petrology, Mlynská dolina, 842 15 Bratislava

*Abstract.* Within the Nízke Tatry Mts. metabasites we have distinguished: (1) typical greenschists, and (2) diapthorites of the greenschists facies appearance. Majority of their bodies is located on tectonic zone between the Hron complex and the Jánov Grúň complex. From realized field as well as laboratory studies if follows that a part of the Jánov Grúň matabasites ranked till now among greenschists represents diaphorites of amphibolites. In the past they have been ranked to the Hron complex; at present we consider them to be member of the leptyno-amphibolite complex of the Western Carpathians.

*Key words:* amphibolites, greenschists, diapthorites, Veporic Unit, Western Carpathians

## Introduction

In the Nízke Tatry Mts. Veporicum complex there are isolated bodies of greenschists and amphibolites. However, gradual transition between the amphibolites and greenschists may be observed frequently as well. This is the reason of different opinions on their genesis.

Some authors suggest common genesis of both meta-basic rock types and they classify these rocks within the Hron Complex (KLINEC, 1966), the metamorphism of which reached PT conditions of the amphibolite facies. The authors explained the different character of metamorphism as the result of progressive metamorphism of basic rocks, and they considered the greenschist to be diaphtorites of amphibolites.

Another opinion assumes different genesis of amphibolites and greenschists. The criteria for this are based on the different grade of metamorphism and geological position. The amphibolites are included into the Hron Complex and the greenschist into the low-metamorphic Janov grúň Formation. This opinion was accepted also by the authors of the latest geological map of this area (BIELY et al., 1992).

During a preliminary study of greenschists from the Janov grúň Fm. we obtained results which are not entirely consistent with the last mentioned conclusion.

## Geology

The Janov grúň Formation (MIKO, 1981; MIKO & IVANIČKA, 1993) consists of chlorite-sericite phyllite, sericite-chlorite-albite phyllites, sericite-quartz phyllites, metamorphosed effusive rocks and volcaniclastics of rhyodacite to dacite composition, metadiabases and greenschists. Paleovolcanic rocks of the Janov grúň Fm. belong, according to MIKO (l.c.), into the spilite-diabase-keratophyre formation. The rocks of the Janov grúň Fm. were metamorphosed in the greenschist facies conditions (T = 340 - 370°C, P = 340-400 MPa, MIKO & KORIKOVSKY, 1994).

The presence of metamorphosed products of basic volcanism - greenschists - is typical for the lower part of the Janov grúň Fm. (MIKO, l.c., MIKO & IVANIČKA, l.c.). One of the largest bodies is lying 2.5 - 3 km ENE of Mýto pod Ďumbierom, on the western slopes of Priehybka (Fig. 1). This body and greenschist bodies in the Ždiarska Valley, NNW of Polomka and N of Závadka nad Hronom and Heľpa (marked in the geological map of BIELY et al., 1992) were the subject of our study.

## Petrography

By a detailed field and thin section study, the following rocks may be distinguished among the meta-basic rocks of the studied bodies:

a) **Typical greenschists.** They are represented by fine-grained rocks of dark green colour, as a rule with well pronounced metamorphic foliation. Fine-augen structure is formed of characteristic tabular albite porphyroblasts. The rock matrix is formed predominantly of sub-microscopic chlorite aggregate. In the greenschists there are fine-grained titanite clusters, irregular grains of minerals of the clinozoisite-epidote group, carbonate nests, idioblastic ore minerals (magnetite, pyrite). Equigranular greenschists are sometimes characterised by a sub-microscopic grain-size. The locally present quartz is concentrated predominantly in small lenses. Such greenschist types are usually described as progressively metamorphosed volcanics/volcaniclastic material of basic volcanites.

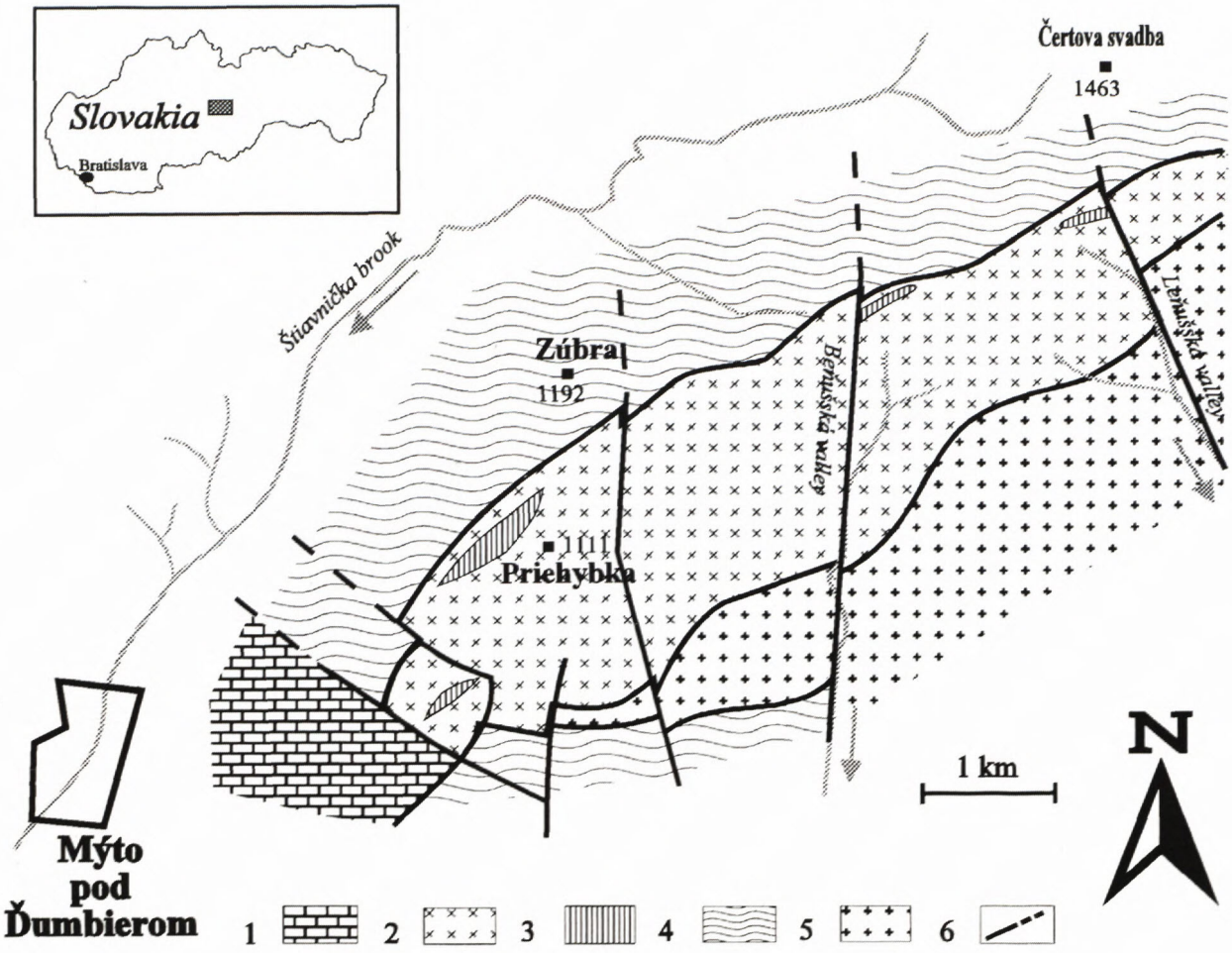



*Fig. 1: Geological map of the western part of the Janov grúň Formation (simplified from* MIKO *and* IVANIČKA *1993). 1 = Mesozoic; 2 = Jánov grúň Formation (phyllites, rhyodacites, dacites and their volcaniclastics); 3 = metadiabases and greenschists; 4 = Hron Complex (micaschists, amphibolites); 5 = biotite granitoids; 6 = tectonic boundaries*

b) **Diaphtorised amphibolites.** They are fine-grained rocks, in which the predominant phase is green to greenish-brown amphibole with plan-parallel orientation. A characteristic feature are wholly or partly preserved (pseudomorphed by chlorite) porphyroblastic garnets. Plagioclases are strongly recrystallised into a fine-grained aggregate of white mica, albite, quartz, chlorite and clinozoisite. A characteristic metamorphic newly-formed mineral is chlorite. Rocks of this group bear frequently signs of faint banded texture, with alternating lighter and darker bands. This type of meta-basic rocks occurs usually in the central part of the studied bodies.

## Geochemistry

The aim of the preliminary geochemical study was to test on a limited number of samples the possibility of obtaining exact geochemical data necessary for the study of genesis of the problematic meta-basic rocks. Therefore, we focused on the determination of REE contents. Analytical determination of REE (carried out by the INAA method in the laboratories of MEGA, a.s., Stráž pod Ralskem, Czech Republic) is listed in Table 1.

From a comparison of REE contents in both end types it is obvious that there are no (or only negligible) differences between them (Tab. 1, Fig. 2). Both samples have low ΣREE, normalised REE curves are flat, similar to primitive basalt types.

## Discussion and conclusions

If we would include all greenschists of the Nízke Tatry Mts. Veporicum unit into the Janov grúň Formation, we would be confronted with the following problems:

- the majority of larger bodies is situated in a tectonic zone between the Hron Complex and the Janov grúň Formation,

Tab. 1 REE contents (in ppm values) in the studied meta-basic rocks of the Nízke Tatry Mts. Veporicum.

| | La | Ce | Nd | Sm | Eu | Gd | Tb | Tm | Yb | Lu | ΣREE |
|---|---|---|---|---|---|---|---|---|---|---|---|
| G-3 | 5.80 | 14.80 | 11.00 | 4.30 | 1.40 | 5.00 | 1.05 | 0.54 | 4.30 | 0.75 | 48.94 |
| G-4 | 5.80 | 14.90 | 12.50 | 4.10 | 1.25 | 5.10 | 0.99 | 0.60 | 3.80 | 0.55 | 49.59 |

*Sample G-3 is a typical greenschist with augen structure. Predominant minerals are albite and chlorite, less abundant is quartz and carbonate.*
*Sample G -4 is diaphtorised garnet amphibolite. From minerals corresponding to PT conditions of the amphibolite facies, predominant are amphibole and plagioclase. Less abundant is garnet. The metamorphic assemblage of the amphibolite facies comprises 70% of the rock, the rest is a younger assemblage corresponding to PT conditions of the greenschist facies (albite, quartz, chlorite, sericite, epidote and carbonate).*

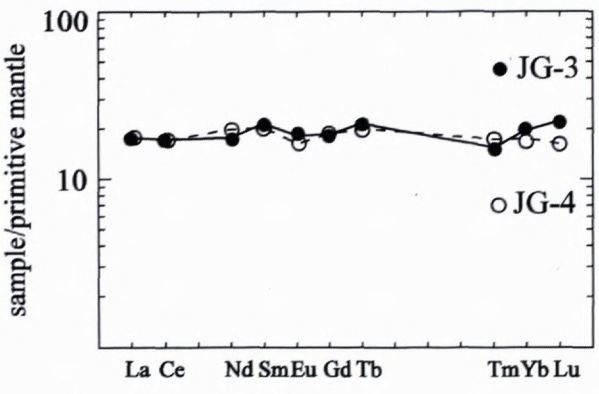



*Fig. 2: REE contents in the studied metabasites, primitive-mantle normalised (SUN 1982)*

- greenschist bodies, as indicated in the geological map (BIELY et al. 1992) north of Heľpa, alternate with amphibolites of the Hron Complex. Such geological position is in our opinion not very probable. This is supported also by mutual transitions of greenschists and amphibolites, which may be observed in field outcrops. A younger mineral assemblage occurs in the amphibolites, corresponding to their recrystallisation in the same conditions as the metamorphism of greenschists.

REE contents in two samples of the studied meta-basic rocks suggests the following preliminary conclusions:

a) the practically identical REE contents in the greenschist and diaphtorised garnet amphibolite indicate that the greenschists represents a totally diaphtorised amphibolite,

b) the protolith of both greenschist and the diaphtorised garnet amphibolite were very probably the same rocks,

c) REE appear to have been immobile during the diaphtoresis, which shows the suitability of their application in the detailed study of the genesis of greenschists and amphibolites,

d) low ΣREE and primitive character of REE distribution in both cases is practically identical with REE characteristics determined in amphibolites of the leptyno-amphibolite complex in the Western Carpathians (LAC - HOVORKA et al. 1992, 1994, HOVORKA & MÉRES 1993, or "banded amphibolites" in the terminology of SPIŠIAK and PITOŇÁK 1992, JANÁK et al. 1993, or amphibolites of the Hron Complex, KLINEC 1966).

From the above facts it follows that a part of the meta-basic rocks marked in the 1 : 50 000 geological map (BIELY et al., 1992) as greenschists of the Janov grúň Formation are diaphtorites of amphibolites. They were formerly assigned to the Hron Complex (KLINEC 1966), at present we classify them with the leptyno-amphibolite complex. These are most probably especially the greenschist bodies situated near the tectonic contact of the Hron Complex (LAC) and the Janov grúň Formation.

## References

BIELY, A., BEŇUŠKA, P., BEZÁK, V., BUJNOVSKÝ, A., HALOUZKA, R., IVANIČKA, J., KOHÚT, M., KLINEC, A., LUKÁČIK, E., MAGLAY, J., MIKO, O., PULEC, M., PUTIŠ, M. & VOZÁR, J. 1992: Geol. mao of Nízke Tatry Mts. 1:50 000. Geol. úst. D. Štúra, Bratislava.

HOVORKA, D, MÉRES, Š. & IVAN, P., 1992: Pre-Alpine Western Carpathian Mts. Basement Complexes: Geochemistry, Petrology, Geodynamic Setting. Terra Nova, Abstract Supl., 2, 32, Oxford.

HOVORKA, D. & MÉRES, Š. 1993: Leptynitovo-amfibolitový komplex Západných Karpát: vystupovanie a litologická náplň. Mineralia slov., 25, 1, 1-9 (in Slovak, Engl. res.).

HOVORKA, D., MÉRES, Š., & IVAN, P. 1994: Pre-Alpine Western Carpathians Basement Complexes: Lithology and Geodynamic Setting. Mitt. Österr. Geol. Ges., 86, 33-44 Wien.

JANÁK, M., BEZÁK, V., BROSKA, I., FRITZ, H., KAHAN, Š., KOHÚT, M., NEUBAUER, F., O' BRIEN, P. J., ONSTOTT, T. C., REICHWALDER, P. & UHER, P. 1993: Deformation, metamorphism and granitoid magmatism in the Tatry Mts., (Central Western Carpathians, tatric unit): record of Variscan and Alpine orogeny. In: "Pre-Alpine Events in the Western Carpathians' Realm", (PITOŇÁK & SPIŠIAK Eds.), Excursion Guide, 51-61.

KLINEC, A. 1966: K problémom stavby a vzniku veporského kryštalinika. Sbor. geol. Vied, Západ. Karpaty, 6, 7-28 (In Slovak).

MIKO, O. 1981: Srednepaleozojskaja vulkanogenno-osadočnaja tolšča Janovogo grunja v veporidnom kristallinike Nizkich Tatr. Geol. Zbor. Geol. carpath., 32, 4, 465-474 (In Slovak, Engl. res.).

MIKO, O. & IVANIČKA, J. 1993: Formácia Janovho grúňa severovýchodne od Mýta pod Ďumbierom. Mineralia slov., 25, 4, 274-276.

MIKO, O. & KORIKOVSKY, S. P. 1994: Metamorphism of the Jánov grúň lower Paleozoic volcano-sedimentary formation (Veporic unit, Western Carpathians). Geol. carpath., 45, 1, 57-65.

SPIŠIAK, J. & PITOŇÁK, P. 1992: Banded amphibolic rocks - Pre-Variscan Basement of the Western Carpathians? Terra Nova 4, Abstract supl., 2 , 63.

SUN, S. S. 1982: Chemical composition and origin of the Earth's primitive mantle, Geochimica et Cosmochimica Acta, 46, 179-192.

SLOVAK GEOLOGICAL MAGAZINE

# Deformation and p-T conditions estimated in "layered migmatites" from southern part of Veporicum crystalline basement (Western Carpathians; Slovakia)

PAVOL SIMAN[1], VERA JOHAN[2], PATRICK LEDRU[2], VLADIMÍR BEZÁK[1] & JÁN MADARÁS[1]

[1] Geological Survey of Slovak republic, Mlynská dol. 1, Bratislava 817 04, Slovakia
[2] BRGM, Ave. de Concyr, BP 6009, 45060 Orléans cedex 2, France

*Abstract:* The relics of high-grade metamorphosed rocks in the SW Veporicum basement (gneisses, migmatites, or "hybridic granitoids") are interpreted as host rocks of the Hercynian granitoids. There are peraluminous rocks occurring here as well lack an $Al_2SiO_5$ polymorph. Migmatites exhibit syngenetic ductile deformation associated with partial melting. It appears that melting was active during the deformation. According to calculated p-T conditions for the earliest metamorphism we assume 680-730°C at 4-6 kbar and around 550-600°C for the retrograde branch. Next metamorphosis signify calculated p-T conditions from 480-510°C at 3.5-4.5 kbar to 490-540°C at ~8-10 kbar. Si contents (6.46 p.f.u./22 ox.) of coexisting phengite points to higher pressure conditions ~7 kbar.

*Key words:* Western Carpathians, Veporicum unit, migmatite, petrology, p-T condition.

## Introduction

Veporicum consists of a crystalline basement and Upper Paleozoic-Mesozoic cover. The complex inner structure of Veporicum may be explained by the combined activity of several tectonic stages.
The evolution and the definition of the Veporicum basement before the intrusion of granitoids has still not been sufficiently explained, due to the strong Alpine metamorphic overprint in greenschist facies conditions. This contribution focused on the estimation of P,T conditions in the "hybridic", gneisso-migmatitic unit of the Veporicum basement (Fig. 1).

## Previous works - a short review

The Veporicum crystalline basement consists of the old orogenic crust, mainly composed of quartzo-feldspathic units, which has been progressively exhumed, covered by detrital sequences, involved in collision and then re-exhumed. The structure of the basement is heterogeneous. Ideas about tectonic setting and pre-metamorphic development were presented by ZOUBEK (1928, 1936), who assumed a uniform Lower Palezoic volcano-sedimentary complex; ZOUBEK & MÁŠKA, KAMENICKÝ (in MAHEĽ et al. 1967) and KAMENICKÝ (1982) distinguished and specified two stratigraphic - tectonic units. The lower unit is a highly metamorphosed, synkinematically migmatised Middle Proterozoic unit. The upper one is low-grade metamorphosed, of Upper Proterozoic age. KLINEC (1966) suggested Alpine nappe structure of the Veporicum. BEZÁK devoted detailed research to the basement (1982, 1988, 1990, 1991,1992). HOVORKA et al. (1992) divided the pre-Alpine complexes of the Western Carpathians into four groups and classified migmatites in two units, according to their origin. Three main Hercynian lithotectonic units were discerned according to BEZÁK (1994).

The Lower Unit occurs mainly in the southern part and it is tectonically superposed by the Middle Unit. The Upper Unit is present in the form of separate tectonic remnants, and it occurs beyond the boundaries of the studied area. Each unit contains yet several particular complexes.

The Lower Unit is built up of metamorphites of the greenschist facies (mica schists, albitic gneisses, chlorite-muscovite schists, amphibolites). Scattered small granitic intrusions are present rarely.

The Middle Unit comprises a broader range of metamorphites, starting from the upper part of the greenschist facies up to the upper part of the amphibolite facies. The age of the above mentioned metamorphites is uncertain, probably Proterozoic - Early Paleozoic. Radiometric data for more exact dating of the Hercynian metamorphism are missing as well.

Granitoids form large bodies with intrusive contacts, surrounded by high grade metamorphites, such as gneisses and migmatites. They originated (were emplaced) in several pulses. According to radiometric data there are three age groups of granitoids - about 350 Ma, 300 Ma, 280-260 Ma (PETRÍK et al., 1993). Thy are often strongly deformed, as much as to orthogneiss.

## Geology of the studied area

The relics of high-grade metamorphosed rocks (gneiss, migmatites, or "hybridic granitoids") are interpreted as host rocks of the Hercynian granitoids. They form a narrow belt beneath the Hercynian granitoids in their southern part.

The descriptive definition refers to more-less stromatitic "migmatites", locally tectonised; biotite-schists (metagreywackes) similar to orthogneiss? from localities Liešnica valley, Klenovec, Muránska Zdychava (Fig. 1).

Peraluminous rocks occurring here as well lack an $Al_2SiO_5$ polymorph, and contain quartz, plagioclase, biotite, muscovite - phengite, garnet, K-feldspar, ± chlorite, rarely hornblende and accessory minerals - monazite, ilmenite, zircon to allanite, magnetite, sphene, apatite.

It is uncertain what was the protolith of these rocks. It seems that they were "active margin" greywackes (intermediate to rich in Qtz) with contents of shale material (or older acid volcanic - magmatic, quartzo-feldspathic rocks by previous study SIMAN, 1995). These experienced several intense metamorphic events with different p-T-t paths.

## Petrography and mineral compositon

*Plagioclase* forms partly retrogressed to granoblastic aggregates of more or less sodic grains filled with sericite ± zoisite. In the most deformed rocks the plagioclase is commonly replaced by albite and/or a sericite filling. There was no zonation observed in plagioclase grains. However, plagioclase adjacent to a Ca-rich hem of garnet from Klenovec indicates a slight decrease in the anorthite component on the contact with garnet. This phenomena could be interpreted as a relic of normal zoning of plagioclase or it could indicate a reaction with garnet during the "compressional event"?.

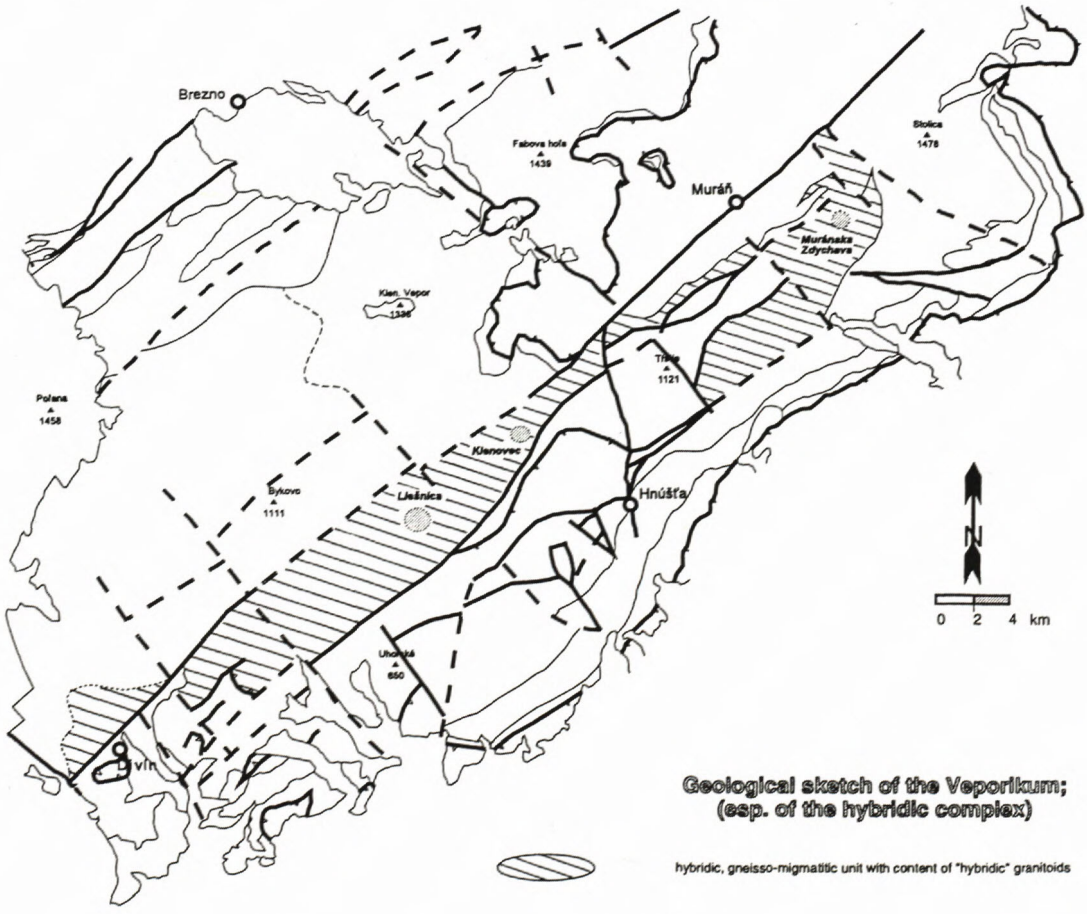



*Fig. 1 Geological sketch-map of the "hybridic complex" of the Veporikum (shaded regions represent studied areas)*

*Quartz* often appears as wavy ribbon-like layers or recrystallised granoblastic aggregates and crushed mylonitic grains.

*K-feldspar* is found as cataclastic, perthitic relics rarely with myrmekitic structures or very small grains in interstitial vacancies between plagioclase, quartz, in Liešnica accompanied on leucogranitoid layers by garnets and muscovites.

*White mica* is represented by flakes of more or less phengitic composition, with lower content of paragonite and sericite, pseudomorphing plagioclase. It may have increased the pressure of metamorphism, contemporaneously decreasing the temperature at the presence of sufficient amount of fluids. Only some white micas from Klenovec contain up to 20 mol% of paragonite. Muscovite-phengite associated with garnet aggregates shows relativelly higher contents of Si (p.f.u.) from 6.4 to 6.6 /22ox.

*Biotite* occurs as two or three types, distinguished according to different colours in thin sections, the contents of $TiO_2$, MgO and FeO/total. $Al^{VI.}$ varies from 0.6 to 1 and Mg/(Mg+Fe) from 0.33 to 0.57, generally, which is relativelly typical of muscovite-bearing amphibolite facies rocks (metapelites, metagreywackes), after GUIDOTTI (1987). However, the biotites from more diferenciated - separated migmatised rocks show a slight shift to lower $Al^{VI.}$ contents, higher Fe contents and they contain about 3 wt % $TiO_2$. However, the relativelly uniform composition of matrix biotite implies some pervasive Mg-Fe diffusion probably associated with deformation. Clearly different composition has biotite in garnet aggregates; it is more Fe-rich with higher $Al^{VI.}$ contents than biotite elsewhere and contains a very small amount of $TiO_2$ (0.65-0.98 wt %), generally.
The presence of two *garnet* generations was confirmed by microprobe analyses in some "migmatites". Garnet occurs as small to medium (up to 3 mm) subhedral and brittle crushed porphyroblasts. The older garnet type forms cores of porphyroblasts consisting of almandine-pyrope solid solutions with low contntes of grossularite and spessartine molecules. The younger garnet type forms rims - hems arround older cores and it differs especially by a high-grossularite composition. These hems alone seem to be progressively zoned and sometimes they contain inclusions of clinozoisite-zoisite.

Lack of zoning or few retrograde features in the garnet cores are interpreted as the result of homogenization by cation volume diffusion at more than 600°C, after WOODSWORTH (1977) or of high-grade origin of garnet cores - arround 600-700°C, after AVČENKO (1982).

Garnet from Muránska Zdychava occupies a particular position in the whole unit. It is generally relativelly progade zoned, with increased contents of grossularite molecule.

Two genetic garnet types, with two explanations, have been distinguished in the Veporicum basement rocks by previous observations, by MÉRES & HOVORKA (1991a,b), KORIKOVSKI et al. (1989, 1990), KOVÁČIK (1991, 1993).

## Deformation

The general strike of dip of hybridic granitoids and migmatites is to NW. Heterogeneous deformation (with brittle, brittle-ductile and ductile shear mylonitic zones) is associated with the layering, which is folded. Re-orientation of migmatitic and metamorphic foliation planes shows syngenetic ductile deformation associated with partial melting. It appears that melting was active during the deformation (there is melted material along the axial plane of folds, specially in the Liešnica valley).

Migmatites exhibit a typical varying course of strike and dip axial planes of folds and B-axis of asymmetric folds, due to high plasticity conditions during the deformation. The local rotation of the mineral lineation defined by Bt (from NW-SE to NE-SW) indicates highly non-homogeneous strain probably near an early ductile shear zone.

High temperature ductile shear zones and shear bands from Liešnica valley, Klenovec show sinistral movement on meso- and microscale. Ductile deformations of plagioclase probably indicate Hercynian kinematics: top to the NE resp. NE-SW shearing. Dykes of granitoids from Muránska Zdychava are strongly boudinaged and folded except their internal parts. Deformation took place within lithons. Melting conditions were reached in the middle part. High temperature deformation indicates NW-SE movement; later shear bands defined by chlorite indicate Alpine shear to the E.

## Geothermometry and geobarometry

Metamorphic temperatures have been estimated from the Fe-Mg exchange reaction between coexisting biotite - garnet, and metamorphic pressure was calculated using garnet - biotite - muscovite - plagioclase callibrations. The first geothermometric and geobarometric results indicate a metamorphic discontinuity across the unit stressed by the presence of regressively zoned cores of garnets with uncertain position of Ca-rich rims (hems).

According to calculated p-T conditions for the earliest metamorphism (equilibration with non-deformed dark brown, $TiO_2$-rich matrix biotite and garnet cores) we assume 680-730°C at 4-6 kbar and around 550-600°C for the retrograde branch, (Fig. 2).

Garnet from Muránska Zdychava (X-ray mapping) indicates prograde growth zonation with calculated p-T conditions from 480-510°C at 3.5-4.5 kbar to 490-540°C at ~8-10 kbar, (Fig. 2). Si contents (6.46 p.f.u./22 ox.) of coexisting phengite (after Massonne-Schreyer calibration) points to higher pressure conditions ~7 kbar.

Ca (Gross)-rich garnet hems with co-existing new-formed low-Ti biotite, phengite and more or less albitic plagioclase yielded different p-T conditions, approx.. 450-530°C at 7-10 kbar, (Fig. 2).

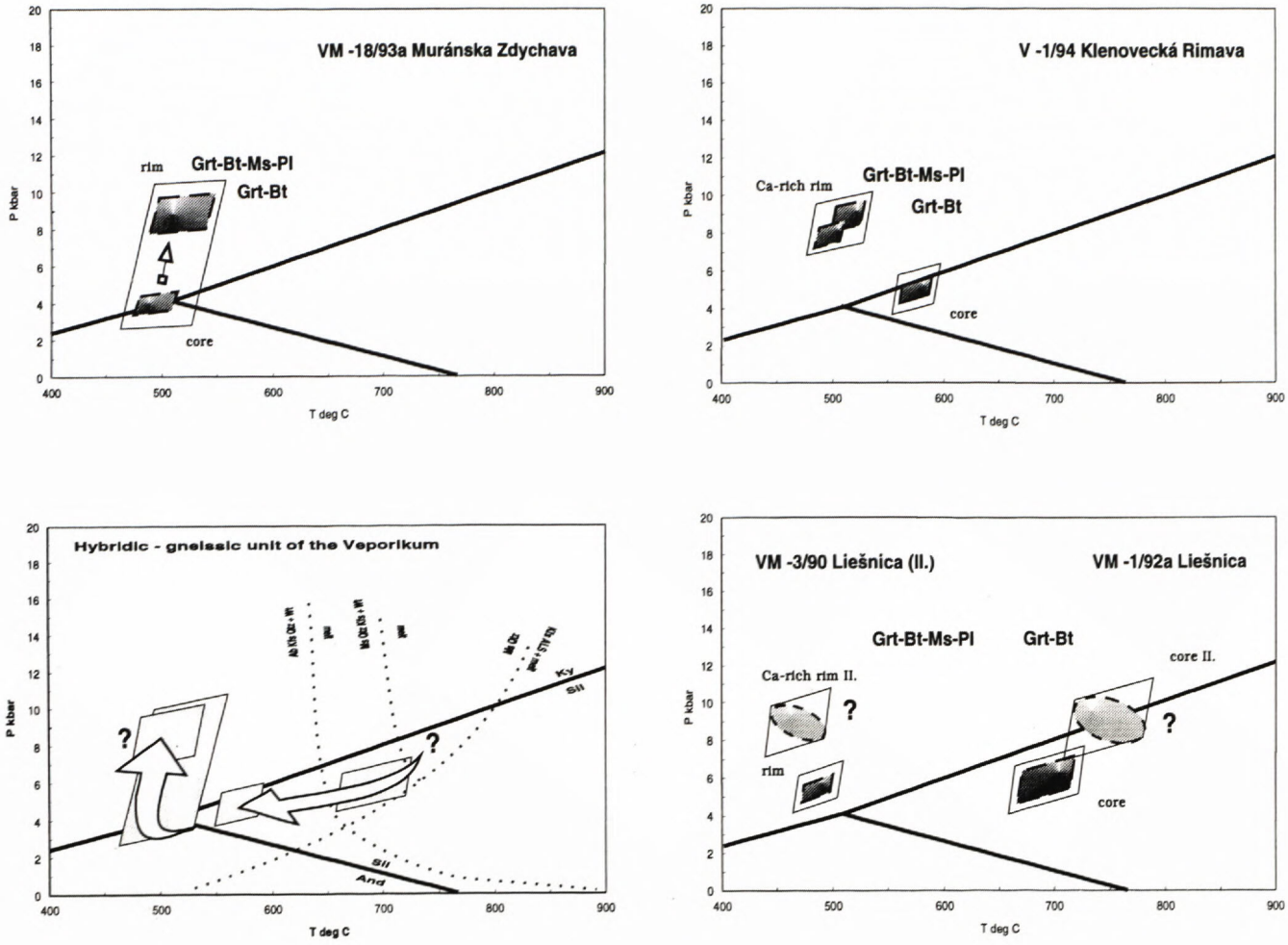



*Fig. 2 Calculated p-T conditions of "layered rocks" from southern part of the Veporikum basement (shaded regions represent error boxes for averages of the p, T determinations)*

## Conclusion

The first results of petrological study and geochemical interpretation suggests complex origin of the "layered migmatites".

The first tectono-metamorphic event reached temperature conditions of the upper part of the amphibolite facies and could be responsible for the Hercynian thickening. The highest p-T conditions probably associated with local partial melting could be also a record of pre-Hercynian history of the basement: migmatites were perhaps products of Cadomian metamorphism (BEZÁK, 1991). There is only indirect evidence of their age: change of metamorphism and different (ductile) deformation pattern in comparison with the Early Paleozoic complexes, tectonic breccias of "layered migmatites" cemented by the Hercynian granitoids. Another next metamorphosis signified by retrograde re-equilibration only. The younger one is characterised by greenschists facies metamorphism, evolving to relatively medium to high pressure conditions.

The main problem for a better understanding of the metamorphic evolution of the Veporicum basement lies in the separation and definition of the intensity and areal extent of the Alpine metamorphic recrystallisation, as both - the Alpine event and the Hercynian retrogression - probably reached very similar conditions. They could be distinguished by the pressure changes.

## References

AVČENKO, O. V. 1982: Petrogenetičeskaja informativnosť granatov metamorfičeskych porod. Nauka, Moskva, 104p.

BEZÁK, V. 1982: Komplexy metamorfitov a granitoidov v kohútskom pásme veporíd (Západné Karpaty). Geol. práce, Správy 78, 65-70 .

BEZÁK, V. 1988: Tektonický vývoj juhozápadnej časti veporika. Miner. slovaca, 20, 2, 131-142.

BEZÁK, V. 1990: Problematika variských tektonických procesov v kryštaliniku tatrika a veporika. Miner. slovaca, 22, 1, 87-88.

BEZÁK, V. 1991: Metamorphic conditions of the Veporic unit in the Western Carpathians. Geol. Carpathica, 42, 4, 219-222.

BEZÁK, V. 1992: The relationship of granitoids and metamorphic rocks in the crystalline of the Tatricum and Veporicum (West Carpathians): a combination of the effects of Hercynian and Alpine tectonics. Special volume to IGCP Project No. 276 by J. VOZÁR (Eds.), GÚDŠ, Bratislava, 21-24.

BEZÁK, V. 1994: Návrh nového členenia kryštalinika Západných Karpát na základe rekonštrukcie hercýnskej tektonickej stavby. Miner. slovaca, 26, 1, s. 1-6

DEER, W. A., HOWIE, R. A. & ZUSSMAN, J. 1962: Rock-forming minerals. Vol. 3, Sheet Silicates. Longmans, Green & co. Ltd., London, 270p.

GUIDOTTI, CH. V. 1987: Micas in metamorphic rocks. In: Baley, S.W. (eds.), Micas. Reviews in Mineralogy, Vol. 13, Miner. Soc. of America, 357-456.

HOOVORKA, D. - MÉRES, Š. - IVAN, P. 1992: Pre - Alpine Western Carpathians Mts. basement Complexes; Geochemistry, Petrology, Geodynamics setting. Terra Nova, 4, Abstract Suppl., 2, 32.

KAMENICKÝ, J. 1982: Petrografia ortorúl a pararúl, synkinematických migmatitov a ich diaftoritov v severozápadnej časti Veporského rudohoria. Miner. slovaca, 14, 6, 481-516.

KLINEC, A. 1966: K problémom stavby a vzniku veporského kryštalinika. Zborník geol. vied, Záp. Karpaty, 6, Bratislava, 7-28.

KORIKOVSKI, S. P., DUPEJ, J. & ZINOVIEVA, N.G. 1989: Genezis zonalnych granatov iz rimavickych (sineckych) granitov v Kogutskoj zone Veporid, Zapadnyje Karpaty. Geol. Carpathica, 40, 6, 697-714.

KORIKOVSKI, S. P., DUPEJ, J., BORONIKHIN, V. A. & ZINOVIEVA, N.G. 1990: Zoned garnets and their equilibria in mica schists and gneisses of Kohút crystalline complex, Hnúšťa region, Western Carpathians. Geol. Carpathica, 41, 2, 99-124.

KOVÁČIK, M. 1991: Reverse zoning of garnet - possible petrological evidence of late variscan tectonometamorphic events (mica shists of SE part of Vepor ore mts.,West Carpathians Mts.). Abstracts from Geological workshop, Moravian Windows, Moravský Krumlov

KOVÁČIK, M. 1993: Polyfázový vývoj staropaleozoických metamorfitov v strednej časti kohútskej zóny. Miner. slovaca, 25, 3, 379-385.

MAHEĽ, M., KAMENICKÝ, J., FUSÁN, O. & MATEJKA, A. 1967: Regionální geologie, díl II., Západní Karpaty , sv. 1. Academia, vyd. ČSAV, Praha, 496 p.

MÉRES, Š & HOVORKA, D. 1991a: Geochemistry and metamorphic evolution of the Kohút crystalline complex mica schists. Acta geol. et geogr. Univ. Comen., Geol., 41, 4, 415-426.

MÉRES, Š & HOVORKA, D. 1991b: Alpine metamorphic recrystallization of the pre-Carboniferous metapelites of the Kohút crystalline complex (the Western Carpathians). Miner. slovaca, 23, 3, 435-442.

PETRÍK, I., BROSKA, I., UHER, P. & KRÁĽ, J. 1993: Evolution of the Variscan granitoid magmatism in the Western Carpathians realm. Geol. Carpathica, 44, 4, 265-266.

SIMAN, P. 1995: "Layered migmatites" in the South-Western part of the Veporikum, the Western Carpathians, Slovakia. Terra Nova, 7, Abstract Suppl., 1, 317.

WOODSWORTH, G. J. 1977: Homogenization of zoned garnets from pelitic schists. Canad. Miner., 15, 2, 230-242.

ZOUBEK, V. 1928: Geologická studie v pohoří Veporu na Slovensku. Věstník Stát. geol. úst. ČSR, IV., Praha, 152-158.

ZOUBEK, V. 1936: Poznámky o krystaliniku Západních Karpát. Věstník Stát. geol. úst. ČSR, XII., 6, Praha, 207-239.

SLOVAK GEOLOGICAL MAGAZINE

# Alpine metamorphism of Southern Veporicum - an evolution model and the problem of correlation with the Eastern Alps

MARTIN KOVÁČIK

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

*Abstract.* Based on stratigraphic records of Mesozoic sequences, the configuration of geological units as well as geochronological and metamorphic data from the metamorphic crystalline complex, an outline of the Cretaceous geodynamic development of the Southern Veporicum domain is proposed. The metamorphic model is based above all on the concept of the intensive fluid circulation at relatively high heat flow derived from depth. The comparison of Cretaceous orogenesis in Southern Veporicum with the Eastern Alps suggests certain relatedness with the s.c. Mittelostalpin, however, the discussion refers to important differences in the tectono-metamorphic development of both regions, too.

*Key words:* Western Carpathians, Southern Veporicum, Alpine regional metamorphism, basement reactivation, retrogression, Cretaceous orogeny, geodynamic model

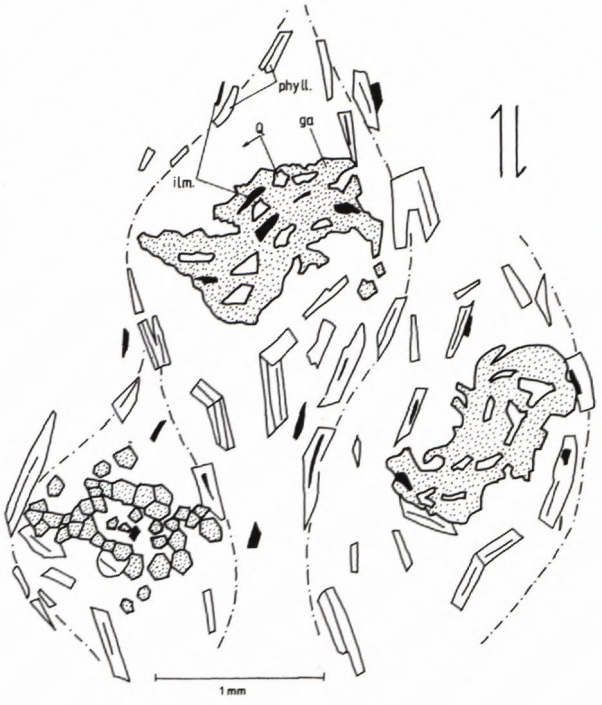
## Introduction

Among the three basic Central Western Carpathian units (i.e. Tatricum, Veporicum and Gemericum sensu BIELY 1989), built besides remnants of the cover Mesozoic of pre-Alpine complexes, the area of Southern Veporicum (Fig. 1) underwent the strongest Alpine metamorphism. The grade of Alpine recrystallisation is apparently connected with the intensive deformation reworking which is, in contrast to other areas, caused by the thrusting of Gemericum on Veporicum (ANDRUSOV 1968, ZOUBEK & SNOPKO 1954 etc.). Alpine tectono-metamorphism is basically interpreted in two ways. The "classical" concept considers a more-or-less uniform pre-Senonian, most probably late Turonian collision (ANDRUSOV l.c., BIELY l.c., TOMEK 1993), when all Alpine units in the Central Western Carpathian region were north-vergently stacked. A more recent idea is based on the time sequence of progressively younger highest stratigraphic members of cover and nappe Mesozoic sequences, from S to N (RAKÚS et al. 1989), which extends the beginning of Alpine orogenic contraction to the Upper Jurassic. As a higher than Triassic litho-stratigraphic record is missing in Southern Veporicum (STRAKA 1981), Alpine metamorphism is here, in the sense of the latest theory, regarded as the result of a collision related to the closure of the Meliata ocean (KOZUR 1991, HÓK et al. 1993, PLAŠIENKA 1993a) and placed into the Upper Jurassic - Lower Cretaceous time. The latest structural-geodynamic concept of the development of the Southern Veporicum area has been published by PLAŠIENKA (1993) and partly also by KOVÁČ et al. (1994).

## Alpine metamorphism - conditions, relations to deformation and age constrains

The Alpine mineral assemblage in metapelites (muscovite, biotite, chlorite, amphibole of tschermakite type, chloritoid, staurolite, plagioclase, kyanite, garnet phases enriched in the grossularite component) has Barrowian character, in spite of the fact that petrostructurally it is usually late-syn- to postkinematic (similarly VRÁNA 1966). The newly formed assemblage overprinted to a various degree the pre-Alpine minerals (well observable e.g. on porphyroblasts of staurolite, plagioclase, micas and garnet - Fig. 1A, B), which, already before retrograde replacement reactions, frequently underwent Alpine deformation (e.g. reactivated foliation, folds, lineation). Alpine regional metamorphism indicate progressive course (evidenced by succession of blastesis and mineral zonality) and reached in average the middle greenschist facies zone (approx. 350-500°C, at 2-4 kb, KOVÁČIK et al. 1996). These conditions are close to the blocking temperatures of the K/Ar system (amphibole 500°C sensu HARRISON 1981), it may be assumed that the obtained data on newly-formed amphiboles more or less reflect the real age of metamorphic blastesis. In general, we connect the metamorphism with increased geothermal gradient (approx. 40-60°C/km).

In the light of recent $^{40}Ar/^{39}Ar$ dating focused on muscovites (blocking T 350±50°C) and newly-formed amphiboles (not rejuvenated pre-Alpine ones) in metamorphites of the basement (KOVÁČIK et al., l.c.) it appears, along with previous data (MALUSKI et al. 1993, DALLMEYER et al. 1993), that a considerable number of $^{40}Ar/^{39}Ar$ spectra is concentrated into a narrow period of about 86-89 Ma (approximately Coniacian). Important



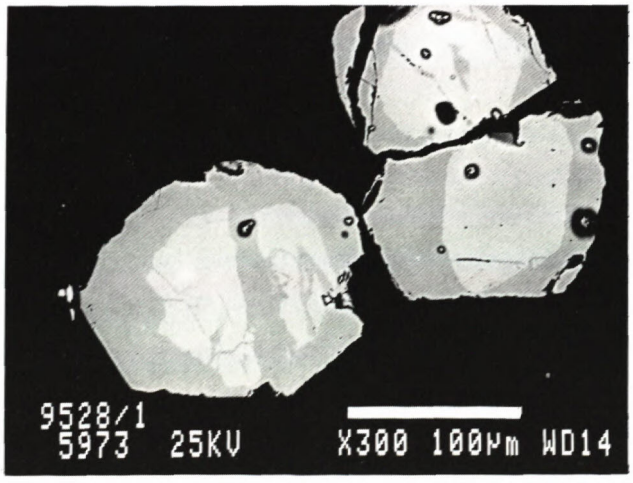




*Fig 1 A) Pre-Alpine garnet porhyroblasts are in a shear regime, connected with pressure dissolution (as a corrosion agent there is predominantly quartz), rotated to form assymmetric clasts (right and top). On left, a late stage of decomposition, with disintegration into tiny fragments*
*B) Catacased relics are along rims and cracks filled with newly-formed garnet enriched in the grossularite component.*

manifestations of Alpine metamorphism are asociated with accelerated uplift in the Coniacian-Lower Santonian time. If we extract only the above period to the considerations of Alpine metamorphism, and e.g. 6 km of the overburden rocks would have been denuded during 2-3 Ma, the average rate of uplift would reach then 2 to 3 mm/a. It was probably thermal uplift (sensu lato), accompanied by intensive fluid infiltration connected with metamorphic recrystallisation. The uplift movements, and partly also metamorphic activities, started apparently already earlier, as discussed in the following.

## Geodynamic model

As indicated by geochronological data (including K/Ar dating - KANTOR 1961, BURCHART et al. 1987), it is still an open problem, to which period may the Alpine thermal reworking be more exactly restricted. In spite of the fact that there are more questions than answers, on the basis of the above data we tried to suggest an outline of the chronology of the Cretaceous development in the Southern Veporicum area (Fig. 2). It appears that metamorphic manifestations of Cretaceous orogeny are directly or indirectly associated with two convergent processes: 1) with the collision of Gemericum and Veporicum, with assumed post-deformational effects in the Albian (Fig. 2 B,C); 2) with thermal uplift (about 86-89 Ma) which probably preceded immediately (or was synchronic?) with the thrusting of the s.c. superficial Mesozoic nappes (Fig. 2 E,F). In general it may be assumed that the uplift was not, at least in the early stages, accompanied by thinning of the crust, as it is frequently indicated by the Barrovian character of post-deformation metamorphic assemblages. An uplift regime, even though a little slower, probably took place earlier, as the effect of the collision of Veporicum with Gemericum. It cannot be also excluded that the Southern Veporicum domain was updomed already before the collision event, as evidenced, below the displaced Gemericum elements by the absence of cover Veporicum members younger than Upper Triassic.

After the uplift and thrusting of superficial nappes in the upper part of the crust, there followed the sedimentation of Gossau beds dated maximally as Upper Santonian (BYSTRICKÝ 1959, ANDRUSOV AND SAMUEL 1983). Probably only from this time, characteristic post-orogenic extensional processes took place (Fig. 2 G), with local temperature perturbantions in the lower/middle parts of the crust (e.g. 81 Ma Rochovce granite, sensu Hraško et al. 1995, or biotite cooling ages). This extensional regime was however no longer connected with penetrative semiductile deformations. Stretching lineation along with parallel (to sub-parallel) b-axes of folds, or cleavage planes, developed already during the collision, probably in transpressional regime (Fig. 2 B) and they generally preceded the thermal peak of Alpine metamorphism (Fig. 2 E?). Structures of this type remind of extension parallel with the orogen, developed in many collision orogens, frequently due to oblique convergence (e. g. ELLIS 1986).

## Metamorphic model

The higher water contents, lower thickness of the lithostatic column, the assumed shorter time range of the

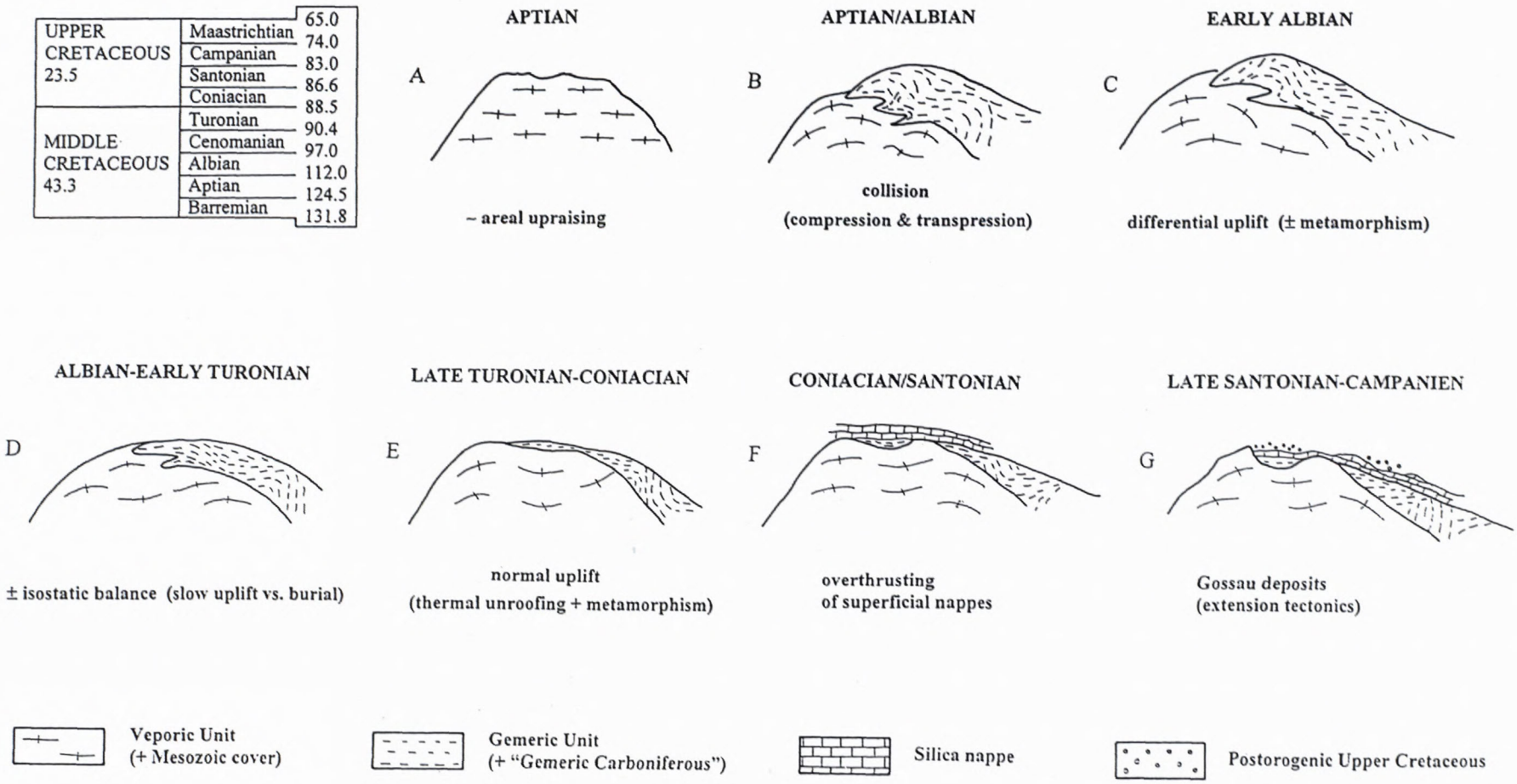



*Fig. 2 A geodynamic concept of the Cretaceous evolution of the Southern Veporicum*
*After assumed morphological elevation (A), there occurred a collision with the Gemericum domain (B) and, due to temperature relaxation, first metamorphic assemblages formed (C). The stratigraphically (with respect to the Northern Veporicum), and partly also geochronologically indistinct period, with possible uplift and/or sedimentation (D) is followed by tectonic denudation with marked manifestations of Alpine matamorphism (E). This "thermal uplift" was subsequently followed by thrusting of the s.c. higher nappes (F). Manifestations of extensional tectonics (completing of F and whole period of G) are in the basement characterised especially by cooling. Geochronological data refer to the chronostratigraphic range of* HARLAND *et al. 1989 (see top left).*



SLOVAK GEOLOGICAL MAGAZINE

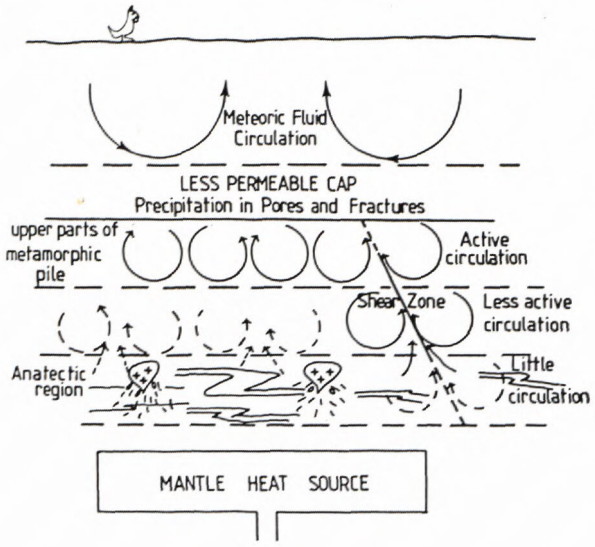



*Fig. 3 A schematic model of the fluid-flow system in the regional metamorphic belt*
*The intensity of circulation increases at higher crustal levels of the crust, where lower-grade metamorphism forms (sensu ETHERIDGE et al. 1983). Similar mechanism may be accepted as a working hypothesis for the explanantion of development of the superimposed Alpine metamorphism in the Southern Veporicum basement*

fundamental Alpine thermal reworking etc. could have caused that Alpine progressive metamorphism did not affect clastic members of the cover Permian and Triassic as intensively as retrograde metamorphism affected the basement. It is probable that the principal sources of Alpine metamorphism must be sought in depth reactivation of the basement, where fluid and thermal circulation increase. The generation of increased fluid flow may be also explained by the ascent of hot mantle material into the lower parts of lithosphere. Thinning of mantle lithosphere, which takes place during crustal thickening, contributes to intensive convection flow (ETHERIDGE et al. 1983, ETHERIDGE and LOOSVELD 1990).). Convective removal of the lowermost litosphere due to ascending asthenosphere (sensu PLATT & ENGLAND 1994) could play a significant role, too. As indicated by the model on Fig. 3, different permeability of layers facilitates the fluid circulation, while Upper Permian-Triassic quartzites and quartzitic arkoses could function as a less permeable cap. From this point of view, and because of the dynamic effects of deformations, we consider the thickness of the tectonic overburden of about 5-10 km (especially Gemericum elements) sufficient to create conditions favourable for the Alpine metamorphism of Southern Veporicum.

## Correlation aspects

The correlation of Triassic facies of Southern Veporicum with the Eastern Alpine Mittelostalpin (sensu TOLLMAN), as well as the similar configuration of the Mesozoic nappe structure, led to suggesting a common sedimentation basin, proved to have existed to the end of the Jurassic (see e.g. ANDRUSOV 1968, TOLLMAN 1986). The definition of the Mittelostalpin as an independent unit, relatively widely accepted by Austrian geologists, has been questioned by some authors (e.g. CLAR 1973, FRANK 1987), and the unit was interpreted as the lowermost element of the Oberostalpin. (If we would accept this idea, then the assumption of GRECULA (1994) on the approach of Veporicum and Gemericum already in the pre-Alpine period would appear in another light). Regardless whether distinguishing of the Mittelostalpin is justified, the Alpine metamorphism of the crystalline complex in this area generally reached the conditions of the amphibolite facies (e. g. FRANK et al. 1987), i.e. it is somewhat higher than in Southern Veporicum. However, a number of similar petrographic features related to the Alpine recrystallisation (e.g. newly-formed staurolite, kyanite, biotite, garnet rims etc.) indicate a lot of similarity in the development of both regions during the Middle and Upper Cretaceous. Extensional phenomena like semiductile stretching lineation, which is aproximatelly parallel to the b-axis of Alpine folding, probably developed during the process of collisional crustal thickening (RATSCHBACHER et al., 1989) has much in common to that in the Southern Veporicum. The very similar age is supported also by K/Ar and Sr/Rb data, grouped at the time of about 85-90 Ma (e.g. THOENI 1983 in FRANK et al. 1987). The generally lower grade of Alpine recrystallisation of the underlying Unterostalpin, or Tatricum, as well as the dispersed geochronological data from the overlying lower-metamorphic Grauwacken-Zone, or Gemericum, are also evidence in favour of the possibility to correlate these domains even in the Cretaceous time.

## Discussion

An important difference in the geodynamic development of both regions may be seen in the findings of Alpine eclogites in the "Mittleostalpin" area. Their possible age is estimated at 95 Ma, however, it is certainly not older than 150 Ma (MILLER 1990, THOENI and JAGOUTZ 1992). The subsequent static Barrovian metamorphism is dated in these rocks at 90 Ma (THOENI - JAGOUTZ l.c.). (Similarly are dated Cretaceous metamorphic events in the Western Alps, where high-temperature metamorphism has been determined at about 110 Ma and peak temperature reworking at 85 Ma, HUNZIGER et al. 1989). Two metamorphic events appear hypothetically also in the Southern Veporicum (see Fig. 2). As high-pressure metamorphism has not been reliably proved from the area of the Cretaceous suture zone between Veporicum and Gemericum, we have no direct evidence that subduction process occurred during this convergence as well. Evidently for this reason, regardless of the

marked thermal effects of the later event, we cannot distinguish the characteristic features of both possible phases of Alpine regional metamorphism. The tectonic-thermal relationship between the local contact aureole (e.g. VOZÁROVÁ 1990) of the Upper Cretaceous Rochovce granite (Fig. 2G) and effects of Alpine metamorphism of regional extent (Fig. 2 C-E) is also not quite clear.

## References


ANDRUSOV, D. 1968: Grundriss der Tectonik der Noerdlichen Karpaten. Verlag SAV, Bratislava, 188pp

ANDRUSOV, D. & SAMUEL, O. 1983: Stratigrafický slovník Západných Karpát. GÚDŠ, Bratislava

BIELY, A. 1989: The geological structure of West Carpathians. In M. RAKÚS at al., eds.: Evolution of the northern margin of Tethys, Vol.II, Mém. Soc. Géol. France, Neuvelle Série No. 154 (II), Paris, 51-57

BURCHART, J., CAMBEL, B. & KRÁĽ, J. 1987: Isochron reassessment of K-AR dating from the West Carpathian crystalline complex. Geol. Zb., Geol. carpath., 38, 131-170

BYSTRICKÝ, J. 1959: Príspevok k stratigrafii Muráňskeho mezozoika. Geol. práce, Zošit 56, 5-43 (In Slovak)

CLAR, E. 1973: Review of the structure of the Eastern Alps. In: KEES, A., YOUNG, G., SCHOTTEN, R.: Gravity and Tectonics, 253-270, London

DALLMEYER, R. D., NEUBAUER, F. & PUTIŠ, M. 1993: $^{40}Ar/^{39}Ar$ mineral age controls for the Pre-Alpine and Alpine tectonic evolution of nappe complexes in the Western Carpathians. PAEWCR Conf., Excursion guide, Stará Lesná 1993, 11-20

ELLIS, M. 1986: Structural morphology and associated strain in the Central Cordillera (British Columbia and Washington): evidence of oblique tectonics. Geology, 14, 647-650

ETHERIDGE, M. A., WALL,V. J. & VERNON, R. H. 1983: The role of the fluid phase during regional metamorphism and deformation. J. metam. Geol.,1, 205-226

FRANK,W. 1987: Evolution of the Austroalpine Elements in the Cretaceous. In: FLUEGEL, H. & FAUPL, P. /eds./: Geodynamics of the Eastern Alps., 379-406, Vienna /Deuticke/

FRANK,W., HOINKES, G., PURTSCHELLER, F. a THOENI, M. 1987: The Austroalpine Unit West of the Hohe Tauern. In: FLUEGEL, H. & FAUPL, P./eds./:Geogynamics of the Eastern Alps.,179-225, Vienna /Deuticke/

GRECULA, P. 1994: Litofaciálny vývoj mladšieho paleozoika hraničnej oblasti veporika a gemerika - problémy a námety. Miner. slovaca,26, 411-426

HARLAND, W. G., ARMSTRONG, R. L., COX, A. V., CRAIG, L. E., SMITH, A. G. & SMITH, D. G. 1989: A Geologic Time Scale 1989. Card published by British Petroleum Comp.

HARRISON, T. M. 1981: Difusion of $^{40}Ar$ in horblende. Contrib. Miner. Petrol., 78, 324-331

HÓK, J., KOVÁČ, P. & MADARÁS, J. 1993: Extenzná tektonika západného úseku styčnej zóny veporika a gemerika. Miner. slovaca, 25, 172-176 (In Slovak)

HRAŠKO, L., MICHALKO, J., HATÁR, J., HÓK, J., VAASJOKI, M. & KOTOV, A. B. 1995: Upper Cretaceous granit in Western Carpathian region. Terra nova,7, Abstract suppl. N°1, 307

HUNZINGER, J. C., DESMONDS, J. & MARTIGNOTTI, G. 1989: Alpine thermal evolution in the Central and the Western Alps. In: COWARD, M. P., DIETRICH, D. a PARK, R. G. (eds.): Alpine Tectonics. Geol. Soc. London, Spec. Publ., 45, 353-367

KANTOR, J. 1961: Beitrag zur Geochronologie der Magmatite und Metamorphite des westkarpathischen Kristallins. Geol. práce, 60, 303-318

KOVÁČ, M., KRÁĽ, J., MÁRTON, E., PLAŠIENKA, D. & UHER, P. 1994: Alpine uplift history of the Central Western Carpathians: Geochronological, paleomagnetic and structural data.Geol. Zb. Geol. Carph.,45, 83-96

KOVÁČIK, M., KRÁĽ, J. & MALUSKI, H.1996: Metamorphic rocks in the Southern Veporicum: their Alpine metamorphism and thermochronologic evolution. In Slovak with English resume. Miner. slovaca, 28, 185-202

KOZUR, H. 1991: The evolution of the Meliata-Halstatt ocean and its significance for the early evolution of the eastern Alps and Western Capathians. Paleogeogr. Paleoclimatol. Paleoecol., 83, 109-135

LOOSVELD, R. J. H. & ETHERIDGE, M. A. 1990: A model of low-pressure facies metamorphism during crustal thickening. J. metamorphic Geol.,4, 257-267

MALUSKI, H., RAJLICH, P. & MATTE, P. 1993: $^{39}Ar/^{40}Ar$ dating of the Inner Carpathians Variscan basement and Alpine mylonitic overprinting. Tectonophysics, 223, 313-337

MILLER, CH. 1990: Petrology of the type locality eclogites from the Koralpe and Saualpe (Eastern Alps), Austria. Schweitz. Miner. Petrol. Mitt.,70, 287-300

PLAŠIENKA, D. 1993: Structural pattern and partitioning of deformation in the Veporic Foederata cover unit. In.: RAKÚS, M. a VOZÁR, J. (eds.): Geodynamický model a hlbinná stavba Západných Karpát, 269-278

PLAŠIENKA, D. 1993a: Brief outline of the West Carpathian structure with an emphasis on the Mesozoic evolution. In: PITOŇÁK, P. a SPIŠIAK, J. (eds.): PAEWCR Conference, Excursion Guide, Stará Lesná, 3-10

PLATT, J. P. & ENGLAND, P. C. 1994: Convective removal of litosphere beneath mountain belts: thermal and mechanical consequences. Amer. J.Sci., 294, 307-336

PURDY, J.W. & JÄGER, E. 1976: K-Ar ages on rock-forming minerals from the central Alps. Mem. Inst. Geol. Min. Univ. Padova, 30, 30pp

RAKÚS, M., MIŠÍK, M., MICHALÍK, J., MOCK, R., ĎURKOVIČ,T., KORÁB,T., MARSCHALKO, R., MELLO, J., POLÁK, M. & JABLONSKÝ, J. 1990: Paleographic development of the Western Carpathians: Anisian to Oligocene: In: RAKÚS, M., DERCOURT, J. a NAIRN, A. E. M. (eds): Evolution of the northern margin of Tetys. Vol. III, Mém. Soc. Géol. France, Nouvelle Sér. 154 (III, pt I), 39-62

RATSCHBACHER, L., FRISCH, W., NEUBAUER, F., SCHMID, S. M. & NEUGEBAUER, J., 1989: Extension in compresional orogenetic belt. Geology, 17, 404-407

STRAKA, P. 1981: O veku série Foederata. Geol. práce, Správy, 75, 57-62

THOENI, 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). Geoch. Cosm. Acta, 56, 347-368

TOLLMANN, A. 1986: Geologie von Oestereich. Band 2, Franz Deuticke, Wien

TOMEK, Č. 1993: Deep crustal structure beneath the central and inner West Carpathians. Tectonophysics, 226, 417-431

VOZÁROVÁ, A. 1990: Development of metamorphism in the Gemeric/Veporic Contact zone (Western Carpathians). Geol. Zb. Geol. carpath.,41, 475-502

VRÁNA, S. 1966: Alpidische Metamorphose der Granitoide und der Foederata-serie im Mittelteil der Veporiden. Zbor. geol. vied, rad ZK, Bratislava, 6, 29-84.

ZOUBEK, V. & SNOPKO, L. 1954: Zpráva o mapování styku veporid a gemerid mezi Slovošovcami a Rejdovou. Zprávy o geol. výsk. v r. 1954, ÚÚG, Praha, 211-213 (In Czech)

SLOVAK GEOLOGICAL MAGAZINE

# Ductile deformation and recrystallization of the Variscan magmatic complex in the hanging wall of Cretaceous thrust (Veporic unit, Central Western Carpathians)

MARIÁN PUTIŠ[1], JÁN MADARÁS[2], SERGEY P. KORIKOVSKY[3], ALEXANDER B. KOTOV[4] & IVANA FILOVÁ[1]

[1]Comenius University, Faculty of Natural Sciences, Department of Mineralogy and Petrology, Mlynská dolina, SK-84215 Bratislava, Slovak Republic. Fax: +4217-729 064. e-mail: putis@fns.uniba.sk
[2]Geological Survey of SR, Mlynská dolina 1, SK-81704 Bratislava, Slovak Republic. Fax: +4217-371 940 e-mail: madaras@GSSR.sk

[3]Russian Academy of Sciences, Institute of Geology of Ore Deposits, Petrography, Mineralogy and Geochemistry, Staromonetny per. 35, 109017 Moscow, Russian Federation. Fax: +7-095-2302179. e-mail: korik@igem.msk.su
[4]Russian Academy of Sciences, Institute of Precambrian Geology and Geochronology, Makarov embankment 2, 199034 St. Petersburg, Russian Federation. Fax: +7-812-218 4801 e-mail: spire@sovamsu.sovusa.com

*Abstract:* The metamagmatic Veľký Zelený Potok (VZP) Complex of the Veporic basement shows Meso/Late Variscan postcollisional collapse of the collided Pre-Alpine supracrustal Čierny Balog and Hron Complexes. The collapse was followed by the emplacement of the VZP magmatic complex into an extensional detachment fault zone (346 Ma ago). This zone was also active during the Early Alpine continental rifting phase.

The VZP Complex is mostly represented by layered diorites, often porphyric Qz-diorites to diorites, which are internally differentiated into dark Pyrx-Amph or Amph-rich layers of meladioritic (gabbrodioritic) composition, or into pale tonalitic-trondhjemitic layers. The whole VZP complex is, after ductile deformation, about 250 m thick. Some serpentinite bodies accompany the base of the VZP Complex, but these are tectonically incorporated into micaschist-gneisses of the Pre-Alpine supracrustal Hron Complex.

Layered diorites and gabbrodiorites were emplaced into Pre-Alpine supracrustal gneiss-migmatitic rocks of the Čierny Balog (CB) Complex which now have the character of the Alpine Gt micaschists. The VZP and CB Complexes are cut by leucocratic granitic to pegmatitic veins (233±10 Ma).

The mylonitic layering was superimposed on magmatic layering due to ductile behaviour of Plg and Qz in dioritic orthogneisses. Newly formed Gt (Gross-rich) is in equilibrium with the mylonitic mineral assemblage: recrystallized Plg and migration recrystallization Qz ribbons, as well as with the newly formed blue-green tiny (Tsch-rich)$Amph_2$, Bt, WhM(Phn), Chl, Rut, Ep-Zoi, ±Chtd. Thus the Alpine metamorphism and deformation occurred at the temperatures 530-600 °C and medium pressures of 8-10 kbar (using geothermobarometry).

Compressional uplift along the Pohorelá detachment fault was accompanied by hanging-wall extensional unroofing. The VZP Complex represents the hanging wall complex of the Alpine South Veporic Kráľova hoľa Nappe detached along the mid-Cretaceous (Pohorelá) shear/fault zone and thrust over the North Veporic (Supratatric) Krakľová Nappe.

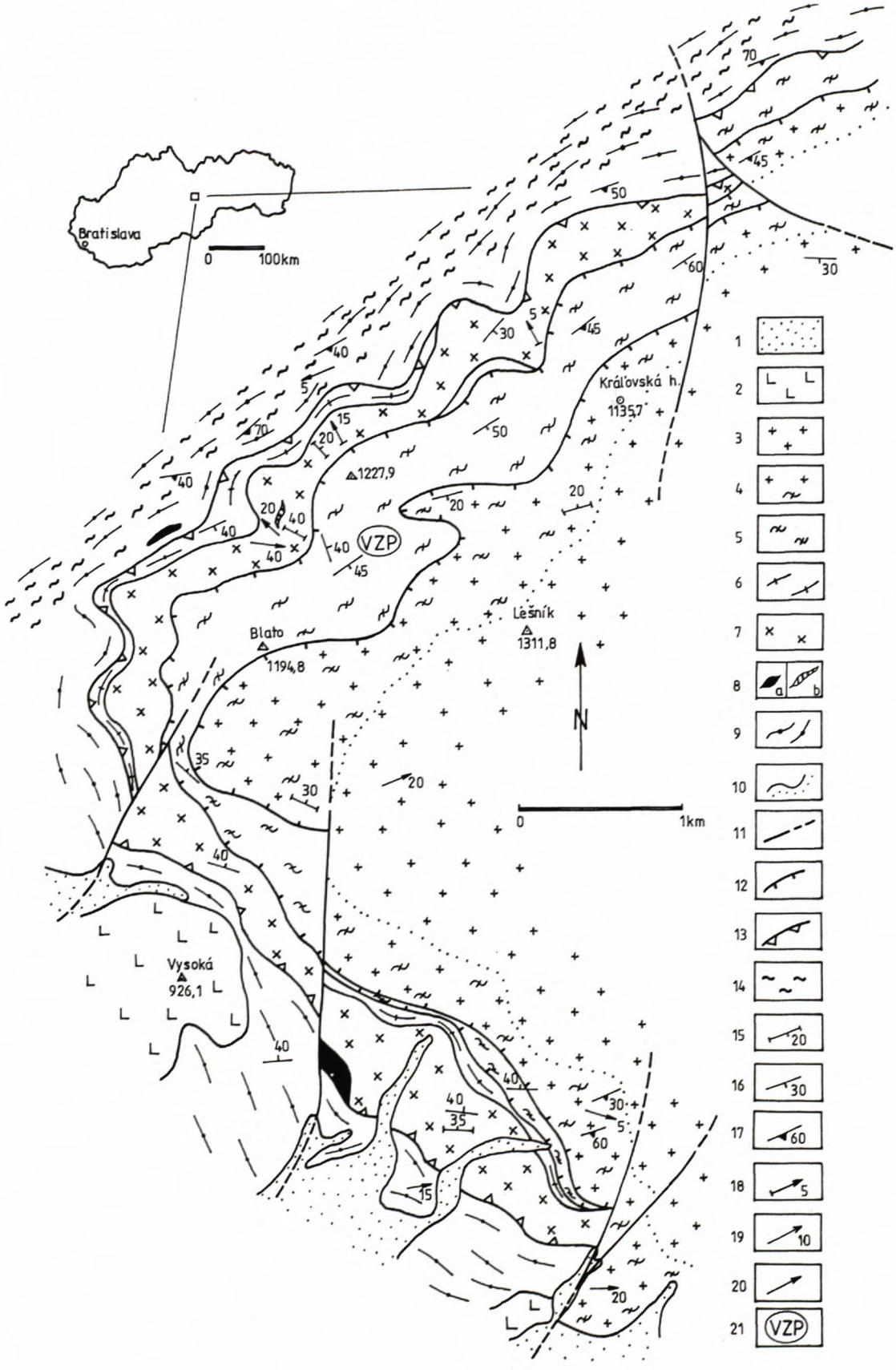
*Key words:* Western Carpathians, Veporic Zone, layered magmatites, detachment fault, collapse, Early Cretaceous, collision, ductile deformation - recrystallization.

## Introduction and geological setting

The Veľký Zelený Potok (VZP) Complex belongs to the Veporic basement of the Central Western Carpathians (Fig. 1). It is composed of Meso/Late Variscan basic, mafic, intermediate to acidic magmatic members. The time of emplacement of the magmatic complex was estimated according to radiometric dating of porphyric metadiorites (346 Ma, U-Pb on Zr, KOTOV et al., pers. comm.).

The VZP metamagmatic complex of the Veporic basement indicates Meso/Late Variscan postcollisional collapse of the collided Pre-Alpine supracrustal Čierny Balog and Hron Complexes. The collapse was accompanied by the emplacement of the VZP magmatic complex into an extensional detachment fault zone, which formed along the former Variscan collisional tectonic boundary between the collided Pre-Alpine supracrustal Čierny Balog and Hron Complexes. Cooling ages of Amph: 357,9±0,7 (40Ar-39Ar method, DALLMEYER et al., 1993, 1996) from amphibolites of the Hron Complex indicate that the collisional (barrovian) stage of the regional Variscan metamorphism in the Veporic Pre-Alpine supracrustal complexes took place at least 370-380 Ma ago.

The extensional detachment fault zone was also active during the Late Paleozoic, when emplacement


Bratislava
0 100km
Blato
1194,8
1227,9
VZP
Lešník
1311,8
Kráľovská h.
1135,7
Vysoká
926,1
N
0 1km
1 2 3 4 5 6 7 8 a b 9 10 11 12 13 14 15 20 16 30 17 60 18 5 19 10 20 21 VZP

of the Vepor granitoid pluton (303-288 Ma, U-Pb, BIBIKOVA et al., 1990), Hrončok granitoid body (265 Ma, Rb-Sr, CAMBEL et al., 1990, PETRÍK et al., 1995), as well as subvolcanic and volcanic rocks (due to Early Alpine continental rifting phase, 276-213 Ma, U-Pb, KOTOV et al., 1996) occurred there at higher structural levels.

In the Alpine tectonic structure the VZP Complex represents the hanging wall complex of the Alpine South Veporic Kráľova Hoľa Nappe detached along the mid-Cretaceous Pohorelá shear/fault zone and thrust over the North Veporic (Supratatric) Krakľová Nappe. Thus the VZP Complex represents a Meso/Late Variscan magmatic sequence incorporated into the Early Cretaceous collisional structure of the Veporic unit (PUTIŠ, 1989, 1991a, b, 1992, 1994, 1995, PLAŠIENKA, 1991, 1993, MADARÁS et al., 1994).

Lower/middle crustal boundary rheology of the mylonitic rocks close to Pohorelá thrust reveals perhaps the highest Alpine metamorphic conditions which have been found to date (VRÁNA 1964, 1966, 1980, PLAŠIENKA et al. 1989, MÉRES & HOVORKA 1991, KORIKOVSKY et al. 1992, MAZZOLI et al. 1992, PUTIŠ 1989, 1994, KOVÁČIK et al. 1996, KOTOV et al. 1996) in the Veporic region: temperatures of 530-600 °C at the pressures 8-10 kb (PUTIŠ et al., 1995, 1996).

The aim of this paper is to define the geological position and lithological sequence of the VZP layered magmatic complex at the type locality (the upper part of the Veľký Zelený Potok valley in the NW Veporské vrchy Mts.), and also to show its tectonic relationship to the deep crustal Alpine detachment (Pohorelá) fault.

The paper gives an overview of the new data concerning ductile mesostructures (foliations, lineations, folds), microstructures (kinematical and deformation mechanisms indicators), rheological behaviour of rock-forming minerals (Qz, Plg, Amph), CPO fabrics of Qz and Plg, as well as the estimation of P-T conditions of ductile strain according to the newly formed mylonitic/metamorphic mineral assemblage and thermobarometric calculations. Existing, so far unpublished radiometric, geochemical and petrological (electron microanalyses of minerals) data are to be published separately.

## Views on rocks and tectonic position of the VZP Complex

The rocks of the proposed Veľký Zelený Potok (VZP) Complex were classified as amphibolites, paragneisses, phyllites and micaschists and their phyllonites (MAHEĽ et al., 1964, KLINEC, 1966, 1976, IVANIČKA & KOVÁČIK, 1989).

A new period of investigation of this complex started with the re-interpretation (MIKO et al., 1987) of the rock sequence in the 500 m deep borehole KV-1 (KLINEC, 1968) near Pohronská Polhora village. PUTIŠ & MIKO (*in* MIKO et al., 1987) distinguished there two different rock sequences, or complexes, one above another, separated by a distinct phyllonite zone (at the depth 220-260 m) of supposedly Alpine age: the upper complex, which is dominated by para- and orthogneisses, and the lower complex, dominated by amphibolites, layered amphibolites, gabbroic intercalations and gneisses. Detailed petrographical and structural data are available in unpublished manuscripts (MIKO et al., 1987, PUTIŠ, 1995). The upper complex appears to be analogous with the Čierny Balog Complex (KRIST, 1976, KRIST et al., 1992, PUTIŠ, 1995), and the lower part of the borehole profile is now proposed as the Veľký Zelený Potok (VZP) Complex.

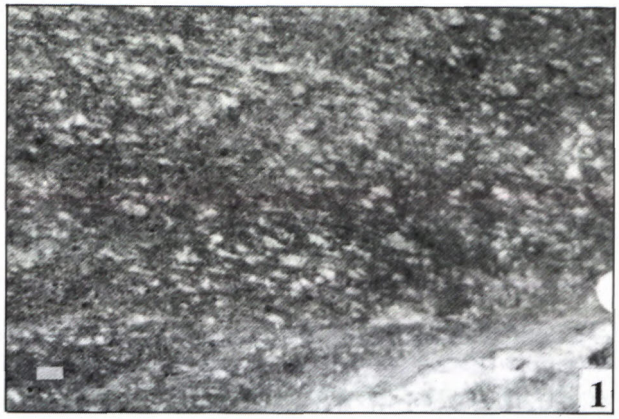
The VZP Complex resembles the gabbro-peridotite-basalt formation with intermediary to acidic members (MIKO & PUTIŠ, 1989 in KRIST et al., 1992, Fig. 74) overlying the micaschist-gneisses of the Hron Complex in the eastern part of the Nízke Tatry (Low Tatra) Mts. (PUTIŠ, 1989, MIKO & PUTIŠ in BIELY et al., 1992).

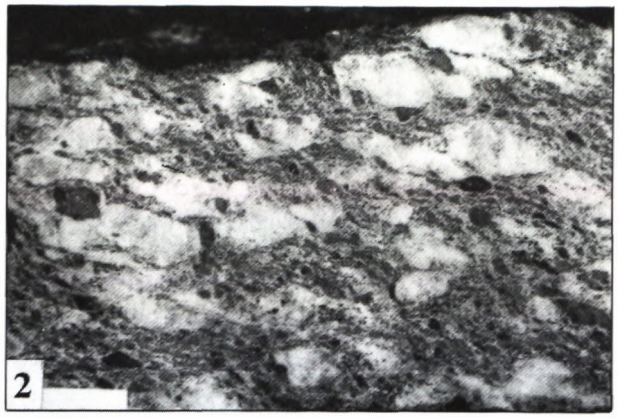
Layered amphibolites, as a part of high-grade metamorphic crystalline complexes, have been studied in the Nízke Tatry Mts. (SPIŠIAK & PITOŇÁK, 1990, 1992), the High Tatra Mts. (JANÁK, 1991, 1992, 1994, JANÁK et al., 1995) and in the Malá Fatra Mts. (JANÁK & LUPTÁK, in press).

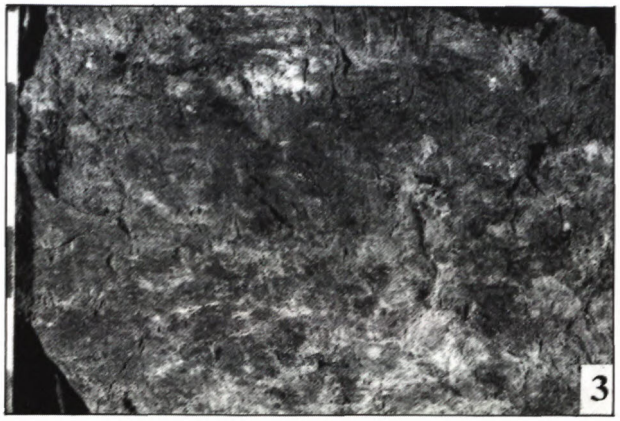
The VZP Complex was included into the high-grade Leptyno-Amphibolite Complex (HOVORKA et al., 1992, HOVORKA & MÉRES, 1993, MÉRES et al., 1996).

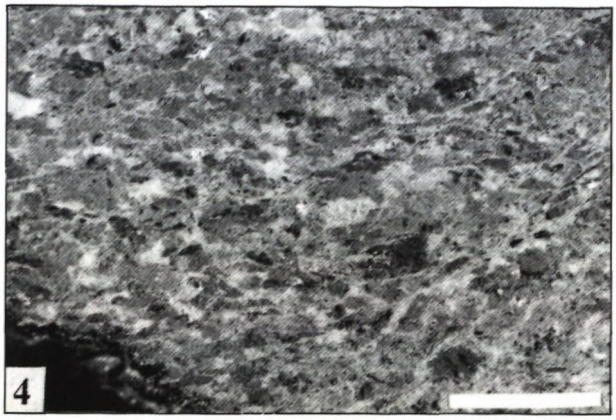
The detailed study of the proposed Veľký Zelený Potok Complex has been carried out at the type locality (the Veľký Zelený Potok valley, Fig. 1) and other characteristic occurrences between Pohronská Polhora and Polomka villages, as well as on the northern slopes of the eastern part of the Nízke Tatry Mts. (PUTIŠ, 1992, 1994).

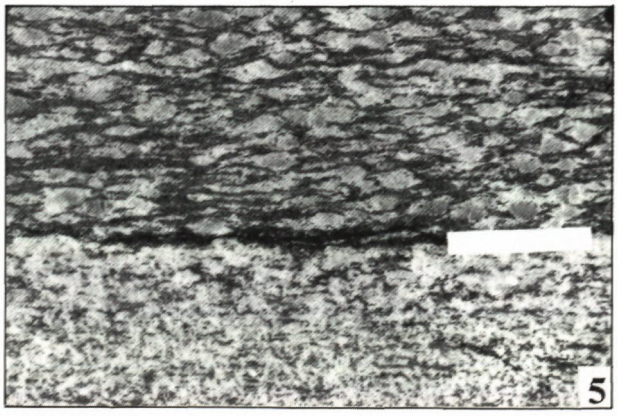
*Fig. 1 Geological-structural sketch of the Veľký Zelený Potok Complex in the Veporic unit of the Central Western Carpathians.*
*1 - Quaternary sediments, 2 - Late Tertiary volcanites - andesite and tuff, 3 - mylonitized granite to tonalite of the Variscan Vepor pluton, 4 - granitoid with xenoliths of gneisseous mantle, 5 - gneiss to migmatite (Čierny Balog Complex, Early Paleozoic), with leucocratic granitic to pegmatitic veins, 6 - Alpine Gt micaschist (after gneiss and migmatite of the Čierny Balog Complex), 7 - dioritic orthogneiss with layers of meladiorite (gabbrodiorite), tonalite, to pale trondhjemite layers, 8a - serpentinite, 8b - (pre-Alpine) amphibolite, 9 - micaschist to gneiss with thin bodies of fine-grained and garnet amphibolite (pre-Alpine supracrustal Hron Complex, Early Paleozoic), 10 - geological boundary, 11 - fault, supposed fault, 12 - thrust, 13 - Cretaceous overthrust (detachment) plane of the Kráľová hoľa Nappe ovber the Krakľová Nappe (Hron Complex), 14 - main mylonite zone of the Pohorelá "line", 15- magmatic/subsolidus foliation $S_0$, 16 - mylonitic/metamorphic foliation $S_1$, 17 - mylonitic foliation $S_2$, 18 - lineation of magmatic flow $L_0$, 19 - mineral and stretching lineation $L_1$, 20 - intersection lineation $L_2$, 21 - VZP - Veľký Zelený Potok Valley.*

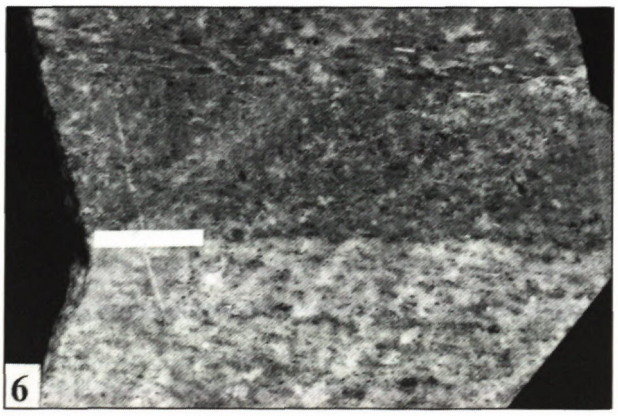

1

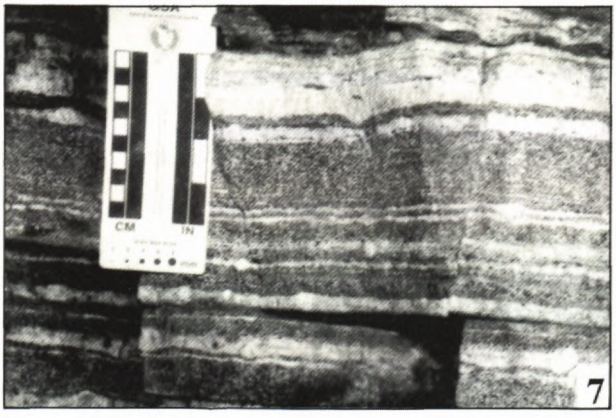

2

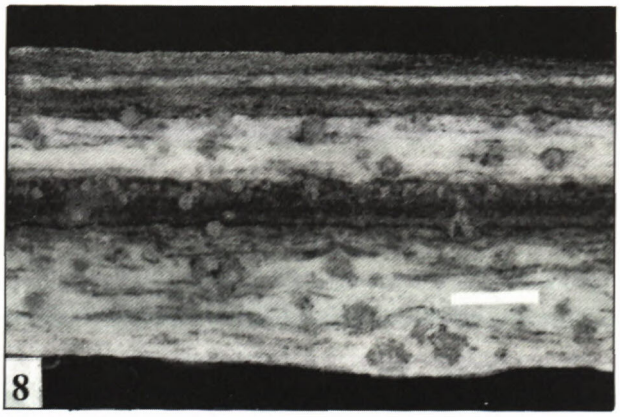

3


4


5


6


CM
IN
7


8

## Lithological composition and succession of magmatic phases of the Veľký Zelený Potok (VZP) layered magmatic Complex

The VZP Complex comprises the following metamagmatic members:

Serpentinites (with the newly-formed Atg and Trem, Pl. III/1) accompany the base of the VZP Complex. They usually occur as protrusive lense-shaped bodies detached(?) from the VZP Complex and attached to the deeper (mid-Cretaceous) Krakľová Nappe (to the Pre-Alpine Hron Complex) that is mostly built of medium temperature micaschists and small bodies of amphibolites.

Layered amphibolites (Pl. I/7, 8) mainly represent the lower and upper part of a large differentiated metadioritic body, now (after ductile deformation) about 250 m thick. Undifferentiated dioritic parts have a composition which is the average of the dark (Amph, Plg, Tit, ±Qz) and pale (Plg, Qz, Mgt, ±Amph) bands. Intermediate tonalitic to pale trondhjemitic bands (Pl. I/5, 6) complete the magmatic sequence of the VZP Complex. A part of dioritic orthogneisses (Pl. I/1, 2) formed from porphyric diorites ($Amph_1$ with rims of $Amph_2$, partially recrystallized often hypidiomorphic Plg, Tit, newly-formed Bt, Qz) and these are dominant in the middle and upper part of the VZP Complex in the Veľký Zelený potok valley area S of Beňuš village.

A part of relatively homogeneous dioritic orthogneisses exposed in both Veľký Zelený Potok and Zavarguľa valleys is characterized by mafic layers of variable thickness of centimetre, decimetre, and less metre order (Pl. I/3-6). These mafic layers are rich in $Amph_1$ (Pl. 1/3) and indicate a metahornblenditic composition. A gradual transition from almost massive types with relic magmatic/subsolidus foliation, through layered orthogneiss up to banded mylonitic types (with distict ductile behaviour of Plg and Qz) may be seen in outcrops (Pl. I, IV).

Small metamafic (metagabbroic: Pyrx, Amph, ±Plg, ±Qz) boudinaged a few dm thick lense-shaped bodies (Pl. IV/1-3) have been found within dioritic orthogneisses in the Veľký Zelený potok Valley. They have scarcely preserved low-Ti monoclinic pyroxenes (with exsolution lamellae) diablastically overgrown by (hyp)idiomorphic low-Ti Amph. The large pale brown-green edenitic hornblende ($Amph_1$) crystals enclose Pyrx- diopside with a characteristic metamorphic reaction rim composed of colourless fine grained aggregates of actinolitic $Amph_2$ (Pl. II/1,2). Lower Ti-content in Amph1 and Pyrx can be explained by the newly-formed Tit or Rut.

Some pale to white leucotonalitic (trondhjemitic) layers (Plg, low content of Qz, Amph, Tit, sometimes higher content of Mgt) a few dm thick are usually situated next to tonalitic layers, often with a gradual transition contact. On the other hand, other occurrences with sharp boundaries could indicate sill-like veins. A few cm thick layers are commonly present in metadiorites. In some places they fill discordant tension cracks cutting the relic subsolidus foliation and they appear to be the youngest member of the VZP Complex.

Different in composition and much younger (233 Ma±10, U-Pb on Zr, Kotov et. al., pers. comm.) appear to be leucocratic granitic to pegmatitic veins (Qz, Plg, Ms, ±Kf) filling extensional mesofaults and cutting the higher-temperature magmatic/subsolidus foliation of the VZP layered magmatic complex, including trondhjemitic veins.

Layered diorites were emplaced into older supracrustal rocks - migmatitic gneisses (with rare thin bodies of normal or Gt amphibolites) having now the character of Gt micaschists (Pl. III/7, 8, Pl. IV/7). It is possible to see transitions from migmatitic augen/stromatitic protomylonites (Qz, Plg, Bt, Ms, Gt-Alm rich cores), through augengneisses, to micaschists or blastomylonites (Qz, Ms replaced by WhM-Phn/Pgn aggregates, Chl, Clz, Gt-Gross-rich rims, Ky?, ±Bt, ±Plg) in large outcrops in the Veľký Zelený Potok Valley. This part of the VZP rock sequence resembles the supracrustal Čierny Balog Complex.

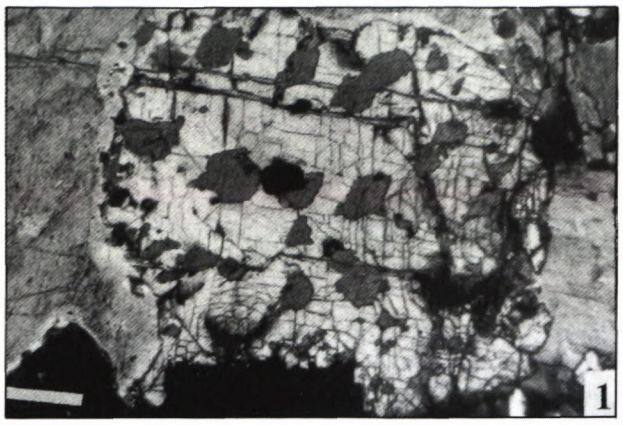
## Succession of deformation - recrystallization events

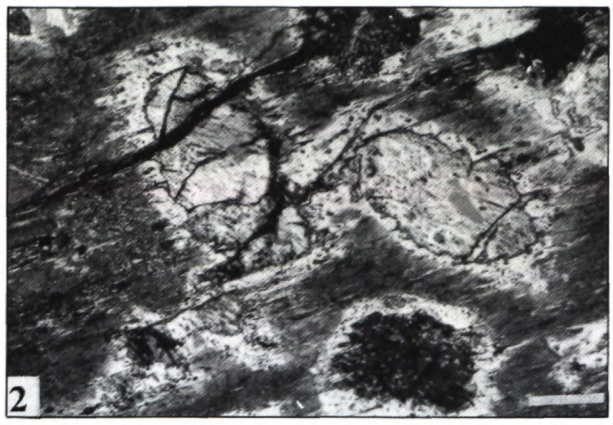
The VZP Complex represents a Meso/Late Variscan magmatic sequence incorporated into the Early Cretaceous collisional structure of the Veporic unit.

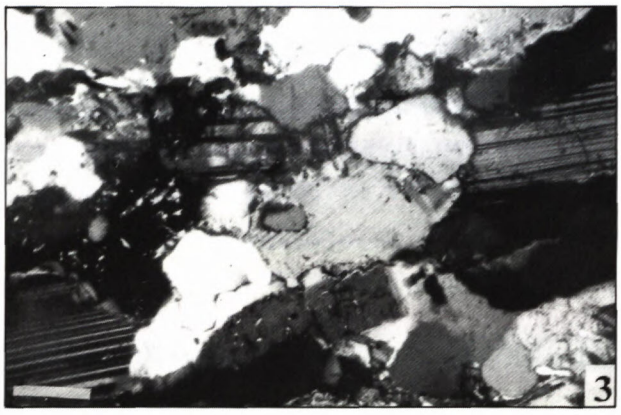
*Pl. I. Macrostructures of the magmatic, subsolidus and solid stage of the layered VZP Complex (scale-bar=1cm): 1 - subhorizontal magmatic foliation ($S_0$) cut by trondhjemite vein of the subsolidus stage of the porphyric (meta)diorite. 2 - magmatic hypidiomorphic Plg (with recrystallized rims) and $Amph_1$ in porphyric dioritic orthogneiss, and superimposed Alpine S-C fabric (Berthé et al., 1979). 3 - Pyrx-Amph slightly recrystallized gabbroic intercalation in diorite. 4 - Pyrx-Amph-Plg gabbroic intercalation in diorite. 5 - contact of (meta)dioritic and (meta)tonalitic layers, 6 - contact of (meta)dioritic and (meta)leucotonalitic (metatrondhjemitic) layers. 7 - layered dioritic orthogneiss (amphibolite) with superimposed ductile deformation (ductile thinning of pale layers with newly formed large Plg porphyroblasts). 8 - the strongest stage of ductile deformation of layered amphibolites (subhorizontal $S_1$ foliation) with newly formed Gross-rich Gt with dark rims of newly formed Tsch-rich fine-grained $Amph_2$.*

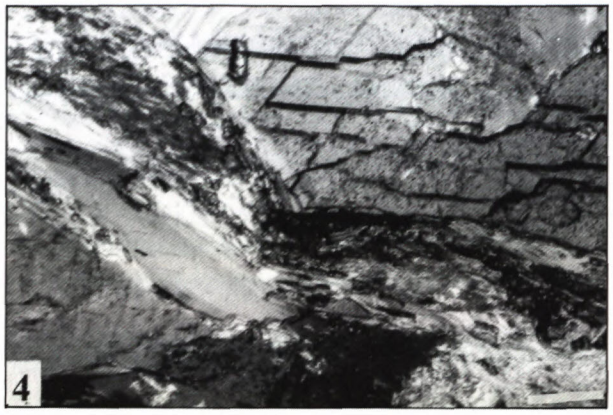


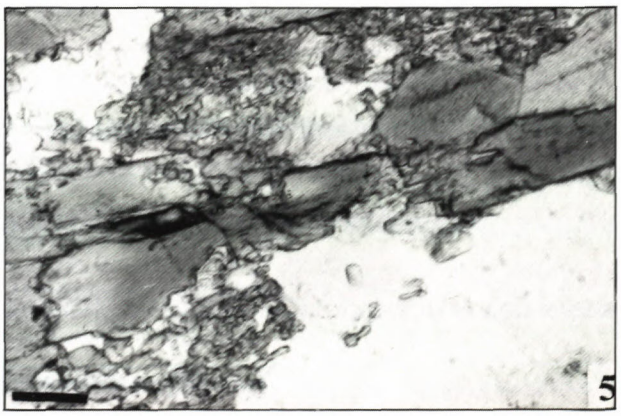
GEOLOGICKÁ SLUŽBA SLOVENSKEJ REPUBLIKY INFORMAČNÉ STREDISKO Bratislava

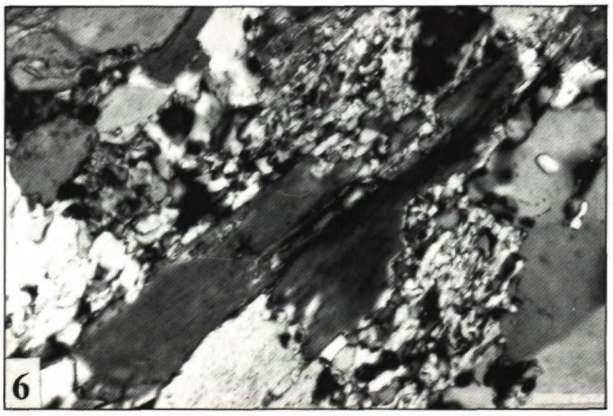

1

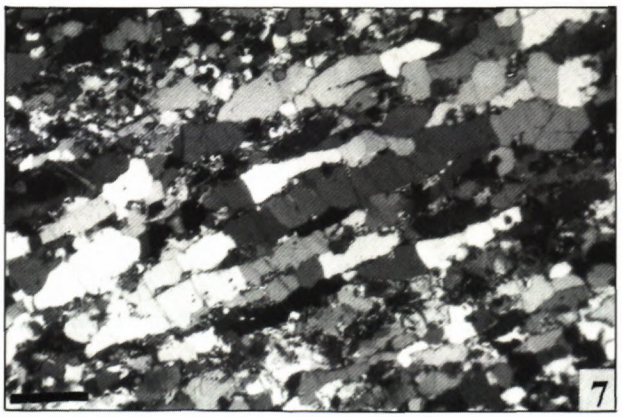

2

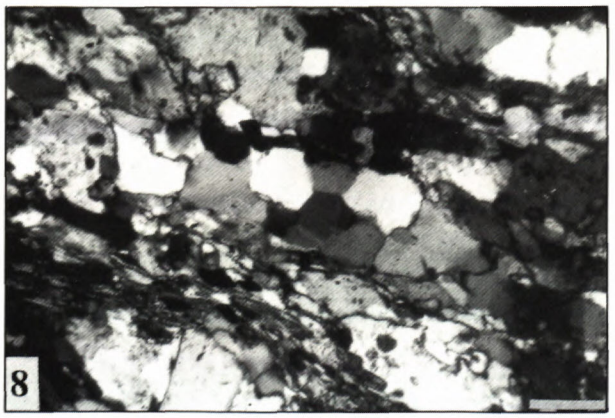

3


4


5


6


7


8

In general, Alpine metamorphic event is dominated in the VZP Complex (with the exception of the less extensive gneiss-migmatitic Čierny Balog Complex within the VZP Complex, with some relics of Pre-Alpine metamorphism). Previous Early Variscan Gt(Alm) - Amph facies metamorphism which occurred in the Čierny Balog and Hron (Early Paleozoic ?) Complexes (e.g. KRIST et al., 1992) was not identified within the VZP metamagmatic Complex. But still Hb1, Pyrx and Plg could preserve their composition since the emplacement P-T conditions of the VZP Complex.

The age of the metamorphic recrystallization of the VZP Complex is constrained by the age of leucocratic granitic/pegmatitic veins (233±10 Ma, U-Pb on Zr, KOTOV et al., pers. comm.) which were concordantly or discordantly emplaced into the (gabbro)dioritic (346±0.7 Ma, U-Pb, KOTOV et al., l.c.) -tonalitic-trondhjemitic magmatic sequence. Similarly, e.g. Late Paleozoic subvolcanic/ volcanic veins (278-216 Ma, U-Pb on Zr, KOTOV et al., 1996) cut the magmatic/subsolid foliation of granitic orthogneisses in the Čierny Balog Complex (near Čierny Balog village). Thus the metamorphism and solid-state ductile deformation of the VZP Complex appear to be Alpine in age.

Mylonitic metamorphism and rheology of rock-forming minerals constrain the low/mid-crustal boundary conditions during the uplift of the VZP metamagmatic Complex. The mylonitic layering in dioritic orthogneisses has (in some places) its origin in magmatic layering, and the ductile behaviour of Plg and Qz clearly reflects superimposed mid-crustal mylonitic rheology in layers (bands) with higher ductile strain localization. Newly formed Gt (Gross-rich, PUTIŠ, 1989, 1994, PUTIŠ & KORIKOVSKY in KOTOV et al., 1996) is in equilibrium with the mylonitic mineral assemblage: recrystallized Plg and migration recrystallization Qz ribbons, as well as with newly formed blue-green tiny $Amph_2$, Rut (Ilm, Tit), Bt, WhM (Phn), Chl, Tit, Clz, Ab and ±Chtd.

Alpine grossularite-rich Gt usually grew within Plg or in some ranges along $S_1$ planes of layered amphibolites. Relics of albitized Plg are often preserved in the core of the Gt (Pl. III/3, 4). The growth started by irregular skeletal nuclei (Pl. III/2) or in the form of a large amount of tiny garnets in Plg gradually joined into a usually idiomorphic Gt rim. The breakdown of Plg indicates higher pressures. These were proved by higher $Si^{4+}$ content (3,46-3,52 f.u.) in Phn of the neighbouring orthogneisses and calculated pressures 8 - 10 kbar (MASSONE & SCHREYER, 1987). Atoll-like forms of Gt (Pl. III/8) were found in granitic orthogneisses.

Alpine blue-green (tschermakite-rich, see also KOVÁČIK et al., 1996) $Amph_2$ substitutes brown-green $Amph_1$ (Mg-Hbl) (Pl. II/5, 6, Pl. III/5, 6). Other newly-formed minerals like Bt, Chl, WhM-Phn, Clz, Tit are concentrated in mylonitic foliation of gabbrodioritic, dioritic and tonalitic orthogneisses (Pl. II/4).

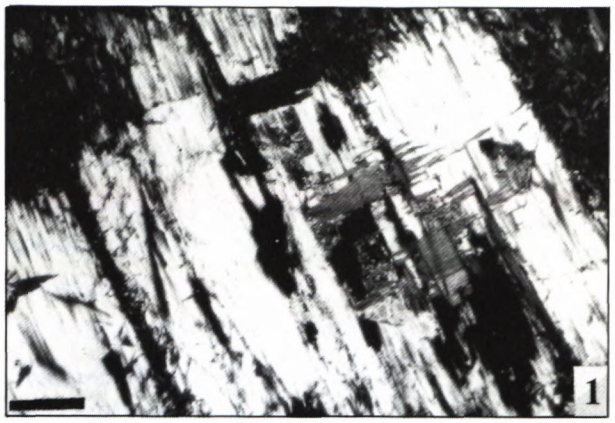
Gneiss-migmatic micaschists of the Pre-Alpine Čierny Balog Complex) also exhibit newly-formed Gross-rich Gt rims (Pl. IV/7) and the relic large-flaked Ms is replaced by fine-grained aggregate of the newly formed WhM of Phn/Pgn composition. Large prismatic crystals of Ky(?) are entirely replaced by WhM (Pl. III/7).

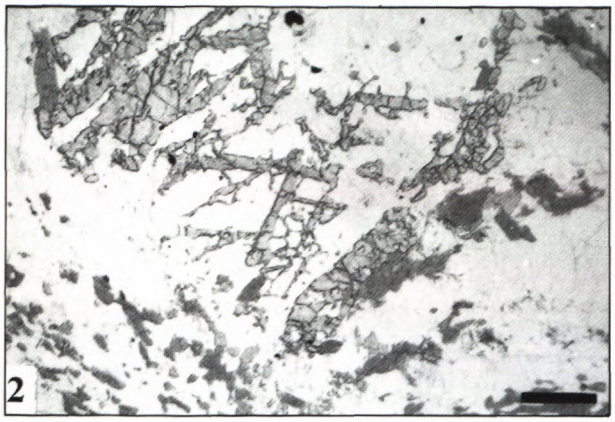
Early Alpine Gt(Gross) - $Amph_{(2)}$ facies metamorphism was reached near the base of the hanging wall VZP Complex within the Pohorelá detachment fault zone. Alpine metamorphism of the VZP Complex indicates the deepest part of the Early Cretaceous Pohorelá detachment fault. Nearly the same Alpine structural and metamorphic level is represented by the Čierny Balog Complex overlying the VZP Complex, or by a part of the underlying Hron Complex (compare with PUTIŠ, 1994, KORIKOVSKY & PUTIŠ in KOTOV et al., 1996).

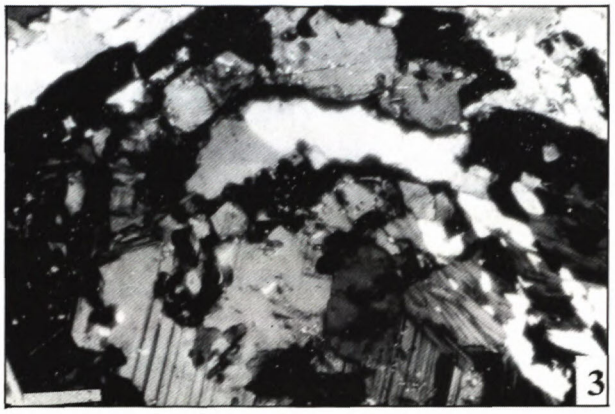
The Vepor granitoid pluton and the accompanying cover (Foederata, or Struženík) complex already represent the upper crustal structural level. It is proved by the perfect ductility of Qz and semiductility of Fsp in dominant Bt zone metamorphic conditions (PUTIŠ, 1991 a, b, 1994, 1995). The granitic mylonites (84-86 Ma, 40Ar-39Ar on WhM, DALLMEYER et al., 1993, 1996) of the Vepor pluton, inclusive the Permian - Mesozoic cover rocks, are overlying the Čierny Balog Complex.

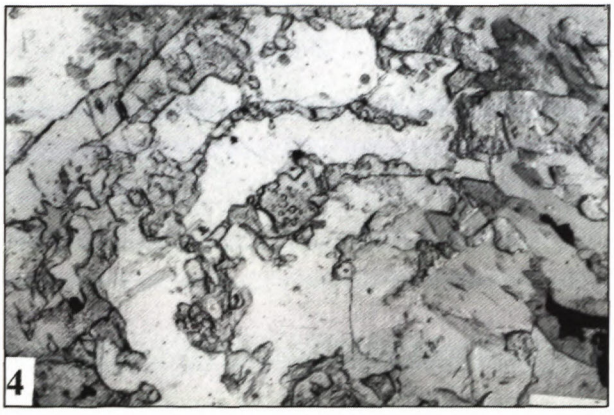
The whole hanging wall structural sequence of the Pohorelá detachment fault (bottom to top: reduced Hron Complex VZP Complex, Čierny Balog Complex and Vepor pluton granitoids, incl. the Permian - Mesozoic cover rocks) was incorporated into the Early Cretaceous (South Veporic) Kráľova Hoľa Nappe thrust over the (North Veporic, or Supratatric) Krakľová Nappe (with dominated Pre-Alpine Hron Complex) along the Pohorelá "line".

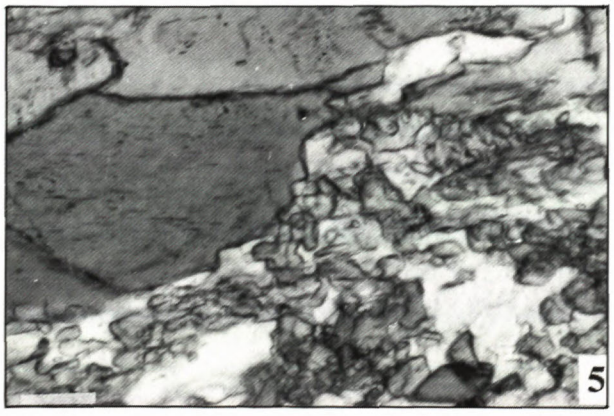
*Pl. II. Microstructures of the magmatic, subsolidus and solid stage. 1 - Pyrx overgrown and enclosed by Amph, with a reaction rim between Pyrx and Amph, in (meta)gabbro; scale-bar=1mm. 2 - Pyrx (with exsolutions) and reaction (pale) rims in contact with later crystallized magmatic $Amph_{(1)}$, in (meta)gabbro; sc.b.=1,5mm. 3 - magmatic-subsolidus foliation ($S_0$) defined by Plg and some larger Qz grains in trondhjemite layer; sc.b.=1mm. 4 - solid-stage foliation ($S_1$) defined by newly formed (Alpine) Bt, WhM, Tit, Chl, Ep-Clz, $Amph_2$, which cut $Amph_1$ aggregate in (meta)diorite; sc.b.=1mm. 5 and 6 - Alpine dynamometamorphic "breakdown" of magmatic Amph1 to newly formed tiny $Amph_2$ grains in dioritic orthogneiss; sc.b.=0,5mm. 7 - higher-temperature Qz ribbon fabric in layered (metadioritic) amphibolite; sc.b.=1mm. 8 - lower-temperature internal dynamic recrystallization of Qz ribbons into polygonal aggregate of subgrains in layered amphibolite; sc.b.=0,5mm.*

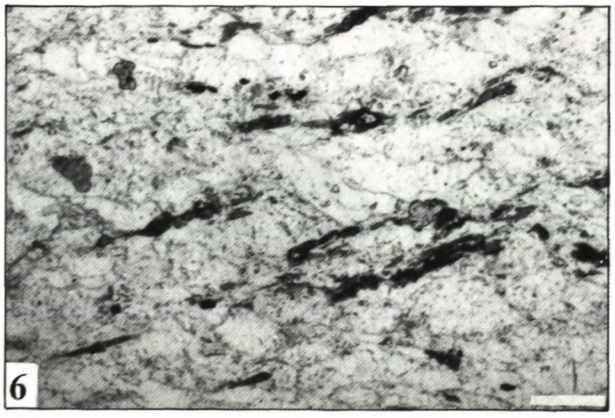

1


2


3


4


5


6


7


8

## Meso- and microstructures of magmatic/ subsolidus and solid-state deformation/ recrystallization

*Magmatic/subsolidus foliation ($S_0$)* is macroscopically visible especially in porphyric dioritic orthogneisses (Pl. I/1,2-S-planes) due to subparallel orientation of hypiiomorphic Plg and some Amph. Oriented structure is also seen in dark gabbrodioritic layers (Pl. I/6). Magmatic layering into pale and more or less dark layers is the most distinct macroscopic feature of the VZP Complex (Pl. I/5-7). Even in the relatively homogeneous dioritic orthogneiss, there is characteristic alternation of coarse-grained and fine-grained layers of comparable composition.

The most probable mechanism of the layering appears to be magmatic laminar flow, accompanying the differentiation and alignment of Plg and Amph mega- and microcrysts parallel to the direction of flow. It is quite characteristic of intermediate magmatic complexes (e.g. PARSONS, 1987, FOUNTAIN et al., eds., 1992, PERCIVAL et al., 1992, SHELLEY, 1992, HALL, 1996), where a viscosity contrast between the mafic and felsic mineral aggregates is supposed during laminar flow and cooling in dynamic conditions of the shear zones. A continuous evolution of the magmatic to subsolidus foliation is characteristic for magmatic complexes emplaced into shear zones (e.g. PATTERSON et al., 1989, 1990). The presence of some sill-like veins can not be excluded.

Mesoscopic magmatic foliation is also recognizable due to leucotonalitic/trondhjemitic veins concordant or discordant with $S_0$ planes (Pl. I/1). The composition of these leucocratic veins (Plg, Qz, ±Amph, Tit, Mgt) strictly depends on composition of the host rocks and they could form by differentiation of primary dioritic rocks .

Other leucocratic granitic to pegmatitic veins contain a great amount Qz, Ms, and much less Kf than Plg. These veins (233±10 Ma, U-Pb, Kotov, pers. comm.) are cutting the subsolidus foliation of the VZP Complex. In some places such veins represent filled conjugate systems of tension fractures.

The position of subhorizontal magmatic/subsolidus foliation (e.g. 30/30, 330/20, 280/20, Pl. V/1.) is influenced by the Alpine collisional structure and kink-type macrofolds with NW-SE directed fold axes.

*Mylonitic/metamorphic foliation ($S_1$)* of the VZP magmatic complex either follows or obliquelly (at an acute angle) cuts the magmatic/subsolid foliation. $S_1$ planes are subhorizontal, or slightly inclined to the N or S (Pl. V/1.). They are usually superimposed on $S_0$ planes. $S_1$ planes are defined by the newly formed mylonitic/ metamorphic minerals like Bt, WhM (Phn/Pgn), Chl, $Amph_2$ (Tsch-rich), Gt(Gross-rich), Ep-Clz and recrystallized ggregates of Qz (Qz ribbons - Pl. II/7, or Qz polygonal aggregates - Pl. II/8) and Plg (Pl. II/7).

Concordant (// to $S_0$) or discordant leucotonalitic, or younger leucogranitic/pegmatitic veins also exhibit mylonitic $S_1$ foliation.

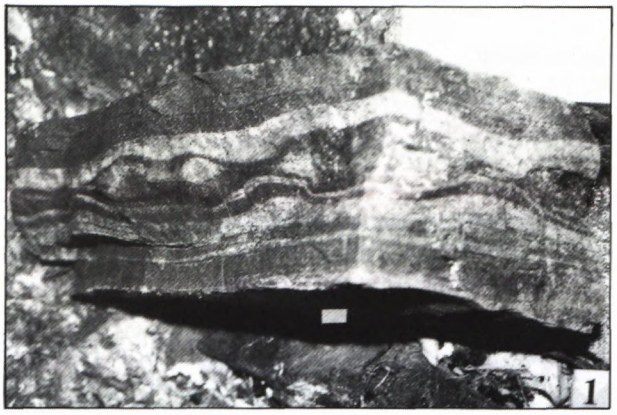
Metamafics and metaultramafics do not have a penetrative foliation $S_1$, because the mafic minerals (Amph±Pyrx) prevail over Plg. Subparallel to irregular systems of ductile-brittle fractures are filled with recrystallization products: Bt, Chl, Tit, WhM(Phn), Clz, $Amph_2$ (Pl. I/4, Pl. II/4).

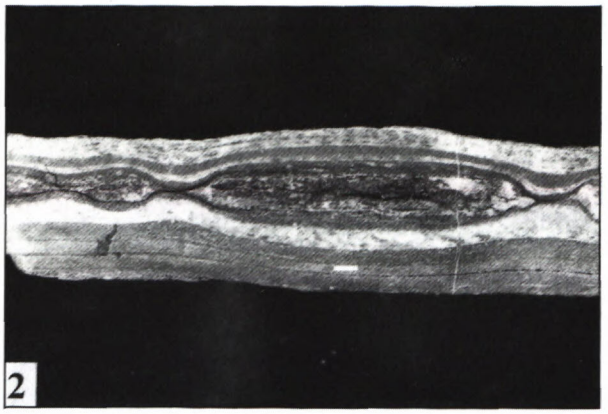
*Lineation of magmatic flow ($L_0$)* has a dominated NW-SE direction (Pl. V/3.). It also varies from 330° or 150° (direction of dip) to 295° or 115°. It is defined by the alignment of (partially recrystallized) magmatic forms of Plg and Amph (Pl. I/1, 2, 5, 6) in magmatic foliation *($S_0$)*.

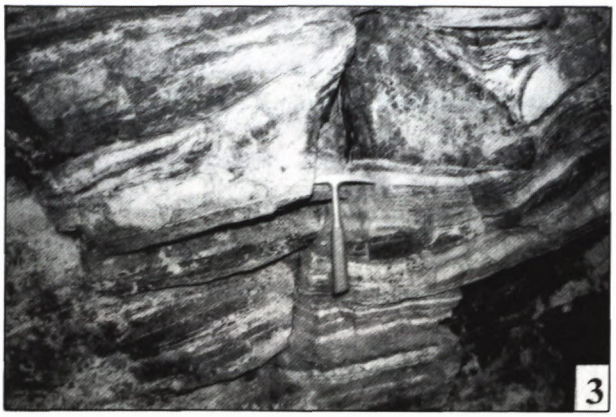
*Mylonitic/metamorphic lineation ($L_1$)* is defined by recrystallized fine-grained aggregates of $Amph_2$ in layered dioritic orthogneisses to amphibolites, or by Bt and WhM in gneiss-migmatitic micaschists (visible on $S_1$ planes of rocks). Brown-green (pre-Alpine) $Amph_1$ was passively rotated into a direction parallel with WNW-ESE mineral and stretching $L_1$ lineation. It is partially (to totally) replaced by (Alpine) blue-green $Amph_2$ (Pl. II/5, 6, Pl. III/5) which also grew parallel to mylonitic foliation *($S_1$)* and lineation *($L_1$)*, or even in C-planes (Pl. III/6). Mylonitized mafic rocks have well visible lineation due to oriented growth of newly formed Bt, together with Chl, WhM(Phn) and $Amph_2$(Act). In general, this type of lineation is oriented in NW-SE to WNW-ESE direction (Pl. V/3.) and it resembles partially the direction of magmatic/subsolidus lineation *($L_0$)*.

*Intersection lineation ($L_2$)* with the 280°-270° (or 100°-90°) (Pl.V/4) direction of dip formed due to development of a dense (E-W) *ductile cleavage ($S_2$)* (Pl.V/2) followed by rotation of Plg and less $Amph_1$ (Pl. IV/6).

*Pl. III. Microstructures of Alpine recrystallization and solid stage fabrics. 1 - newly formed tremolite aggregate in antigoritic serpentinite, usually parallel to $S_1$ foliation; scale-bar=0,25mm. 2 - newly formed (Alpine) skeletal Gros-rich Gt in equilibrium with newly formed Tsch-rich tiny $Amph_2$ in layered amphibolite; sc.b.=0,5mm. 3 and 4 - zonal Gross-rich Gt encloses the relics of albitized Plg; all Gt zones appear to be in equilibrium with $Amph_2$, Bt, Chl, Clz; sc.b.=0,5mm. 5 - Alpine dynamometamorphic replacement of $Amph_1$ by tiny $Amph_2$ aggregate; sc.b.=0,25mm. 6 - Alpine S-C fabric in pale layers of amphibolite; C-planes are defined by newly formed $Amph_2$; sc.b.=1mm. 7 - Gt-Ky(?) migmatitic-granitic micaschist (the surface of $S_1$ foliation); sc.b.=1cm. 8 - Atoll-like newly formed Gross-rich Gt in granitic orthogneiss; sc.b.=1mm*

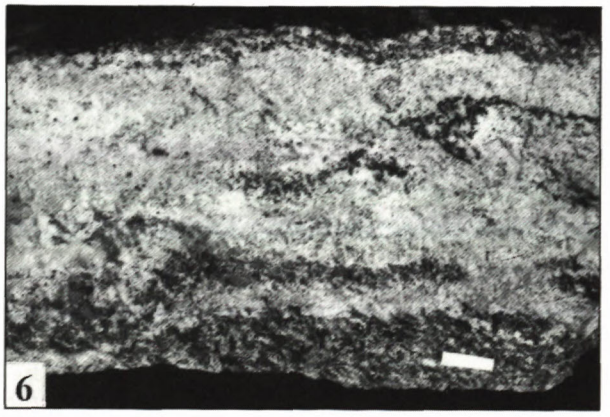

1

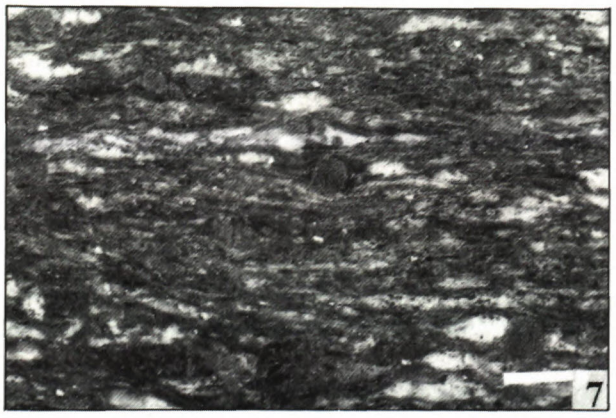

2

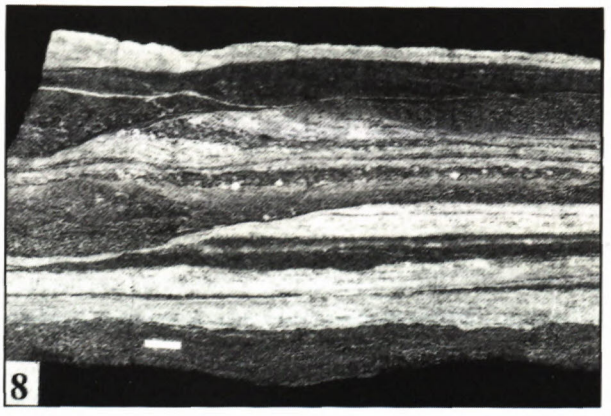

3


4


5


6


7


8

*Intrafolial folds ($F_1$)* (Pl. IV/5) with the B-axes parallel to mylonitic mineral and stretching lineation *($L_1$)* formed due to layer-parallel shortening connected with thickening or thinning of layers. Accompanying compressional ductile mesothrusts with NW vergency are scarcely preserved too.

Among the most characteristic mesostructures are symmetrically *boudinaged layered structures* in both XZ and YZ planes (Pl. IV/1, 2), which indicate a pure shear regime of mylonitic deformation. The development of superimposed extensional lineation, circular cores of mesofolds and intersection lineation (Pl. IV/6), on the other hand, indicate a transition to constriction.

The cores of lense-shaped boudins elongated in the direction of $L_1$ lineation are represented by relatively more rigid massive coarse-grained Pyrx-Amph meladiorites or gabbrodiorites (Pl. IV/3), which are not mylonitized (Pl. II/1, 2) and were avoided by the ductile flow.

Similar structures are observable even in homogeneous dioritic orthogneisses due to high ductile strain localization into some layers surrounding 1-2 m thick only slightly deformed orthogneisses (Pl. IV/4). Internal structures of such metadioritic boudins have at least partially preserved magmatic/subsolidus structures. On the other hand, the surrounding, both dark and pale layers exhibit strong ductile deformation and recrystallization in the form of fine-grained distincly oriented aggregates. The originally magmatic layering can be stressed by a more intensive (dense) ductile layering due to localized ductile flow (PASSCHIER & TROUW, 1996). Ductile flow can be accompanied with the diffusional migration of Ca, Na, Si to pale layers and Fe, Mg to dark ones (e.g. KRETZ, 1994), thus supporting the formation of ductile (mylonitic) layering.

*Sigma and/or delta structures* of Plg mostly indicate top-to-SE-ESE extensional sliding connected with porphyroclast rotation (Pl. I/2, 7, Pl. IV/7, 8).

Younger appear to be *ductile or ductile-brittle extensional mesofaults $S_3$* (320-345/60-75). Some of them are filled with Qz or Ep.

Approximately the same age is assigned to *brittle-ductile to brittle extensional mesofaults $S_4$* of the NW-SE direction, inclined to the SW-SSW (230-190/20-35) (Pl. IV/8).

The deeper foot wall unit - pre-Alpine Hron Complex of the mid-Cretaceous Krakľová Nappe, exhibits NE-SW directed mylonitic foliation (dipping to the SE: 135-150/45-70) and lineation (dipping to the ENE: 70/5-10, or to the WSW: 240/5-10) - (Pl. V/2, 4) which are closely related to the Pohorelá detachment fault system.

## Rheological behaviour and crystallographic preferred orientation (CPO) fabrics of rock-forming minerals

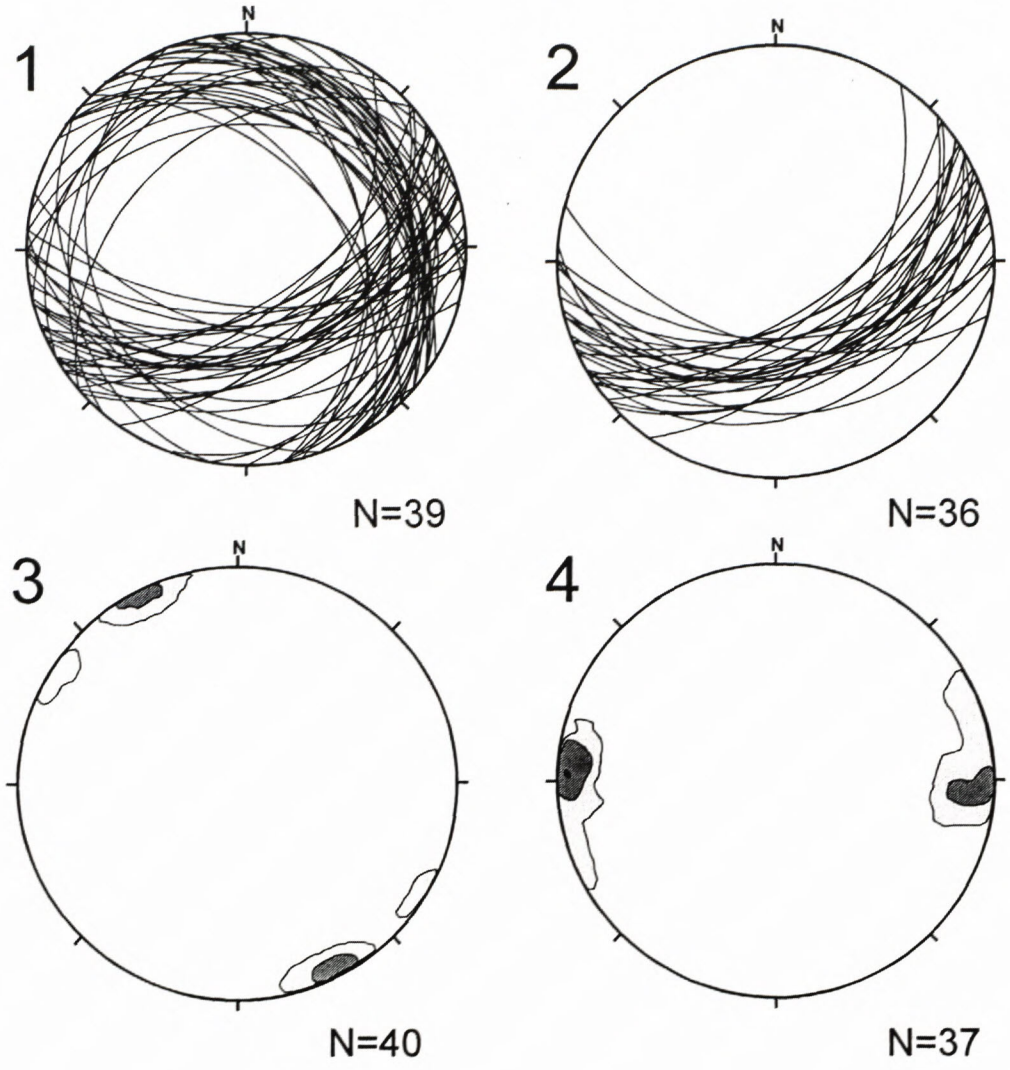
*Ductile behaviour of Qz.* Well preserved magmatic structures of some pale layers of trondhjemitic composition reveal intersticial position of Qz grains within Plg (±Amph, Tit) aggregates (Pl. II/3). Superimposed deformation at higher temperatures caused migration recrystallization of Qz to microscopic ribbons (Pl. II/7) separated from Plg-rich microlayers. The Qz ribbons exhibit two stages of recrystallization. The higher-T stage is represented by subgrains with boundaries perpendicular to ribbons. Their c-axes patterns represent higher-T (over 500 °C) rhomb and/or prism <c> glide systems (Pl. VI/1-3) in subgrains.

The superimposed dynamic recrystallization of large Qz ribbons into a polygonal aggregate of Qz (Pl. II/8) already belongs to the lower-T stage of deformation. A combination of basal <a> and prism <a> glide systems is evident from Qz c-axes preferred orientation patterns (Pl. VI/4-7) indicating temperatures of power law (dislocation) creep between 500 and 300 °C (e.g. LISTER & HOBBS, 1980, SCHMID & CASEY, 1986). The asymmetry of diagrams reflects top-to-ESE direction of extension (Pl. VI/4-7).

*Ductile behaviour of Plg* (and Qz) indicates a typical mid-crustal rheology (at the temperatures over 500°C at medium pressures) of the layered metamagmatic complex during the initial stage of hanging wall exhumation on the Pohorelá detachment fault.

Porphyric hypidiomorphic Plg of Qz diorites to diorites exhibit recrystallization along crystal rims and formation of dynamically recrystallized aggregates in tails of porphyroclasts (Pl. I/2). Ductile mylonitic microlayering

*Pl. IV. Alpine solid-stage mesostructures of the metamagmatic VZP complex (scale-bar=1cm). 1, 2 and 3 - boudinaged dark metamafic (Pyrx-Amph ±Plg, metagabbroic) layers within ductilely thinned layered amphibolites due to viscosity contrast during Alpine extensional uplift. 4 - boudinaged dioritic orthogneiss within layered amphibolites with high strain localization. 5 - intrafolial mesofolds due to layer parallel shortening. 6 - circular cores of mesofolds in YZ cut indicating constriction in direction of stretching ($L_1$) and intersection ($L_2$) lineations parallel to XZ plane. 7 - Alpine migmatitic/granitic Gt micaschist with flattened and stretched Plg and Plg+Qz aggregates, respectively. 8 - ductile-brittle extensional cleavage ($S_3$ and $S_4$ planes) in layered amphibolite*




*Pl. V. Great Circle (Equal area, lower hemisphere projection) and Contour orientation diagrams of mesostructures of the VZP Complex. 1 - Magmatic $S_0$ and mylonitic/metamorphic foliation planes $S_1$. 2 - Alpine extensional cleavage planes $S_2$. 3 - Lineations of magmatic flow $L_0$, and mylonitic/metamorphic lineations $L_1$. 4 - intersection lineations $L_2$.*

of Qz and Plg aggregates causes formation of distinct macroscopic banded structures.

Flattened individual Plg grains of metamagmatic rocks are usually covered by recrystallization products: Clz, $Amph_2$, Chl, Gt, Bt.

Some pale low strained layers have quite well preserved (pre-solid) oriented textures of Plg aggregates (Pl. II/3) separated by intersticial Qz grains. Plg layers (due to migration recrystallization of Qz and dynamic recrystallization of Plg) exhibit higher-T mylonitic fabrics characterized by (001) planes (// with Nγ) subparallel to $S_0$.

*Behaviour of Amph.* Less deformed and recrystallized gabbro-dioritic to tonalitic rocks have often still randomly distributed $Amph_1$(Mg-Hbl) with brown-green to green pleochroism. These Amph-s appear to be of magmatic origin, but they already have metamorphic composition. Pre-Alpine brown-green $Amph_1$ is replaced by Alpine blue-green $Amph_2$ at least along the rims, or it is replaced by an aggregate of tiny newly formed blue-green $Amph_2$ during dynamic recrystallization (Pl.II/5,6, Pl.III/5). "Symplectitic" forms of the newly formed $Amph_2$ with Ep-Clz are characteristic too. $Amph_2$ is also present within recrystallized $Plg_1$ grains together with Ep-Clz and Gt(Gross-rich).

The most intensive deformation and recrystallization of Amph (either brown-green or blue-green) is recognizable in fine-grained banded amphibolites (Pl. I/8) with the maximum strain localization in both Plg-Qz-rich and Amph-rich layers. We can find there only some relics of larger brown-green, but mainly blue-green Amph, which

are almost totally replaced by fine grained $Amph_2$ aggregates oriented in $L_1$ lineation.

Oriented $Amph_1$ (in *S-planes*) of mafic meladioritic to metagabbrodioritic rocks are cut by microshears (*C-planes*) filled with the newly formed Bt, Chl, WhM-Phn, Clz, Tit, $Amph_2$.

## Conclusions

The VZP Complex of the Veporic basement indicates Meso/Late Variscan postcollisional crustal collapse and emplacement of a magmatic complex into the extensional Variscan detachment fault zone (since appr. 346 Ma, U-Pb, Kotov et al., pers. comm.). It probably occurred due to melting and differentiation processes in the collapsing lower crust. The VZP Complex seems to be a precursor of Early Alpine continental rifting magmatism (Kotov et al., 1996) in the former continental margin of the Meliata-Hallstatt Ocean (KOZUR, 1991, PUTIŠ, 1991a, PLAŠIENKA, 1991) which included the Veporic unit.

The Veľký Zelený potok (VZP) Complex is mostly represented by layered and porphyric Qz-diorites to diorites, which are internally differentiated into some mafic (Pyrx-Amph or Amph-rich) meladiorites (gabbrodiorites), or pale tonalitic to (plagiogranitic) trondhjemitic layers.

The layers are usually a few dm or cm (scarcely a few m) thick. The whole VZP complex is about 250 m thick (after the ductile deformation). Some serpentinite bodies accompany the base of the VZP Complex.

Layered diorites are emplaced within gneiss-migmatitic rocks (Pre-Alpine Čierny Balog Complex) which have after the Alpine recrystallization the character of Gt micaschists. The youngest magmatic rocks that do not belong to the VZP Complex, appear to be leucocratic granitic-pegmatitic veins (233±10 Ma, U-Pb, Kotov et al., l.c.) parallel to or cutting the magmatic/subsolidus layering of dioritic orthogneisses.

The superimposed solid state mylonitization-recrystallization is Alpine in age. The mylonitic layering in dioritic orthogneisses has locally its origin in magmatic layering. The ductile behaviour of Plg and Qz in high-strained layers (bands) reflects superimposed mid-crustal mylonitic rheology and the formation of some layers due to localization of high ductile flow. The newly formed Gt (Gross-rich) is in equilibrium with mylonitic mineral assemblage: recrystallized Plg and recrystallized Qz ribbons, as well as with other newly formed minerals such as blue-green tiny $Amph_2$ (tschermakite-rich), Bt, Tit, WhM, Chl, Rut (partially replaced by Ilm and Tit), Clz, ±Chtd.

The VZP Complex represents the deepest part of the hanging wall complex of the Pohorelá detachment fault. The VZP Complex belongs to the Alpine South Veporic Kráľova Hoľa Nappe detached along the mid-Cretaceous Pohorelá shear/fault zone and thrust over the North Veporic (Supratatric) Krakľová Nappe. Thus the VZP Complex represents Meso/Late Variscan dioritic-tonalitic-trondhjemitic complex cut by Early Alpine leucogranitic-pegmatitic veins and both were incorporated into the Early Cretaceous collisional structure of the Veporic unit.

Qz and Plg CPO patterns indicate power-law (dislocation) creep as the main micromechanism of ductile (plastic) deformation during the exhumation. Pure shear regime of deformation passed into simple shear dominated regime near the base of the VZP Complex, close to the detachment fault. The simple shear regime dominated in the upper part of the complex with the top-to-ESE direction of extension. It means that compressional (Pohorelá) thrust was accompanied by the hanging wall extensional unroofing (PUTIŠ, 1994).

## Discussion

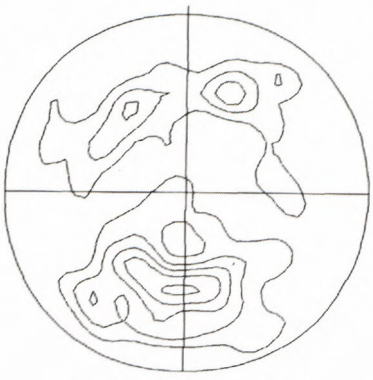
The age and the evolution of the VZP Complex are not compatible with the Leptyno-amphibolite Complex (LAC). The LAC (HOVORKA et al., 1992, HOVORKA & MÉRES, 1993) was defined as a Pre-Alpine lower-crustal cumulate complex metamorphosed at higher amphibolite to granulite facies conditions. The representative rocks of the LAC are layered amphibolites with inclusions of Rut-Gt-Cpx (HP/HT) metabasites, as well as high-grade Ky-Gt gneisses. Partial melting of the amphibolite complex has been mentioned either.

The VZP Complex formed after the main (regional) Variscan metamorphism and is represented by a Meso/Late Variscan magmatic complex (since 346 Ma) that is cut by the Early Alpine (233±10 Ma) granitic-pegmatitic veins.

The VZP Complex underwent Alpine, Early Cretaceous distinct metamorphic event with the temperatures between 500 and 600 °C at medium pressures 8-10 kbar. Such conditions are compatible with the mid-crustal rheology of rock-forming minerals during the Early Alpine exhumation of the complex. The VZP Complex does not show any signs of typical lower crustal rheology and metamorphism. It was metamorphosed due to Cretaceous collisional-extensional events in the medium pressure Ab-Ep amphibolite facies conditions (e.g. BUCHER & FREY, 1994).

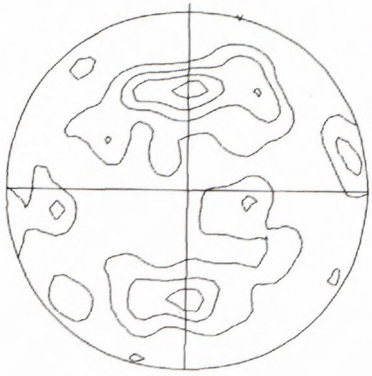
The VZP Complex has locally well preserved relic magmatic structures (magmatic layering) of the original rocks. The layered amphibolites mostly formed from dioritic protoliths, with some layers of meladioritic (gabbro-dioritic) rocks, and/or tonalitic/trondhjemitic ones due to previous differentiation of the magmatic complex within the shear zone bound to a detachment fault. Despite the preserved relic magmatic structures ($S_0$, $L_0$), the minerals (Hb1, Pyrx, Plg) already have a metamorphic/mylonitic composition due to re-equilibration just after emplacement of the VZP Complex.

1



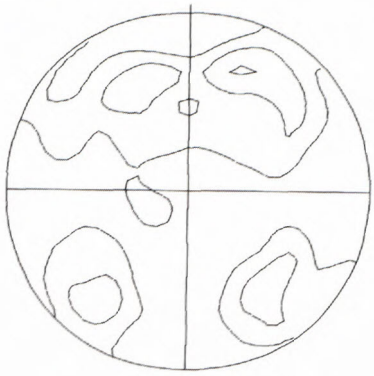
N = 365 E = 4.39
k = 83.11 Sigma = 1.46
(Peak - E)/Sigma = 8.6
Peak position : 185.7 / 43.5

2



N = 362 E = 4.39
k = 82.44 Sigma = 1.46
(Peak - E)/Sigma = 7.0
Peak position : 0.0 / 43.7

3



N = 249 E = 4.34
k = 57.33 Sigma = 1.45
(Peak - E)/Sigma = 4.2
Peak position : 22.6 / 28.6

4



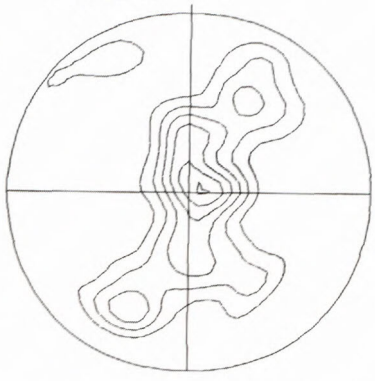
N = 404 E = 4.40
k = 91.78 Sigma = 1.47
(Peak - E)/Sigma = 20.3
Peak position : 90.0 / 90.0

5



N = 202 E = 4.31
k = 46.89 Sigma = 1.44
(Peak - E)/Sigma = 8.6
Peak position : 180.0 / 81.0

6



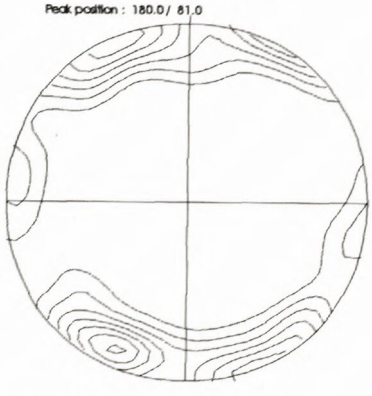
N = 291 E = 4.37
k = 66.67 Sigma = 1.46
(Peak - E)/Sigma = 10.2
Peak position : 90.0 / 85.5

7



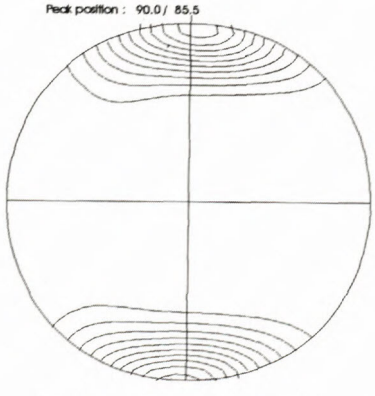
N = 585 E = 4.43
k = 132.00 Sigma = 1.48
(Peak - E)/Sigma = 13.6
Peak position : 16.4 / 1.8

8



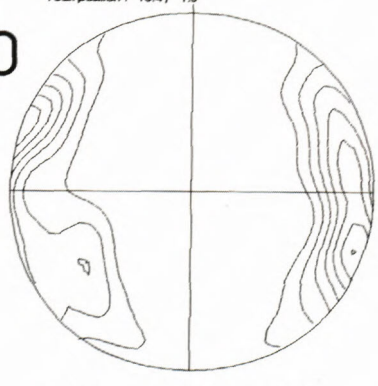
N = 179 E = 4.28
k = 41.78 Sigma = 1.43
(Peak - E)/Sigma = 12.5
Peak position : 205.0 / 8.9

9



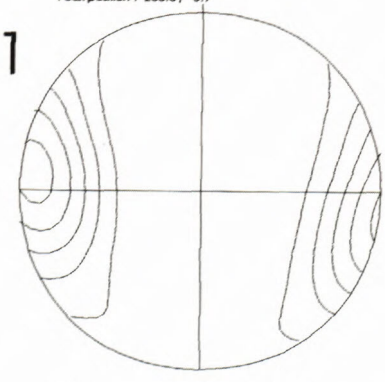
N = 62 E = 3.93
k = 15.78 Sigma = 1.31
(Peak - E)/Sigma = 19.1
Peak position : 3.2 / 0.2

10



N = 154 E = 4.25
k = 36.22 Sigma = 1.42
(Peak - E)/Sigma = 12.1
Peak position : 112.4 / 2.5

11



N = 31 E = 3.49
k = 8.89 Sigma = 1.16
(Peak - E)/Sigma = 8.9
Peak position : 276.7 / 5.5

The VZP Complex may be found also in the eastern part of the Nízke Tatry Mts. It overlies tectonically the micaschists of the (Pre-Alpine) Hron Complex of the Alpine Krakľová Nappe. It builds the base of the South Veporic Kráľova Hoľa Nappe. The VZP Complex was thrust together with (Sihla type) metatonalites of the Vepor pluton over the Krakľová Nappe. The inverted metamorphic zoning thus formed in the North-Veporic (Supratatric) area (PUTIŠ, 1994).

Only the layered Gt amphibolites (overlying the micaschistgneisses of the Pre-Alpine Hron Complex) at the crest between the Veľký Zelený Potok and Malý Zelený Potok valleys could belong to the LAC. Their garnets have relic Alm-rich cores replaced by Gross-rich rims. Thermobarometric calculations: T 614-640 °C (Gt-Hbl thermometer, GRAHAM & POWELL, 1984) at P 8,5 kbar (Gt-Hbl-Plg-Qz barometer, KOHN & SPEAR, 1990) of the prograde trend are not compatible with the results obtained from the VZP layered amphibolites. On the other hand, Gt zoning in these amphibolites is compatible with the Gt zoning in micaschist-gneisses of the underlying Pre-Alpine, supracrustal Hron Complex.

Garnets of the VZP Complex layered amphibolites always exhibit prograde zoning and Gross-rich compositions. Using of Bt and Hbl inclusions in Gt, and Bt-Hbl-Gt geothermometry, T estimates are from 520-530 °C (cores) up to about 600 °C (medium to outer parts of grains). Among early inclusions inside Gt also Chl and Ep-Clz are present. The prograde zoning of central parts of Gt, and the presence of Chl inclusions in Gt exclude any suppositions about manifestation of the preceding higher amphibolite facies in the VZP Complex. Any certain relics of a high-T stage in the VZP Ep-amphibolites are fully absent and their metamorphism appears to be exclusively Alpine in age.

## References


BERTHÉ D., CHOUKROUNE P. & JEQUOZO P., 1979: Orthogneiss, mylonite and non-coaxial deformation in granites: The example of the South Armorican shear zone. J. Struct. Geol. (Oxford), 1, 31-42.

BIBIKOVA E. V., KORIKOVSKY S. P., PUTIŠ M., BROSKA I., GOLZMAN Y. V. & ARAKELIANTS M. M., 1990: U/Pb, Rb/Sr and K/Ar dating of Sihla tonalites of Vepor pluton (Western Carpathians). Geol. Zbor. Geol. Carpath. (Bratislava), 41, 427-436.

BIELY A., BEŇUŠKA P., BEZÁK V., BUJNOVSKÝ A., HALOUZKA R., IVANIČKA J., KOHÚT M., KLINEC A., LUKÁČIK E.., MAGLAY J., MIKO O., PULEC M., PUTIŠ M. & VOZÁR J., 1992: Geological map of the Nízke Tatry Mts. 1: 50 000. D. Štúr Inst. of Geol., Bratislava.

CAMBEL B., KRÁĽ J. & BURCHART J., 1990: Isotopic geochronology of the Western Carpathian crystalline basement. Veda-Press, Bratislava, 183p. (in Slovak, with English summary).

DALLMEYER R. D., NEUBAUER F. & PUTIŠ M., 1993: 40Ar/39Ar mineral age controls for the Pre-Alpine and Alpine tectonic evolution of nappe complexes in the Western Carpathians. PAEWCR Confer., Excursion guide, Stará Lesná, 11-20.

DALLMEYER R. D., NEUBAUER F., HANDLER R., FRITZ H., MÜLLER W., PANA D. & PUTIŠ M., 1996: Tectonothermal evolution of the internal Alps and Carpathians: Evidence from 40Ar/39Ar mineral and whole-rock data. Eclogae Geol. Helv. (Basel), 89, 1, 203-227.

BUCHER K. & FREY M., 1994: Petrogenesis of Metamorphic Rocks. Springer-Verlag, Berlin, 318 p.

FOUNTAIN D. M., ARCULUS R. & KAY R.W., eds., 1992: Continental Lower Crust. Elsevier, Amsterdam, 485 p.

GRAHAM C. M. & POWELL R., 1984: A garnet-hornblende geothermometer: calibration, testing, and application to the Pelona Schist, Southern California. J. Metam.Geol., 2, 13-21.

HALL A., 1996: Igneous Petrology. Longman Group Limited, Essex, 2-nd ed., 551 p.

HOVORKA D., MÉRES S., & IVAN P., 1992: Pre-Alpine Western Carpathians Mts. basement complexes: Geochemistry, petrology, geodynamic setting. Terra Abstr. (Oxford) to Terra nova 4, Abstr. suppl. 2, 32.

HOVORKA D. & MÉRES S., 1993: Leptyno-amphibolite complex of the Western Carpathians: occurrences and lithology. Mineralia Slov., 25, 1-9. (in Slovak, with English abstract).

IVANIČKA J. & KOVÁČIK M., 1989: Geological-lithological and petrographical-geochemical characteristics of metamorphites in Hron Complex SE of Benuš. Reg. geol. Záp. Karpát, Správy o výsk. GÚDŠ. (Bratislava), 25, 113-120. (in Slovak, with English summary).

JANÁK M., 1991: Petrology of metamorphic rocks of the High Tatra Mts., Unpublished thesis, Comenius. Univ. Bratislava. (in Slovak).

JANÁK M., 1992: Variscan mid-crustal trusting in the Carpathians I: Metamorphic conditions and P-T paths of the Tatry Mts. Terra Abstr. (Oxford) to Terra nova 4, Abstr. suppl. 2, 35.

JANÁK M., 1994: Variscan uplift of the crystalline basement, Tatra Mts., Central Western Carpathians: evidence for 40Ar/39Ar laser probe dating of biotite and P-T-t paths. Geol. carpath. (Bratislava), 45, 293-300.

JANÁK M., PITOŇÁK P., SPIŠIAK J., PETRÍK I. & O'BRIEN P. J., 1995: Trondhjemitic-tonalitic melts in the Western Carpathian basement: implications for partial melting of amphibolite and differentiation of the lower crust. Terra Abstr.(Oxford) to Terra nova 7, Abstr. suppl. 1, 307.

JANÁK M. & LUPTÁK B., in press: Pressure-temperature conditions of high-grade metamorphism and migmatitization in the Malá Fatra Mts. Geol. Carpath. (Bratislava), 48.


*Pl. VI. Crystallographic mineral preferred orientation (CPO) patterns. 1 - 3 - Qz ribbons c-axes isoline patterns of the layered amphibolite. 4-7 - polygonal Qz grains c-axes isoline patterns of the layered amphibolite. 8-9 Nβ optical direction isoline patterns of Plg of the layered dioritic orthogneiss to amphibolite. 10-11 - Nγ optical direction isoline patterns of Plg of the layered dioritic orthogneiss to amphibolite.*

KLINEC A., 1966: Zum Bau und Bildung des Veporiden-Kristallin. Sbor. Geol. Vied, Záp. Karpaty (Bratislava), 6, 7-28. (in Slovak, with German summary).

KLINEC A., 1968: Report on structural borehole KV-1, near Pohronská Polhora village, Vepor Mts. Manuscript - Archive of Geol. Survey of Slovak rep., Bratislava. (in Slovak).

KLINEC A., 1976: Geological map of the Slovak Ore Mts and Low Tatra Mts. Slovak Ore Mts.-central part, Low Tatra Mts.- eastern part, 1: 50 000. D. Štúr Inst. of Geol., Bratislava.

KOHN M. J. & SPEAR F. S., 1990: Two next geobarometers for garnet amphibolites, with application to eastern Vermont. Am. Miner. (Washington), 75, 89-96.

KORIKOVSKY S. P., PUTIŠ M. & BORONIKHIN V. A., 1992: Anchimetamorphism of Permian metasandstones of the Struženík Group on the Northern flanks of the Kráľova hoľa Mts. (Veporicum, the Western Carpathians). Geol. Carpath. (Bratislava), 40, 2, 187-200.

KOTOV A. B., MIKO O., PUTIŠ M., KORIKOVSKY S. P., SALNIKOVA E. B., KOVACH V. P., YAKOVLEVA S., BEREZNAYA N. G., KRÁĽ J., & KRIST E., 1996: U/Pb dating of zircons of postorogenic acid metavolcanics and metasubvolcanics: A record of Permian-Triassic taphrogeny of the West-Carpathian basement. Geol. Carpath. (Bratislava), 47, 2, 73-79.

KOVÁČIK M., KRÁĽ J. & MALUSKI H., 1996: Metamorphic rocks in the southern Veporicum basement: their Alpine metamorphism and thermochronologic evolution. Mineralia Slov. (Bratislava), 28, 185-202.

KOZUR H., 1991: The geological evolution at the western end of the Cimmerian ocean in the Western Carpathians and Eastern Alps. Zbl. Geol. Paläont., (Stuttgart), T.1, H.1, 99-121.

KRETZ R., 1994: Petrology of veined gneisses of the Otter complex, southern Grenville Province. Can. J. Earth. Sci. (Ottawa), 31, 835-851.

KRIST E., 1976: Occurrence of metamorphic tuffs and tuffites in the Veporic crystalline complex of the central West Carpathians. Geol. Zbor. Geol. carpath. (Bratislava), 27, 141-147.

KRIST E., KORIKOVSKY S. P., PUTIŠ M., JANÁK M. & FARYAD S. W., 1992: Geology and petrology of metamorphic rocks of the Western Carpathian crystalline complexes. Comenius University Press, Bratislava, 324p.

LISTER G. S. & HOBBS B. E., 1980: The simulation of fabric development during plastic deformation and its application to quartzite: the influence of deformation history. J. Struct. Geol. (Oxford), 2, 355-370.

MADARÁS J., PUTIŠ M. & DUBÍK B., 1994: Structural characteristic of the middle part of the Pohorelá tectonic zone. Mineralia Slov. (Bratislava), 26, 177-191. (in Slovak, with English summary).

MAHEĽ M., et. al., 1964: Explanations to geological map 1:200 000 (Banská Bystrica sheet). Geofond, Bratislava, 270 p. (in Slovak).

MASSONE J. J. & SCHREYER W., 1987: Phengite barometry based on the limiting assemblage with K-feldspar, phlogopite and quartz. Contr. Mineral. Petrol., 96, 212-224.

MAZZOLI C., SASSI R. & VOZÁROVÁ A., 1992: The pressure character of the Alpine metamorphism in the Central and Inner Western Carpathians (Czecho-Slovakia). In: Vozár J. (ed.): The Paleozoic geodynamic domains - Western Carpathians, Eastern Alps, Dinarides. D. Štúr Inst. of Geol., Bratislava, 109-117.

MÉRES S. & HOVORKA D., 1991: Alpine metamorphic recrystallization of the pre-Carboniferous metapelites of the Kohút crystalline complex (the Western Carpathians). Mineralia Slov. (Bratislava), 23, 435-442.

MÉRES S., HOVORKA D. & IVAN P., 1996: Gabbroids within the Veporic Unit of the Nízke Tatry Mts. (Western Carpathians). Mineralia Slov. (Bratislava), 28, 38-44. (in Slovak, with English summary).

MIKO O., PLANDEROVÁ E., PUTIŠ M., HATÁR J., GREGUŠ J., SUCHÝ S. & STRÁNSKA V., 1987: Petrology and reinterpretation of crystalline rocks in borehole profile KV-1- Pohronská Polhora village, Veporské vrchy Mts. Manuscript - Archive of Geol. Survey of Slovak Rep., Bratislava. (in Slovak).

PARSONS I. (ed.), 1987: Origin of Igneous Layering. Reidel, Dordrecht, 666p.

PASSCHIER C. W. & TROUW R. A. J., 1996: Microtectonics. Springer, Berlin, 289p.

PATTERSON S. R., VERNON R. H. & TOBISCH O. T., 1989: A review of criteria for identification of magmatic and tectonic foliations in granitoids. J. Struct. Geol. (Oxford), 11,3, 349-363.

PATTERSON S. R., TOBISCH O. T. & MORAND V. J., 1990: The influence of large ductile shear zones on the emplacement and deformation of the Wyangala Batholith, SE Australia. J. Struct. Geol. (Oxford), 12, 5/6, 639-650.

PERCIVAL J. A., FOUNTAIN D. M. & SALISBURY M. H., 1992: Exposed crustal cross sections as windows on the lower crust.In: D.M. Fountain, R. Arculus and R.W. Kay (eds.): Continental Lower Crust. Elsevier, Amsterdam, 485 p.

PETRÍK I., BROSKA I., BEZÁK V. & UHER P., 1995: Hrončok granite - a Hercynian A-type granite in shear zone. Mineralia Slov. (Bratislava), 27, 351-364. (in Slovak, with English summary).

PLAŠIENKA D., JANÁK M., HACURA A. & VRBATOVIČ P., 1989: First illite-crystalinity data from Alpine metamorphosed rocks of the Veporicum, Central West Carpathians. Mineralia Slov. (Bratislava), 21, 43-51 (in Slovak, English summary).

PLAŠIENKA D., 1991: Mesozoic tectonic evolution of the epi-Variscan continental crust of the Central Western Carpathians - a tentative model. Mineralia Slov, (Bratislava), 23, 447-457.

PLAŠIENKA, D., 1993: Structural pattern and partitioning of deformation in the Veporic Foederata cover unit (Central Western Carpathians). In M. Rakús and J. Vozár (eds.): Geodynamic model and deep structure of the Western Carpathians. Conf., Symp., Sem., D. Štúr Inst. Geol., Bratislava, 269-277.

PLAŠIENKA D. & PUTIŠ M., 1993: Kinematics of Cretaceous uplift of the Veporic dome (Western Carpathians). Terra Abstr. (Oxford) to Terra nova 5, Abstr. suppl. 2, 27.

PUTIŠ M., 1989: Structural-metamorphic evolution of the crystalline complex of the eastern part of the Low Tatra Mts. Mineralia Slov, (Bratislava), 21, 217-224. (in Slovak, with English summary).

PUTIŠ M., 1991a: Tectonic styles and Late Variscan - Alpine evolution of the Tatric-Veporic crystalline basement in the Western Carpathians. Zbl. Geol. Paläont., (Stuttgart) T.1, H.1, 181-204.

PUTIŠ M., 1991b: Geology and petrotectonics of some shear zones in the West Carpathian crystalline complexes. Mineralia Slov., (Bratislava), 23, Newsletter No. 3, Project IGCP No. 276, 459-473

PUTIŠ M., 1992: Variscan and Alpidic nappe structures of the Western Carpathian crystalline basement. Geol. carpath., (Bratislava), 43, 6, 369-380.

PUTIŠ M., 1994: South Tatric-Veporic basement geology: Variscan nappe structures; Alpine thick-skinned and extensional tectonics in the Western Carpathians (Eastern Low Tatra Mts., Northwestern Slovak Ore Mts.). Mitt. Österr. Geol. Ges. (Wien), 86, 83-99.

PUTIŠ M., 1995: Deformation-recrystallization process in the shear zones: Tatro-Veporic Zone of the W. Carpathians; the Middle Austroalpine Sieggraben Unit of the E. Alps. Manuscript - Habil. thesis. Comenius University, Bratislava. (in Slovak).

PUTIŠ M., KORIKOVSKY S. P. & PLAŠIENKA D., 1995: 1.Alpine metamorphism of the South-Veporic Permian rocks and the North-Gemeric Carboniferous rocks of the Ochtiná type. 2. Phyllonites vs. phyllites of the North-Veporic zone. 3. Microfabrics of minerals in the transpressional North-Veporic zone. Manuscript - Archive of Geol. Survey of SR, Bratislava. (in Slovak).

PUTIŠ M., KORIKOVSKY S. P. & PLAŠIENKA D., 1996: Alpine metamorphism of the North Veporic Zone (Ľubietová, Bacúch and Predná hoľa Permian Complexes). Manuscript - Archive of Geol. Survey of SR, Bratislava. (in Slovak).

SCHMID S. M., & CASEY M., 1986: Complete fabric analysis of some commonly observed quartz c axis patterns. In: B. E. Hobbs & H. C. Heard (Editors), Mineral and Rock Deformation: Laboratory Studies. Geoph. Monogr. Ser., 36, 263-286.

SHELLEY, D., 1992: Igneous and metamorphic rocks under the microscope. Chapman & Hall, London, 445p.

SPIŠIAK J. & PITOŇÁK P., 1990: The Nízke Tatry Mts. crystalline complex - new facts and interpretation (Western Carpathians, Czechoslovakia). Geol. Zbor. Geol. carpath., (Bratislava), 4, 377-392.

SPIŠIAK J. & PITOŇÁK P., 1992: Banded amphibolitic rocks - pre-Variscan basement of the Western carpathians ? Terra Abstr. (Oxford) to Terra nova 4, Abstr. suppl. 2, 63.

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

VRÁNA S., 1966: Alpidische Metamorphose der Granitoide und der Foederate-Serie im Mittelteil der Veporiden. Zbor. geol. Vied, Západ. Karpaty (Bratislava), 6, 29-84.

VRÁNA S., 1980: Newly-formed Alpine garnets in metagranitoids of the Veporides in relation to the structure of the Central zone of the West Carpathians. Čas. Mineral. Geol. (Prague), 25, 41-54.

## Footnotes

***Mineral abbreviations in text and figures:*** Ab=albite, Act=actinolite, Alm=almandine, Amph=amphibole, Atg=antigorite, Ap=apatite, Bt=biotite, Cal=calcite, Chl=chlorite, Chtd=chloritoid, Clz=clinosoizite, Ep=epidote, Fsp=feldspars, Gross=grossularite, Gt=garnet, Hbl=hornblende, Ilm=ilmenite, Kf=kalifeldspar, Ky=kyanite, Mgt =magnetite, Ms=muscovite, Olv=olivine, Pgn=paragonite, Phn=phengite, Plg=plagioclase, Pyrx=Pyroxene, Qz=quartz, Rut=rutile, Tit=titanite, Trem=tremolite, Tsch=tschermakite, WhM=white mica, Zoi=zoisite, Zr=zircon.

SLOVAK GEOLOGICAL MAGAZINE

# Problems of geodynamic evolution and geological structure of the Paleozoic gemeric Unit (Inner Western Carpathians) as inferred by magmatic rock study

PETER IVAN

Comenius University, Department of Geochemistry, Mlynská dol. G, 842 15 Bratislava, Slovakia

*Abstract.* Based on geochemical and petrological data from basic magmatic rocks a redefinition of lithostratigraphic division of the Paleozoic of Gemeric Unit (Inner Western Carpathians) has been made. Lithostratigraphic formations were generated in the three types of geodynamic setting: (1) back-arc basins, (2) neighbourhood of magmatic arc of convergent plate margins and (3) amagmatic passive-like plate margin. Recent tectonic structure of this area is a product of multistage deformation and nappe formations during the variscan and alpine time.

*Key words:* Paleozoic, metabasites, lithostratigraphy

## Introduction

The Gemeric Unit is the northernmost unit of the Inner Western Carpathians. It is composed of Paleozoic and Mesozoic rock complexes. In spite of the fact that the Gemeric Unit belongs to the most intensively studied regions of the Western Carpathians, opinions on its geodynamic evolution and geological structure are controversial and insufficiently supported by exact data. Geochemical and petrologic study of magmatic, especially basic rocks, provided in the last time new data for the construction of a geodynamic model, especially due to a more precise lithostratigraphic division and determination of the geodynamic setting of Paleozoic formations of Gemericum.

## Lithostratigraphy

The Paleozoic of the Gemeric Unit is built of Early and Late Paleozoic complexes. Traditionally they used to be divided into five ltihostratigraphic groups. The Early Paleozoic was represented by (1) the Gelnica Group and (2) the Gočaltovo Group, the Late Paleozoic by (3) the Dobšiná Group, (4) the Krompachy Group and (5) the Gočaltovo Group (BAJANÍK et al., 1983). However, identification of the geochemical type of metabasalts, combined with lithological data, has shown that some sequences of the Rakovec and Dobšiná Groups appear rather to be independent formations. A lithostratigraphic classification of the Paleozoic of the Gemeric Unit, incorporating these new data, is presented in Fig. 1.

The areally most extensive lithostratigraphic group is the Gelnica Group. Its Early Paleozoic age has not been yet reliably proved. It is a typical volcano-sedimentary formation, the volcanogenic material predominating over sedimentogenic. It is represented especially by acid, less by intermediary volcanoclastics, effusive acid, intermediary or basic rocks are rare. The sedimentary material is partly of deep-water (silicites, black shales) and pelagic origin (allodapic limestones), it is partly continental, chemically mature, bearing signs of multiple recycling (VOZÁROVÁ, 1993). The Gelnica Group sedimented in an environment near the base of a continental slope, and the detritic material was transported by turbidite currents (IVANIČKA et al., 1989). Acid to intermediary volcanic and volcanoclastic rocks are products of calc-alkaline volcanism. The occurrences of metabasalts in the Gelnica Group are concentrated into three discontinuous belts. Three geochemical metabasalt types have been identified in the northern belt, geochemically similar to (1) calc-alkaline basalts (CAB), back-arc basin basalts (BABB) and (3) enriched mid-ocean ridge basalts (E-MORB), or ocean island tholeiites (OIT; IVAN, 1994). The other belts contain only the last mentioned metabasalt type. Based on the preserved texture relics, the majority of metabasalts crystallised in sub-volcanic conditions. The Gelnica Group underwent multistage metamorphism. Maximum metamorphic conditions did not exceed the greenschist facies, only in the central belt of metabasalt occurrences there are indications of a higher-pressure metamorphic stage. Probably the oldest and most important metamorphic stage is the regional alkaline metasomatism caused by extensive convection of thermal water. The Gelnica Group has been sub-divided into three lithostratigraphic sequences (IVANIČKA et al., 1989). These sequences however rather reflect some properties of the tectonic structure and they are not consistent with the spatial distribution of geochemical types of basic metavolcanites.

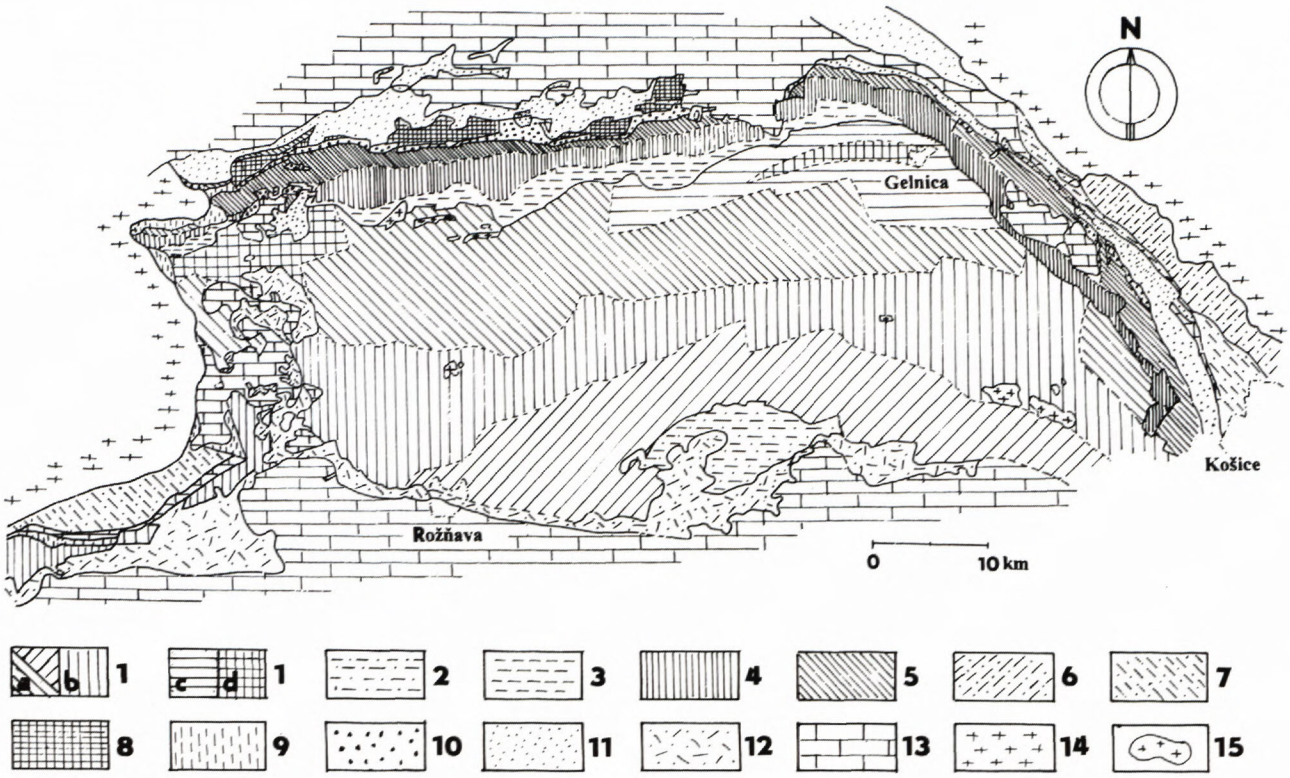



*Fig. 1: Lithostratigraphic formations of the Gemeric Unit Paleozoic (BAJANÍK et al., 1983 - adopted). Explanations: 1- Gelnica Group ( a-d - areas with different geochemical types of metabasalts; a - E-MORB/OIT , b- without metabasalts, c - BABB, d - CAB + E-MORB/OIT), 2 - Štós Formation, 3 - Smrečinka Formation, 4 - Rakovec Group, 5 - Klátov Group s.l. (1-5 - Early Paleozoic), 6 - Črmeľ Formation, 7 - Ochtiná Formation, 8 - Zlatník Formation, 9 - Hámor Formation, 10 - Rudňany Formation, 11 - Krompachy Group, 12 - Gočaltovo Group (6 -12 - Late Paleozoic), 13 - Mesozoic formations of the Gemeric and Meliatic Units, 14 - Veporic Unit (Central Carpathians), 15 - Gemeric granites*

The Štós Formation is located south of the Gelnica Group. It used to be classified as the southern part of the Rakovec Group. It is a monotonous complex of LP/LT metamorphosed alternating pelites and psammites. The assumed Early Paleozoic age of the formation has not been reliably proved yet. Rare small metabasalt bodies are geochemically similar to CAB.

The Smrečinka Formation, having a boundary with the Gelnica Group in the north, is lithologically similar to the Štós Formation. It consists of pelitic and psammitic rock metamorphosed in the greenschist facies. A small quantity of metamorphosed basic volcanoclastics is present as well as very rare effusive metarhyolites and metabasalts. The so far only chemical analysis of a metabasalt has shown a similarity of its composition with alkaline within-plate basalts (WPB). The Smrečinka Formation was traditionally considered the lower part of the Rakovec Group (BAJANÍK et al., 1983).

The Rakovec Group is in our concept of lithostratigraphic classification represented by a complex of metamorphosed lava flows overlying the Smrečinka Formation, or directly the Gelnica Group. Besides metabasalts, pelitic metasediments are found in a smaller quantity, rarely also acid and intermediary metavolcanites. Besides the predominant lava flows there are also basic rocks of subvolcanic origin. The metabasalts are, according to their composition, similar to typical E-MORB/OIT (IVAN, 1994). They display considerable variations in composition caused by the fractionation processes. Pelitic sedimentation and the occurrence of pillow textures in some lava flows indicate subaquatic environment far from the sources of clastic material. The Rakovec Group experienced multi-stage metamorphism with evidence of a MP/LT stage and superimposed LP/LT metamorphism. There are several indications in favour of a possible HP/LT metamorphic stage. Estimated age of the Rakovec Group is probably Early Paleozoic, however, geochronological data are missing to date.

The name "Klátov Group" has been assigned to metamorphic rocks of the amphibolite facies, mostly gneisses and amphibolites, which had been formerly included into the Rakovec Group (HOVORKA et al., 1990).

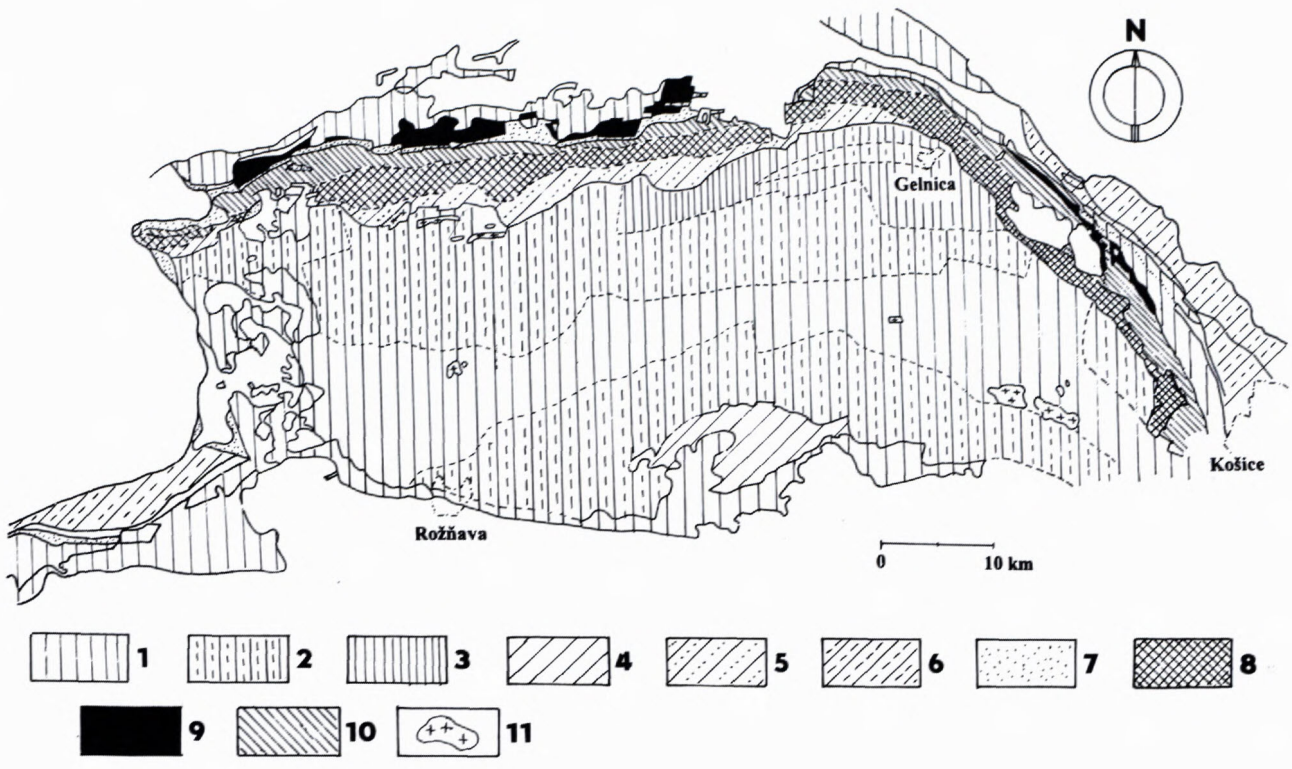



*Fig. 2: Geodynamic setting of the Paleozoic formations of the Gemeric Unit.*
*Explanations: 1 - formations with subduction-related (calc-alkaline) volcanic rocks, 2 - the same as 1 - with volcanic rocks of immature stage of back-arc basin opening, 3 - the same as 1- with volcanic rocks of more evolved stage of back-arc basin opening (BABB), 4 - pelitic rock dominated sedimentary formations of the back-arc basin margin, 5 - the same as 4 - with volcanic rocks of initial stage of back-arc basin opening, 6 - the same as 4 with volcanic rocks of immature stage of of back-arc basin opening, 7 - amagmatic clastic formations, 8 - relic of the crust of the back-arc basin in immature stage of opening, 9 - relic of the crust of more evolved back-arc basin, 10 - reworked lower island arc (continental?) crust, 11- Gemeric granites*

More recently, the Klátov Group was compared to leptyno-amphibolite complexes of the Central Western Carpathians (IVAN, 1994). The banded amphibolites, as far as the rare element distribution is concerned, resemble BABB, the enclaves of garnet amphibolites with clinopyroxene are similar to N-MORB. Metamorphic evolution of the Klátov Group was complex, multi-stage. There are indications of an oldest metamorphic stage in eclogite-, or granulite-facies conditions, followed by metamorphism in amphibolite and greenschist facies. The Klátov Group was originally known only from isolated occurrences.

According to latest preliminary data, newly found phyllonites of amphibolites and gneisses, together with a part of metasediments and metavolcanites, belong probably also to the Klátov Group, although they were previously assumed to be the top part of the Rakovec Group. The Klátov Group s.l. would thus form a continuous belt overlying the Rakovec Group. Relics of HP/LT metamorphic stage have been found also in the phyllonites.

Carboniferous complexes of the Gemeric Unit have been described by BAJANÍK et al. (1983) as the Dobšiná Group. The authors defined four stratigraphic sequences, which, according to the results of our studies, we consider to be separate formations. They are: (1) the Ochtiná Formation, (2) the Rudňany Formation, (3) the Zlatník Formation and (4) the Hámor Formation. Carboniferous age has been proved also in the Črmeľ Group. The Rudňany and Hámor Formations consist of metapsammites and metapsephites, volcanic rocks are missing. The source of sedimentary material for the Rudňany Formation was the Klátov Formation (VOZÁROVÁ & VOZÁR, 1988). Both formations were metamorphosed in greenschist facies conditions. The Ochtiná and Črmeľ Formations are built predominantly of metapsammites and metapelites, less of metabasalts and carbonates, partly substituted by metasomatic magnesite. In the Ochtiná Formation there were also found small bodies of metaultrabasites, in the Črmeľ Formation there are rare acid metavolcanoclastics. The metabasalts are geo-

chemically similar to E-MORB/OIT to BABB. Both formations were metamorphosed in greenschist facies conditions. Metabasalts are predominant in the Zlatník Formation, less frequent are metadolerites, metagabbro, from sediments metapelites and rarely also metapsammites with abundant chromium-spinelid. The metabasalt composition corresponds to typical BABB. Pelitic sedimentation is the result of a very limited contribution of clastic material into the sedimentation basin. Metamorphic conditions of the Zlatník Formation vary from prehnite-pumpellyite to amphibolite facies and they are the result of an ocean ridge type metamorphism. The age of the formation has not been supported either by geochronological or paleontological data.

The Krompachy Group occur above the Zlatník Formation and it is of Permian age. In the basalt part, conglomerates are predominant (the Knola Formation), in the middle metapsammmites alternate with acid, intermediary and rarely also basic metavolcanics and volcanoclastics (Petrova hora Formation). In the uppermost part of the Krompachy Group, metapelites with evaporites (Nová Ves Formation) are predominant. Sedimentation took place in continental conditions, at the end of the evolution also in mixed continental-marine conditions (Vozárová & Vozár, 1988). The volcanites are of calc-alkaline type. Metamorphism was connected with alkaline metasomatism and it was probably caused by the circulation of heated marine water. It varies from very low to greenschist facies, located especially around tectonic zones.

The Gočaltovo Group is located in the southern and western part of the Gemeric Unit, overlying the Gelnica Group and the Štós Formation (Fig.1). It is of Permian age. The basal part is built predominantly of metapsephites and metapsammites, acid metavolcanites and metavolcanoclastics occur sporadically. The upper part of the Gočaltovo Group contains metapelites and metapsammites, rarely also acid volcanic rocks and limestones. Sedimentation took place in continental environment, in the upper part in mixed continental-marine environment. The Gočaltovo Group was metamorphosed maximally in greenschist facies conditions.

## Geodynamic setting

A scheme of the geodynamic setting of Paleozoic formations of the Gemeric Unit is shown in Fig. 2. Gelnica, Krompachy and, probably, also the Gočaltovo Groups formed in the environment of a destructive litospheric plate margin. In the case of the Gelnica Group it was probably the back-side part of a magmatic arc of a rifted island arc. The Krompachy Group formed maybe in the area of a magmatic arc and the adjoining basins, on an active continental margin. The Gočaltovo Group formed in an analogous environment, indicating the beginning of the formation of a riftogenic basin (Vozárová & Vozár, 1993) in the neighbourhood of a volcanic arc of an active continental margin. The Štós and Smrečinka Formations represent probably the clastic filling of basins which formed in the initial stages of rifting of an Early Paleozoic island arc. The Črmeľ and Ochtiná Formations formed already during a more evolved stage of rifting, on the margins of an immature basin. The Rakovec Group and the Zlatník Formation may be considered relics of the crust on the bottom of back-arc basins (Ivan et al., 1994). In the first case it is the crust of an immature basin forming on the thinned crust of an island arc (or continent). The Zlatník Formation is the relic of a more evolved back-arc basin, where magmatic activity concentrated already into the active ridge. And, finally, the amagmatic Rudňany and Hámor Formations are the products of rapid sedimentation in a delta cone, or cyclic sedimentation in a stabilised basin, in both cases in an environment which behaved as a passive micro-plate margin. The Klátov Group has been interpreted as a relic of a metamorphically reworked and migmatitised lower crust of an island arc (or continent;, Ivan, 1994). The more broadly defined Klátov Group including metavolcanites and metasediments could represent a crust thinned by extension, on which the Rakovec back-arc basin formed.

From Fig. 2 it is obvious that coincident geodynamic environment appear in Early as well as Late Paleozoic formations. In both cases, there is evidence of a subduction-related geodynamic setting and back-arc basin formation. However, the lack of geochronological data does not allow a reconstruction of these processes in time and their correlation with neighbouring areas.

## Tectonic structure

Differences in lithology, geodynamic setting and metamorphic reworking of the Paleozoic formations of the Gemeric Unit Paleozoic indicate permanent interaction of the litospheric plate margins in this area in Pre-Alpine and Alpine time. They are evidence of a considerable shortening of the original space and of nappe-scale structure of the Gemeric Unit Paleozoic. The evolution of the tectonic setting was a multi-stage process. It includes Pre-Alpine, Alpine as well as Alpine stages. Among the earlier are e.g. tectonic processes connected with the exhumation of high-grade metamorphic complexes of the lower crust prior to the Upper Carboniferous, or the change of the divergent geodynamic regime in the Carboniferous to a convergent regime in the Permian. Dominant position among Alpine tectonic processes could be assigned to the reworking in an accretionary prism of an Alpine subduction zone, indicated by relics of HP/LT mineral assemblages in some Paleozic formations. In the Mesozoic rocks of the Meliatic Unit, which adjoins the Gemeric Unit in the south, the

age of the HP/LT metamorphism is Jurassic (155±2 Ma; MALUSKI et al., 1993). The last important contribution to the tectonic structure of the Gemeric Unit occurred probably in the Cretaceous (KOVÁCH et al., 1986) as a result of the closing of the Meliata-Hallstatt ocean and the subsequent collision connected with the thrusting of superficial nappes.

## References


BAJANÍK, Š., et al. 1983: Explanatory notes on the geological map of the Slovenské rudohorie Mts. - The eastern part (1 : 50 000). (In Slovak). Bratislava, D. Štúr Geol. Inst., 223 p.

Hovorka D., IVAN, P. & SPIŠIAK, J. 1990: Lithology, petrology, metamorphism and tectonic position of the Klátov Group (Paleozoic of Gemeric Unit, Inner Western Carpathians) Acta geol. geogr. Univ. Com., Geologica, 45, p. 55-69.

IVAN, P., 1994: Early Paleozoic of the Gemeric Unit (Inner Western Carpathians): Geodynamic setting as inferred from metabasalt geochemistry data. Mitt. Osterr. geol. Gesell., 86, p. 23-31

IVAN, P., MÉRES, Š. & HOVORKA, D. (1994): Oceanic crust in geological history of the Western Carpathian orogeny. Acta geol. Hung. 37, 19-32

IVANIČKA, J., SNOPKO L., SNOPKOVÁ P. & VOZÁRová A., 1989: Gelnica Group - lower unit of Spišsko-gemerské rudohorie Mts. (West Carpathians), Early Paleozoic. Geol Zbor. Geologica carpath., 40, p. 483-501

KOVÁCH, A., SVINGOR E. & GRECULA P., 1986: Rb-Sr isotopic ages of granitoide rocks from the Spišsko-gemerské rudohorie Mts., Western Carpathians, Eastern Slovakia. Mineralia slov., 18, p. 1-14

MALUSKI, H., RAJLICH P. & MATTE P., 1993: Ar-39/Ar-40 dating of the inner Carpathians Variscan basement and Alpine mylonitic overprinting. Tectonophysics, 223, p. 313-338

VOZÁROVÁ, A., 1993: Provenance of Gelnica Group metasandstones and relationship to paleotectonics of the basin of deposition. (English summary of Slovak text). Západ. Karpaty, Sér. Mineral., Petrogr., Geochém., Metalog., 16, p. 44-54

VOZÁROVÁ, A., & VOZÁR, J., 1988: Late Paleozoic in West Carpathians. Bratislava, D. Štúr Geol. Inst., 314 p.

VOZÁROVÁ, A. & VOZÁR J., 1993: Pre-Alpine terrains in the Western Carpathians: reconstruction of collision and post-collision stage of Variscan orogeny. (In Slovak). In: Geodynamic model and deep structure of the Western Carpathians. M.Rakús and J. VOZÁR eds. Bratislava, D. Štúr Geol. Inst., p. 129-143

SLOVAK GEOLOGICAL MAGAZINE

# Geodynamic position of acid volcanism of the Gelnica Group (Early Paleozoic, Southern Gemericum; Inner Western Carpathians)

ANNA VOZÁROVÁ[1] & JÁN IVANIČKA[2]

[1]Department of Mineralogy and Petrology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, 842 15 Bratislava
[2]Geological Survey of Slovak Republic, Mlynská dolina 1, Bratislava, Slovakia

*Abstract*: Rhyo-dacite volcanism of the Early Paleozoic of the Gelnica Group (Southern Gemericum) has been studied on the basis of macroelements and the distribution of microelements and REE. From the viewpoint of Sr, K, Rb,Th LREE and Zr, Y, HREE, Ta, Nb, Hf distribution, we suggest that the studied volcanics belong to the magmatic suite of normal calc-alkaline continental arcs associated with a subduction zone. The assumed mantle magmatic source was enriched in the subduction zone by crustal assimilation, connected with fractional crystallisation.

*Key words:* Western Carpathians, Southern Gemericum, Early Paleozoic, CAB rhyolite-dacite volcanism

## Introduction

The Gelnica Group makes up the predominant part of the Alpine Southern Gemeric unit. It consists of a thick flysch sequence prevailing over rhyolite-dacite volcanoclastics. Flysch deposition is indicated by structural signs as well as vertical sequence of beds suggesting that clastic detritus was transported by turbidity currents and/or downslope gravity slides (SNOPKO 1967; SNOPKO & IVANIČKA 1978, IVANIČKA et al. 1989). The acid to intermediate volcanism was largely of extrusive character. Gravity slides and turbidity currents were the key phenomena controlling the redeposition of the volcanogenic material as indicated by preserved structures: graded bedding, horizontal planparallel lamination, swarms of black-shale flow rolls amidst slide bodies and on erosional contacts, alternating layers of graded-bedded volcanoclastic greywackes with non-volcanic sandstones etc.

The Gelnica Group turbidite sequence also contains small bodies of mafic and ultramafic rocks and/or related redeposited detritus. The chemical composition and mainly the distribution of incompatible elements made it possible to distinguish metabasalts of several geotectonic settings: N-MORB, E-MORB/OIT, CAB (IVAN 1994). This wide range of metabasalts and metaultramafic rocks, originated in a considerably different geotectonic setting, is associated with mass currents and gravity slides sediments, whose detritus came from a continental source combined with coeval rhyolite-dacite volcanism.

Detrital modes of the Gelnica Group metasandstones reflect mixed sources of clastic material:continental, volcanic arc and elevated subduction complex. Heavy-mineral spectra as well as zircon-crystal typology and mean I.T. and I.A. values (in the sense of PUPIN 1980, 1985) confirmed the provenance from a orogenic-type magmatism of crustal-mantle origin (VOZÁROVÁ 1993).

Lithofacial analysis allowed to divide the Gelnica Group into three formations overlying each other - the Vlachovo, Bystrý Potok and Drnava Frms. (SNOPKO & IVANIČKA in BAJANÍK et al. 1984). This concept was also backed by biostratigraphic data - sporomorphs and acritarch assemblages indicating a relatively wide range from the Upper Cambrian to Lower Devonian age (SNOPKOVÁ & SNOPKO 1979).

Gelnica Group sediments underwent low-pressure regional metamorphism corresponding to the lower part of greenschist facies (T = 350-370 °C; P = 250-270 MPa with geothermal gradient of some 40 °C/km; SASSI & VOZÁROVÁ 1987).

## Geologic setting

Over one-third (37%) of the Gelnica Group rock are acid volcanic rocks, from which only 1% are effusive equivalents, the rest are volcanoclastic rocks. They belong to the rhyolite-dacite to andesite formation, which is sporadically complemented by basic basalt volcanism.

Generally, the Gelnica Group sequences sedimented in a deep-water sedimentation environment, where transport by turbidity currents and other types of gravitational currents and slides predominated. The volcanoclastic material, along with neo-volcanic detritus, was transported from the source area by submarine channels and further on distributed by submarine fans, as

proved by the preservation of distal and proximal facies with typical Bouma sequence members. The chain of volcanic centres in the source area (magmatic arc; the whole sequence is interpreted as the filling of a fore-arc basin, VOZÁROVÁ 1993), provided above all a large amount of redeposited pyroclastic material of ash and sand grain-size, but redeposited ignimbrites have been described as well (CHMELÍK in CHMELÍK & SNOPKO 1979).

The Vlachovo Formation is the oldest known lithostratigraphic horizon of Gemericum. It occurs especially in the western part of the Gelnica Group, forming there a large sedimentary-volcanogenic complex composed of three independent mesorhythms. The lowest lithologic member of the Vlachovo Fm., not found on the surface (it has been proved by boreholes in the surroundings of Vlachovo) are dark hidden-bedded and laminated sericite-chlorite phyllites. Above them, there are lying rhythmically sedimented quartzose meta-graywackes with small lenses of fine-grained meta-conglomerates - the base of the second mesorhythm, which is completely developed in the Podsúľová area. The basal complex is gradually fining upwards due to the increase of the abundancy of pelitic component, replacing the psammitic one. The rocks have the character of fine-grained metasandstones, quartzite phyllites and various types of laminated phyllites. During the sedimentation of this rock complex, intensive acid volcanism took place, the products of which strongly disturb the overall symmetry of sedimentation. Above the volcanics, there is lying a thick complex of fine-laminated phyllites with layers of lydites and allodapic carbonates.

The Bystrý potok Formation is the middle stratigraphic horizon of the Gelnica Gr. lying as a normal stratigraphic overlier on the Vlachovo Fm. It occurs in a continuous west-east belt, 2-5 km wide. From the viewpoint of the distribution of rock complexes it may be said that volcanic members are predominant west of the line Zlatý stôl - Heckerová, while sediments occur in a greater extent in the east. The most typical profile where this formation is completely developed is found in the area between Starovodská dolina Valley and Bystrý potok. Volcanic activity disturbed the symmetry of flysch facies distribution in relation to the assumed axis of the sedimentation basin. In the east it is the Kojšová hoľa volcanic complex and in the west the volcanic complex of Turecká and Lužica, reaching with its eastern margin into the Bystrý potok Valley. The products of acid volcanism are substantially represented only by volcanoclastic rocks. The vertical and lateral relationship of metarhyolite tuffs and tuffites to sediments is usually gradual, frequently finger-like. It is manifested by gradual increase in the quantity of volcanic material in the sediments, by the forming of individual layers, from which, by a gradual increase of thickness, large, several hundreds of meters thick bodies formed, affecting considerably the composition of the sedimentary mesorhythm. Above the volcanoclastic bodies there is lying a thick complex of fine-laminated phyllites, which are the most frequent lithofacies in the Bystrý potok Valley. The uppermost sequences are composed mostly of hidden-bedded metapelites, in the black- schist facies, with which there are usually associated lenses and beds of lydites and crystalline limestones.

The Drnava Formation occurs in the normal overlier of the Bystrý potok Fm. and it represents the uppermost stratigraphic horizon of the Gelnica Gr. It covers a wide zone in the southern part of the area, where, in profiles at Drnava - Smolník - Medzev, we may observe its complete development. The lowermost parts of the Drnava Fm. are composed of metasediments of sandstone facies, fining upward. First manifestations of volcanism in the Drnava Fm. started relatively early, we may observed them already in the basal coarse-psamminitc sedimentation. It gradually increased in intensity, the maximum of occurrences being in distal turbidite facies. The predominant material are transported volcanoclastics, forming several hundred meter thick bodies. During its development, the volcanism acquired a more basic character, reflected in the increasingly basic trend and the formation of basalts, their tuffs and tuffites. In comparison with acid volcanics, the metabasics are however represented only in a minor quantity. After the termination of the volcanic activity, distal turbidity sedimentation continued, represented by various petrographic types of fine-laminated phyllites. At the southern margin of the Gelnica Gr., between Medzev and Jasov, there is a complex of greenish quartzites and quartz phyllites. REICHWALDER (1969) assigned them to the Gelnica Group, as the uppermost known horizon of the Drnava Frm., and, according to SNOPKO (1969), they represent the base of the sixth mesorhythm.

## Characterisation of the volcanics

### *Petrography*

Metamorphosed acid to intermediary volcanics and their volcanoclastics, described formerly generally as porphyroids, are represented mostly by vitreous varieties, in which phenocrysts constitute maximally 1/3 of the rock volume. Among the phenocrysts, predominant are magmatically corroded high-temperature quartz, acid plagioclases and K-feldspars, their crystal form being often of sanidine type. In varieties with an affinity to intermediary composition, there is preserved above all biotite in relics. Rarely there have been determined "phantoms" after amphiboles.

The texture of these rocks is oriented, with a recrystallised and oriented original vitreous matrix, and often with pressure-deformed phenocrysts. The metamorphic

mineral assemblage corresponds to the low-temperature part of the greenschist facies. It is represented by quartz + muscovite + chlorite, accompanied by a small amount of albite or K-feldspar and biotite.

## *Chemical composition*

*Macroelements:* The studied rocks have an acid to intermediate composition (Tab. 1), with a relatively wide range of $SiO_2$ content (from 54 to 83 wt. % $SiO_2$), while the greater part of the analysed samples is concentrated between rhyodacites/dacites (according to WINCHESTER and FLOYD 1976, Fig.1). Within the whole sample set, there may be observed a not very marked, but still increasing acid trend in volcanics of the Drnava Fm., in comparison with the other two formations. The $K_2O$ contents vary in the majority of rhyodacite samples in the range 1.3 - 3.5 wt. %, corresponding, according to LE MAITRE (1989), to medium-potassium types (Fig. 2). Only a small part of samples with andesite composition with low $K_2O$ contents (below 1 wt. %) was ranged with low-potassium types. A part of rocks with rhyodacite composition belong to high-potassium types, in the range of 3.5 - 5 wt. % $K_2O$. The $K_2O/Na_2O$ ratio is very variable, while $K_2O$ predominates in 76% of samples and, on the other hand, $NA_2O$ in 24%. However, we must consider the fact that extreme alkali contents, especially $Na_2O$, may be the product of superimposed metasomatic processes, although we attempted to eliminate this fact when selecting the samples. Generally, the analysed sample set is poor in CaO (less than 1 wt. %) and has varying $TiO_2$ and $P_2O_5$.

Relatively higher $Al_2O_3$ contents allow to assign the whole set to the peraluminous group. This trend is well visible in the MANIAR and PICCOLLI diagram (1989;Fig. 3), the varieties with lower $SiO_2$ contents being strongly peraluminous, and, on the other hand, those with higher

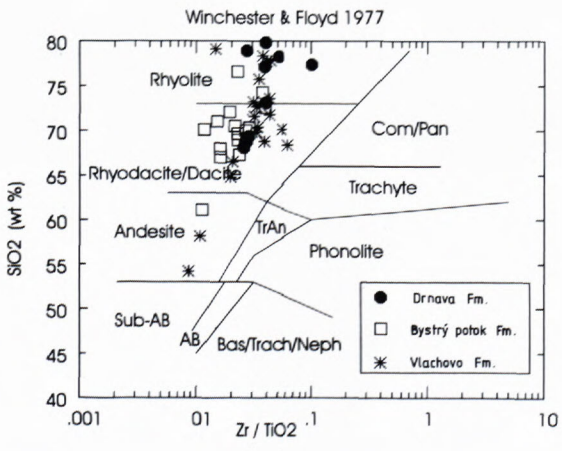



*Fig. 1 Distribution of selection of volcanic suites on the $SiO_2$ - $Zr/TiO_2$ diagram.*

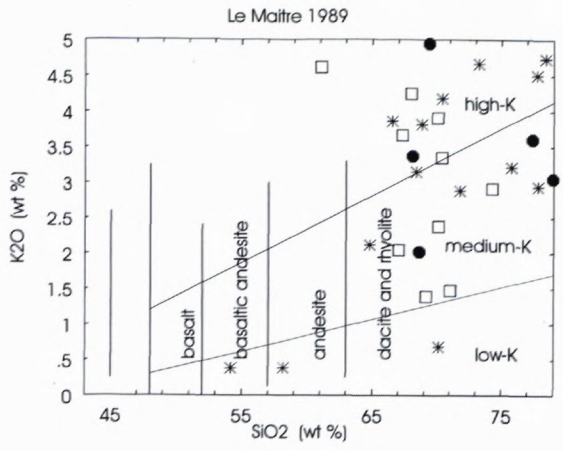



*Fig. 2 Distribution of volcanic suites based on $K_2O$ contents. Symbols as Fig. 1.*

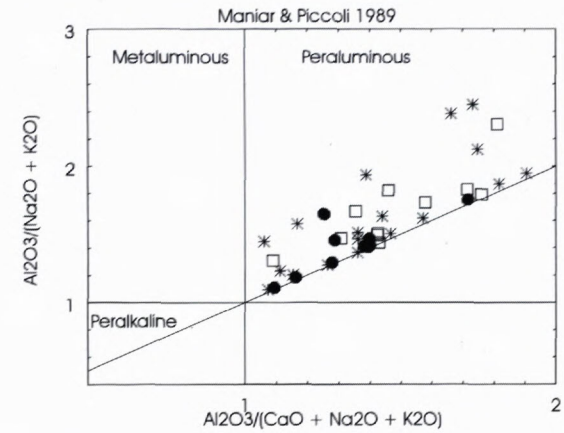



*Fig. 3 Characteristics based on Shand's index. All volcanic rocks have a distinct peraluminous trend and orogenic affinity. Symbols as Fig. 1.*

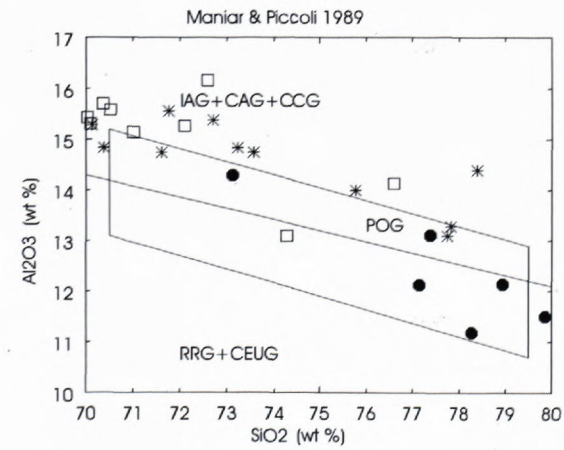



*Fig. 4 Discrimination of the Gelnica Gr. volcanic rocks in $Al_2O_3$ versus $SiO_2$ diagram, which shows distinct orogenic trend for prevalent volcanics of the Vlachovo and Bystrý potok Fms. and a slight affinity of the Drnava Fm. volcanics to post-orogenic suites. Symbols as Fig. 1.*

$SiO_2$ are approaching the boundary of metaluminous varieties. This trend is well displayed in the discrimination diagrams of MANIAR and PICCOLLI (1989), by the ratio $SiO_2$ : $Al_2O_3$ (Fig. 4), where a substantial part of rhyolites of the Vlachovo Fm. and Bystrý potok Fm. is inclined to orogenic types, and, on the other hand, rhoylites of the Drnava Fm. to post-orogenic ones. The trend is less marked in the FeO*/Fe*+MgO) ratio (Fig. 5), although the substantial part of samples falls within orogenic granites. A part of the samples from both of the above formations bears signs of relative Fe enrichment, which probably has not been caused by primary magma composition, but by later enrichment.

In the same way, normative composition in the QAP diagram (LE MAITRE 1989) confirmed that the analysed set belongs to the calc-alkaline magmatic series, of trondhjemite-granodiorite composition (Fig. 6). A part of the samples with higher alkalinity, equivalent to leucogranites, is probably genetically associated with hydrothermal-metasomatic processes, which could have been a primary phenomenon (crustal fusion in the source area) or derived from later superimposed processes. According to MANIAR & PICCOLLI (1989), this trend is typical for continental magmatic arcs. Samples extremely enriched in Si (field 1b) correspond to vitreous varieties and they have no indicative value for the geotectonic interpretation.

*Microelements and REE:* The contents of microelements in all three distinguished lithostratigraphic units display approximately the same regularities (Tab. 2).

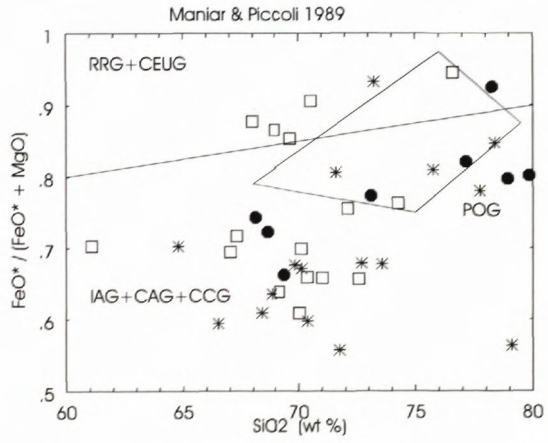



*Fig. 5 Discrimination of the Gelnica Gr. volcanics in FeO* /FeO* +MgO versus $SiO_2$ diagram. Distinct orogenic trend is attested. Symbols as Fig. 1.*

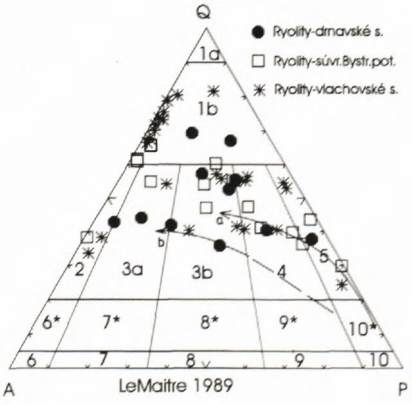



*Fig. 6 QAP mesonormative diagram showing calc-alkaline-trondhjemitic (a) and calc-alkaline-granodioritic (b) (medium K) trend for prevalent part of volcanics. Arrows according to LAMEYRE & Bowden (1982). Symbols as Fig. 1.*

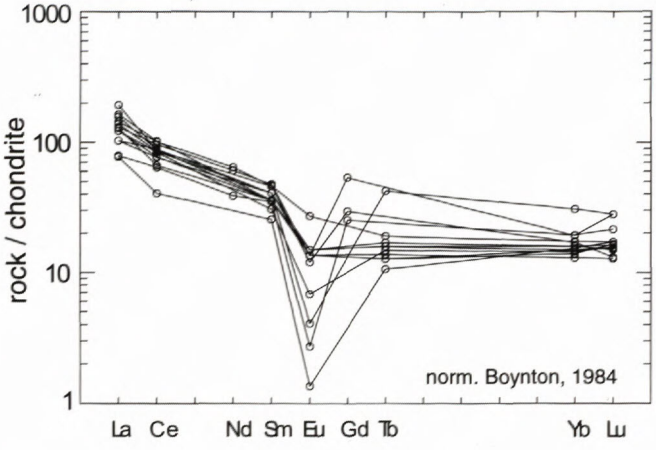



*Fig. 7 Chondrite of normalized REE patterns for the Gelnica Gr. volcanites.*

Above all, there are lower Rb, Sr, Pb, Zr, Nb and Y contents, and, on the other hand, higher contents of Sc, V, Cr, Ni, Zn. The relationships of Ba, Rb and Sr are strongly dependent on the K-substitution, above all in feldspars, and on fractional differentiation. The increased Ba content in comparison with Rb is associated with the presence of higher-temperature potassium feldspars, where Ba is preferentially substituted by K. A characteristic feature are also only medium contents of Y, Nb, Hf and Th.

LREE enrichment and a flat HREE part of the curve is typical for the distribution curves of rare earth elements from the Drnava Fm. (chondrite normalised - BOYNTON 1984). A characteristic feature, however, is the marked negative Eu-anomaly, which, along with the relatively marked LREE/HREE ratio, indicates a REE distribution strongly controlled by fractional crystallisation of plagioclases (Fig. 7). REE totals are low (average contents: D. Fm. - 108.7 ppm; By. Fm. - 115.4 ppm; V. Fm. - 101.5 ppm). The low Rb/Zr to Nb and Y ratios (in the range of

**TAB. 1 Average chemical composition (weight. %)**

| DRNAVA Fm. | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | $CO_2$ | S | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **X** | **74.97** | **0.30** | **12.47** | **1.29** | **1.02** | **0.02** | **0.85** | **0.23** | **2.40** | **4.33** | **0.11** | **1.06** | - | - |
| Sx | 4.85 | 0.27 | 1.94 | 0.41 | 0.95 | 0.01 | 0.68 | 0.28 | 1.36 | 2.27 | 0.08 | 0.34 | - | - |
| Number of samples | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 10 | 6 | - | - |

| BYSTRÝ POTOK Fm. | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | $CO_2$ | S | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **X** | **68.83** | **0.61** | **14.86** | **2.26** | **1.89** | **0.07** | **1.45** | **0.56** | **2.70** | **3.86** | **0.17** | **0.33** | **0.010** | **0.04** |
| Sx | 2.85 | 0.14 | 0.78 | 1.88 | 1.02 | 0.07 | 0.76 | 0.48 | 2.10 | 2.22 | 0.05 | 0.25 | 0.008 | 0.01 |
| Number of samples | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 13 | 7 | 7 | 7 |

| VLACHOVO Fm. | $SiO_2$ | $TiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | FeO | MnO | MgO | CaO | $Na_2O$ | $K_2O$ | $P_2O_5$ | $CO_2$ | S | F |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **X** | **74.56** | **0.28** | **12.85** | **1.82** | **0.95** | **0.05** | **1.17** | **0.33** | **1.78** | **3.61** | **0.08** | **0.34** | **0.03** | **0.04** |
| Sx | 5.87 | 0.18 | 2.47 | 1.30 | 1.24 | 0.04 | 1.18 | 0.45 | 1.91 | 2.13 | 0.07 | 0.48 | 0.04 | 0.01 |
| Number of samples | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 26 | 18 | 17 | 16 |

**TAB. 2 Average contents of microelements (in ppm)**

| DRNAVA Fm. | B | Be | Li | Rb | Sr | Ba | Sc | Yr | Y | Nb | Pb | V | Cr | Ni | Co | Zn | Ga | Th | Hf | Ta | La | Ce | Sm | Eu | Tb | Yb | Lu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **X** | **24.0** | **3.3** | **20.0** | **120.0** | **29.0** | **594.0** | **5.0** | **132.0** | **39.0** | **14.0** | **5.0** | **35.0** | **30.0** | **13.0** | **6.0** | **35.0** | **16.0** | **16.0** | **4.5** | **0.8** | **36.0** | **60.0** | **7.0** | **0.7** | **0.9** | **3.7** | **0.6** |
| Sx | 17.0 | 2.2 | 12.0 | 32.0 | 27.0 | 336.0 | 5.0 | 71.0 | 18.0 | 4.0 | 3.0 | 32.0 | 23.0 | 13.0 | 7.0 | 16.0 | 7.0 | 5.0 | 1.9 | 0.6 | 11.0 | 13.0 | 1.0 | 0.7 | 0.6 | 1.2 | 0.2 |
| Number of samples | 13 | 13 | 9 | 9 | 12 | 12 | 4 | 13 | 13 | 6 | 12 | 13 | 13 | 13 | 13 | 9 | 13 | 6 | 6 | 6 | 10 | 10 | 7 | 7 | 6 | 7 | 7 |

| BYSTRÝ POTOK Fm. | B | Be | Li | Rb | Sr | Ba | Sc | Yr | Y | Nb | Pb | V | Cr | Ni | Co | Zn | Ga | Th | Hf | Ta | La | Ce | Sm | Eu | Tb | Yb | Lu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **X** | **24.0** | **2.5** | **27.0** | **144.0** | **54.0** | **676.0** | **20.0** | **64.0** | **26.0** | **13.0** | **11.0** | **56.0** | **46.0** | **17.0** | **6.0** | **64.0** | **15.0** | **13.0** | **6.0** | **0.5** | **38.0** | **65.0** | **7.0** | **1.1** | **0.7** | **3.3** | **0.5** |
| Sx | 21.0 | 0.4 | 9.0 | 62.0 | 40.0 | 234.0 | - | 42.0 | 8.0 | - | 13.0 | 19.0 | 23.0 | 7.0 | 4.0 | 42.0 | 3.0 | - | - | - | 12.0 | 15.0 | - | - | - | - | - |
| Number of samples | 14 | 17 | 16 | 16 | 17 | 17 | 1 | 16 | 17 | 1 | 17 | 17 | 17 | 17 | 17 | 16 | 17 | 1 | 1 | 1 | - | 16 | 16 | 1 | 1 | 1 | 1 |

| VLACHOVO Fm. | B | Be | Li | Rb | Sr | Ba | Sc | Yr | Y | Nb | Pb | V | Cr | Ni | Co | Zn | Ga | Th | Hf | Ta | La | Ce | Sm | Eu | Tb | Yb | Lu |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **X** | **40.0** | **2.4** | **42.0** | **114.0** | **40.0** | **530.0** | **12.0** | **113.0** | **28.0** | **13.0** | **4.0** | **49.0** | **21.0** | **8.0** | **5.0** | **44.0** | **15.0** | **14.0** | **8.0** | **0.7** | **32.0** | **56.0** | **8.0** | **1.0** | **0.5** | **3.4** | **0.6** |
| Sx | 33.0 | 1.0 | 50.0 | 55.0 | 34.0 | 580.0 | 8.0 | 62.0 | 11.0 | 0.6 | 7.0 | 48.0 | 20.0 | 5.0 | 8.0 | 30.0 | 5.0 | 1.0 | 3.0 | 0.3 | 10.0 | 20.0 | 1.0 | 0.1 | 0.3 | 0.4 | 0.2 |
| Number of samples | 27 | 32 | 26 | 26 | 32 | 32 | 6 | 32 | 32 | 3 | 32 | 32 | 31 | 31 | 32 | 25 | 32 | 3 | 3 | 3 | 28 | 28 | 5 | 5 | 3 | 5 | 5 |

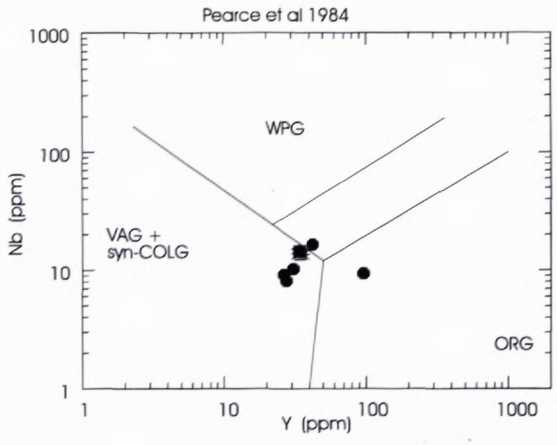



*Fig. 8 Nb versus Y + Nb diagram confirms VAG trend. Symbols as Fig. 1.*

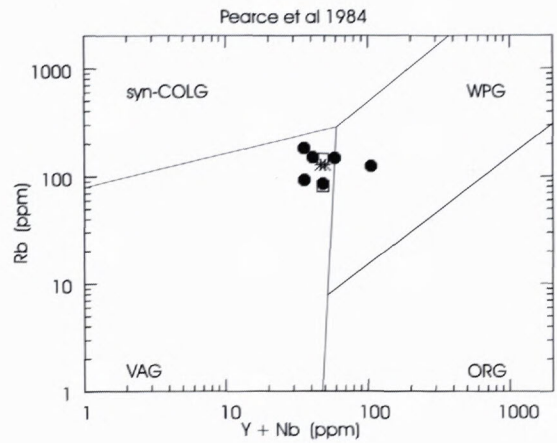



*Fig. 9 Rb versus Y+Nb diagram confirms VAG trend. Symbols as Fig. 1.*

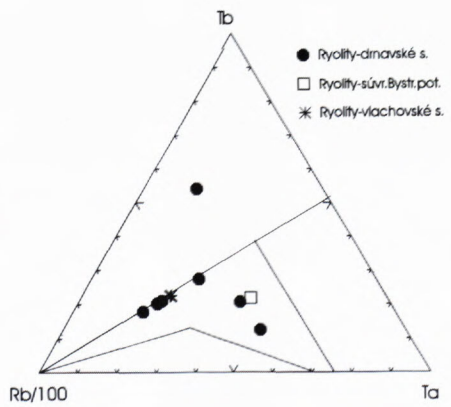



*Fig. 10 Tb:Rb/100:Ta geotectonic discrimination diagram (after THIÉBLEMONT & CABANIS 1990) pointing at syn-subduction setting. Symbols as Fig. 1.*

0.06-0.2, and 0.02-0.09, respectively) indicate an affinity of the studied volcanics to normal continental arcs (according to BROWN et al. 1984). A similar geotectonic interpretation may be derived from the ratios Nb : Y, Rb : (Y+Nb) and Tb : Rb/100 Ta (Figs. 8, 9, 10).

LIL, LREE and HFS contents normalised according to PEARCE et al. (1984) indicate selective enrichment in K, Rb, Th and marked depletion in Sr in all studied samples. Relative Ta, Sm contents are equal to approximately 1, or they are only slightly depleted. Nb and Ce display only slight enrichment (1.6 - 1.8). Marked depletion has been determined at Hf, Zr, Y, Yb. These rocks show a low value of the HFS/LIL element ration, especially of (Ta, Nb)/(K, Rb,La).

## Conclusion

1. Geochemical variations indicate an affinity of the Gelnica Group acid volcanism to normal calc-alkaline continental arc, while, in the whole set there appear varieties inclined to the calc-alkaline, meta- to peraluminous magmatic suites.
2. Contents of lithophilous elements, as well as of LREE, are selectively enriched and HREE, Zr, Ta, Nb, Hf, Y are average or depleted. Low values of the ratios of Rb/Zr to Ta, Nb and Y are characteristic for normal continental arcs, associated with a subduction zone. The mantle magmatic source was enriched in the subduction zone by crustal assimilation connected with fractional differentiation.
3. REE distribution curves, with a trend of LREE enrichment, the negative Eu anomaly due to fractional differentiation and the flat course of the HREE part of the curve indicate rhyo-dacites associated with an active continental margin.

## References

BAJANÍK, Š., IVANIČKA, J., MELLO, J., PRISTAŠ, J., REICHWALDER, P., VOZÁR, J. & VOZÁROVÁ, A. 1984: Geological map of the Slovenské rudohorie Mts., 1: 50.000. D. Štúr Inst. Geol., Bratislava.

BROWN, G. C., THORPE, R. S. & WEBB, P. C. 1984: The geochemical characteristics of granitoids in contrasting arcs and comments on magma sources. J. Geol. Soc. London, vol. 141, 3, London, 413-426.

BOYNTON, W. V. 1984: Cosmochemistry of the rare earth elements: meteorite studies. In: Rare earth elements geochemistry. Ed. HENDERSON, P., Development in geochemistry, 2, Elsevier.

CHMELÍK, L. & SNOPKO, L. 1979: Prehodnotenie chemizmu vulkanogénnych a sedimentárnych hornín gelnickej série. Manuskript, Archív D. Š. Inst. Geol., Bratislava.

IVAN, P. 1994: Early Paleozoic of the Gemeric Unit (Inner Western Carpathians): Geodynamic Setting as inferred from Metabasalt Geochemistry data. Mitt. Österr. Geol. Ges., 86, Wien, 23-31.

IVANIČKA, J., SNOPKO, L., SNOPKOVÁ, P. & VOZÁROVÁ, A. 1989: Gelnica Group - Lower Unit of Spišsko-gemerské rudohorie Mts. (West Carpathians), Early Paleozoic. Geol. Zborn. Geol. carpath., 40, 4, Bratislava, 483-501.

LAMEYRE, J. & BOWDEN, P. 1982: Plutonic rock types series: discrimination of various granitoids series and related rocks. Journ. Volc. Geoth. Res., 14, 1-2, Amsterdam, 169-186.

LE MAITRE, R.W. Ed. 1989: A Classification of Igneous Rocks and Glossary of Terms (recommend. of IUGC). Blackwell, 1-193.

MANIAR, P. D. & PICCOLI, P. M. 1989: Tectonic discrimination of granitoids. Geol. Soc. Amer. Bull., 101, 635-643.

PEARCE, J. A., HARRIS, N. B. & TINDLE, A. G. 1984: Trace elements discrimination for the tectonic interpretation of granitic rocks. J. Petrol., 25, 4, 956-983.

PUPIN, J. P. 1980: Zircon and granite petrology. Contr. Mineral. Petrology, 73, Berlin - Heidelberg-New York, 207-220.

PUPIN, J. P. 1985: Magmatic zoning of Hercynian Granitoids in France based on Zircon Typology. Schweiz. Mineral. Petrogr. Mitt., 65, 29-56.

REICHWALDER, P. 1969: Geological structure of the Paleozoic of the Spišsko-gemerské rudohorie Mts. - SE part. Manuscript, Archives GS SR (in Slovak).

SASSI, F. P. & VOZÁROVÁ, A. 1987: The pressure character of the Hercynian metamorphism in the Gemericum (West Carpathians, Czechoslovakia). Rend. Soc. Ital. Min. Petr., 42, 73-81.

SNOPKO, L. 1967: Lithostratigraphy of the Gelnica Serie. Záp. Karpaty, Sér. Geol. 7, D.Š. Inst. Geol., Bratislava, 7, 103-152 (in Slovak).

SNOPKO, L. 1969: O novom rudonosnom pruhu v okolí Vlachova. Manuskript, Archív D.Š. Inst. Geol., Bratislava.

SNOPKO, L. & IVANIČKA, J. 1978: Considerations on the paleogeography in the Early Paleozoic of the Spišsko-gemerské rudohorie Mts. In: Paleogeogr. Evol. W. Carpathians. Ed. J. VOZÁR, D. Š. Inst. geol., Bratislava, 269-280 (in Slovak).

SNOPKOVÁ, P. & SNOPKO, L. 1979: Biostratigraphy of Gelnica Group (Spišsko-gemerské rudohorie Mts.): based on palynology. Záp. Karpaty, Sér. Geol., 5, D.Š. Inst. Geol., Bratislava, 57-102 (in Slovak).

THÉBLEMONT, D. & CABANIS, B. 1990: Utilization d' un diagramme (Rb/100)-Tb-Ta pour la discrimination geochémique et l' etude pétrogenetique des roches magmatiques acides. Bull. Soc. Géol. France, (8), VI, 1, 23-25.

VOZÁROVÁ, A. 1993a: Provenance of Gelnica Group metasandstones and relationship to paleotectonics of the basin of deposition. Záp. Karpaty, sér. miner., petrogr., geochém., metalogen., 16, D. Š. Inst. Geol., Bratislava, 7-54 (in Slovak, Engl. res.).

WINCHESTER, J. A. & FLOYD, P. A. 1977: Geochemical discrimination of different magma series and their differentiation products using immobile elements. Chem. Geol., vol. 20, 325-343. rocks.

SLOVAK GEOLOGICAL MAGAZINE

# Tectono-sedimentary Evolution of Late Paleozoic Basins based on Interpretation of Lithostratigraphic Data (Western Carpathians; Slovakia)

ANNA VOZÁROVÁ

Department of Mineralogy and Petrology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, Bratislava

*Abstract*: The Carboniferous-Permian basins in the Western Carpathians originated in time and space in consequence of collision events of the Variscan orogeny. The distribution of these basins as well as the lithofacial character of their filling documents the opposite, southern vergency of the Variscan orogeny in comparison with the Alpine branch of the Western Carpathians. The sedimentary basins formed in three zones differing in the type of crust and their position in relation to the Variscan orogenic polarity. They were:

I. thickening continental plate with maximum manifestations of deformation, metamorphism and magmatism connected with subduction/collision events;

II. thrust wedges of oceanic crust;

III. active continental margin with extensive fore-arc basin filling.

On the basis of an analysis of relics of the Carboniferous-Permian sedimentary basin filling, indications of two Variscan collision events were identified.

a) Bretonian-Sudetian - indications in present-day relics in the frame of the paleo-Alpine, Tatro-Veporic and Northern Gemeric realm;

b) Asturian - indications in the paleo-Alpine Southern Gemeric Unit and adjacent Bükkium area in the south.

Both sutures represented the main zones of extension and following shortening in the Alpine orogeny.

*Key words*: Western Carpathians, Variscan orogeny, southern polarity, Carboniferous-Permian syn- and postorogenic basins, collision events

## Introduction

The kinematic evolution of the Western Carpathian orogenic system was affected during both Variscan and Alpine times. Fragments of newly formed Epi-Variscan crust were incorporated in the Paleo-Alpine Western Carpathian units, as indicated by repeated subduction/collision and transform fault processes. The Epi-Variscan crust gradually amalgamated due to crustal thickening during Early to Late Carboniferous collision events, as the overriding microplates of Eurasian affinity moved southwards. The Lower Carboniferous flysch troughs originated in an intrasutural embayment continuing in the Upper Carboniferous peripheral basin on the underthrusting plate of the African promontory. The post-collisional Permian evolution of the Western Carpathian realm continued by the formation of transtension/transpression and rifting-related sedimentary basins.

The stages of the Variscan orogenic cycle were directly reflected in the tectono-sedimentary development of Late Paleozoic sedimentary basin. The distribution of these basins in time and space indicates a polarity of the Variscan orogeny, which is in the Western Carpathians reverse in comparison with the Alpine orogeny. The result of Variscan orogenic events was the unevenly consolidated continental crust, which, after a short period of stability, was incorporated again in the new orogenic-Alpine cycle.

The fundamental fact that this Late Variscan continental crust was again extensionally segmented in the Alpine tectonic cycle, which led to the formation of new sedimentation basin in the southernmost zones even with oceanic bottom, leads to the greatest difficulty in the reconstruction of the Variscan orogeny in the Western Carpathians. The Alpine compression liquidated the substantial part of the original filling of Late Variscan sedimentation basins, as well as their substrate, and thus only their fragments were preserved in the Alpine-formed tectonic units. Besides the incomplete preservation of the bed successions and often unclear facial relationships, another important problem regarding the reconstruction of the Variscan orogeny is the absence of suitable biostratigraphic dating. The proposed analysis of tectono-sedimentary development of Late Paleozoic basins in the Western Carpathians is based above all on sedimentological-petrographic study complemented by biostratigraphic, geochemical and isotope data.

Like most of other collisional fold belts, the Western Carpathians have been traditionally divided into external and internal structural zones. The main difference between the distinguished structural zones is in the age of the main Alpine events and in the intensity of their deformational and metamorphic effects. The fragments of the Late Paleozoic sedimentary basin filling is preserved only inside of the internal zone, as a part of principal crustal-scale superunits (from N to S: the Tatricum, Veporicum and Gemericum), and several cover nappe systems (Fatric, Hronic and Silicic) as well as of the Bôrka and Turňa nappe slivers.

## Lithostratigraphic Correlation of the Late Paleozoic Sequences

### PERMIAN OF THE TATRIC UNIT

Permian sedimentary sequences are preserved mostly only sporadically and in small thickness, with the exception of relatively more important occurrences, such as in Považský Inovec Mts. and Malá Fatra Mts. Common features are: different angle of deposition on the immediate crystalline basement, continental, predominantly coarse-clastic development, weak manifestations of synsedimentary volcanic activity and erosive covering by mineralogically mature Lower Triassic sediments. The complex crystalline substrate is represented by high-grade (gneisses, amphibolites, migmatites, granulite gneisses) as well as relatively low-grade metamorphic rocks (quartz +muscovite as stable phases) and magmatic rocks (Tatra Terrane sensu VOZÁROVÁ & VOZÁR 1996). Permian sediments are of two types:

- the first (Malé Karpaty Mts., Vysoké Tatry Mts.,. Veľká Fatra Mts.) represents occurrences of coarse-grained arkose and fine-conglomerate sediments with small areal extent, usually only several tens of m thick;
- the second type (Považský Inovec Mts. Malá Fatra Mts.) is relatively better vertically lithofacially differentiated, more extensive, the thickness exceeds the order of 100 m, it is represented above all by coarse-grained arkose sediments and polymict conglomerates, with only minor proportion of shales. A common feature of both occurrence types is the continental, predominantly alluvial sedimentation environment, mineralogically and structurally immature detritus and absolute absence of biostratigraphic dating.

Synsedimentary volcanism of rhyolite composition is sporadic (small occurrences in the Malé Karpaty Mts.; relatively more intensive only in the Považský Inovec Mts.). From a horizon with U-mineralization associated with rhyolite volcanism in the Považský Inovec Mts. there comes also the only radiometric dating of Permian horizons in Tatricum (Pb/U + 280 Ma; ARCHANGELSKIJ & DANIEL 1989, manuscript information).

The chemical composition of Permian rhyolites in Tatricum shows a marked alkalic trend. Zircon typology from rhyolite volcanites and volcanoclastics from the Hundsheim Hills in the continuation of the Malé Karpaty Mts. and from the Považský Inovec Mts. supported the multi-stage character of this volcanism, with a trend from calc-alkaline to low- and high-temperature alkaline magma (BROSKA et al. 1993).

### PERMIAN OF THE NORTHERN VEPORIC UNIT

The Northern Veporic unit consists of Variscan and/or pre-Variscan crystalline rock complexes (Tatra Terrane in the sense of VOZÁROVÁ & VOZÁR 1996), as well as overstep Permian formations and Mesozoic envelope series of characteristic lithofacial development. Relics of Permian basin filling generally correspond to continental volcano-sedimentary formations. They overlapped the underlying crystalline rock complexes with distinct unconformity and they are also separated from the overlying Lower Triassic sediments by a hiatus and disconformity. Among several occurrences the sequence of the Ľubietová Gr. (Tab. 1) from the Čierťaž Mts. is the best preserved. It comprises the Brusno and Predajná Fms. (VOZÁROVÁ 1979).

Principal features of the Brusno Fm. are the following: dominant arkosic sediments of psammitic/psephitic grade and evidence of synsedimentary volcanism (the Harnobis volcanogenic horizon). Monotonous, mostly light-gray and greenish-gray coarse-grained sediments indicate an environment of low-sinusoity rivers. Frequent washouts, erosive channels and in fact poorly preserved overbank and crevasse sediments are evidence of quick and chaotic changes of braided alluvia with prevalent autocyclic erosive processes. The provenance of detritus has been proved to be the underlying crystalline basement, mainly the granitoid and migmatite rock complexes (VOZÁROVÁ 1979). The Harnobis volcanogenic horizon consists mostly of dacite effusions associated with dominant pyroclastic tuffs, a part of them containing ignimbrites and epiclastic deposits. Less frequent are andesites and their volcanoclastics. According to their chemical composition the volcanics correspond to calc-alkaline variety with affinity to subalkaline magmatic trend.

The Saxonian age of the Brusno Fm. is indicated by zoned monosaccate spores - *Florinites* sp., *Punctatisporites* sp., *Reticulatisporites* sp., *Cordaitales* sp. (PLANDEROVÁ in PLANDEROVÁ & VOZÁROVÁ 1982).

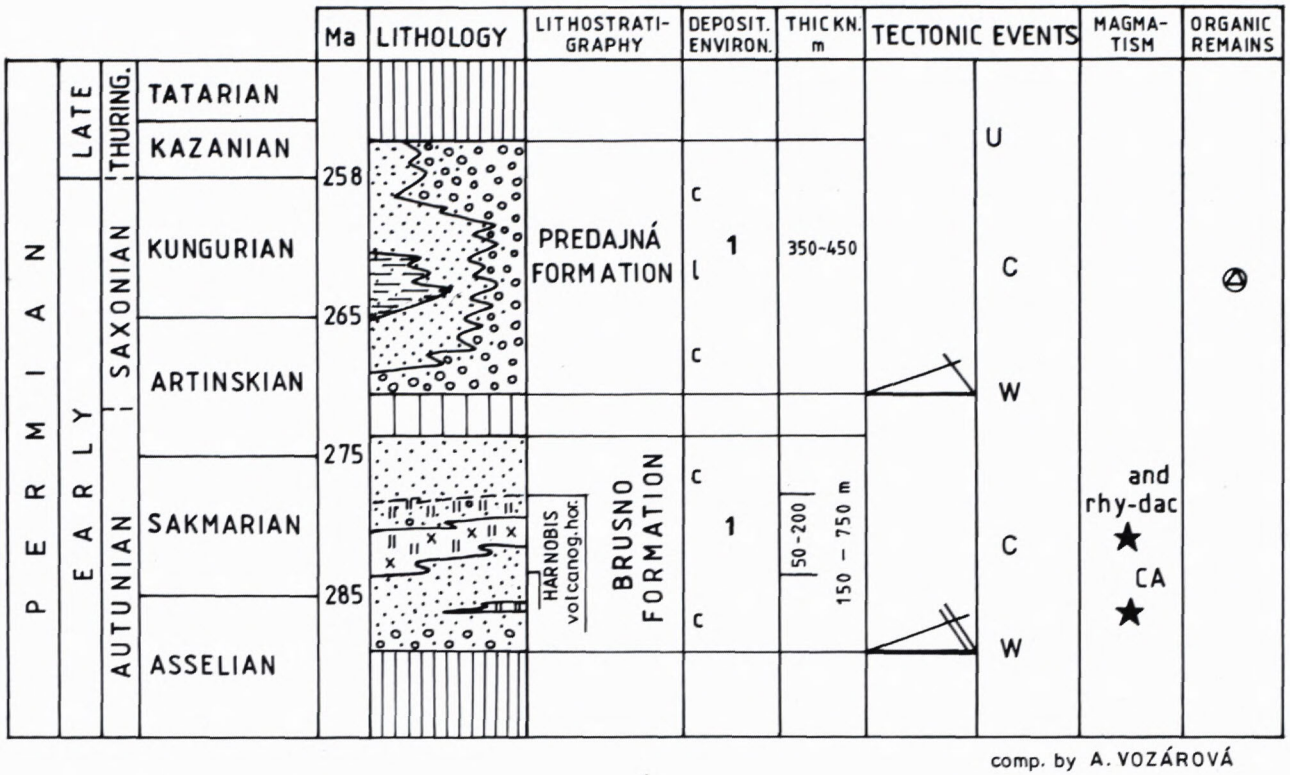
The Predajná Fm. overlaps disconformably the Brusno Fm. The hiatus is documented by a conspicuous change of the drainage system as well as of the source area, the latter being reflected in distinct differences in the composition of the detritus (mostly micaschist, paragneisses, microgranites and the Harnobis volcanics). Variegated polymict clastic sediments indicate an alluvial fan and piedmont flood plain sedimentary environment with isolated distal ephemeral lakes. Two regionally developed megacycles, with a thick horizon of conglomerates at the base of each of them, are the reflection of synsedimentary tectonics. The second is partially reduced due to pre-Triassic erosion.

Upper Permian age was assigned to the Predajná Fm. according to poor microflora: *Monosulcites minimus gynetaceaepollenites* sp., *Gymatiosphaera* sp., *Karpatisporites minimus* PLAND., *Punctatisporites* sp., *Reticulatisporites* sp., *Florinites* sp. (PLANDEROVÁ & VOZÁROVÁ 1982).

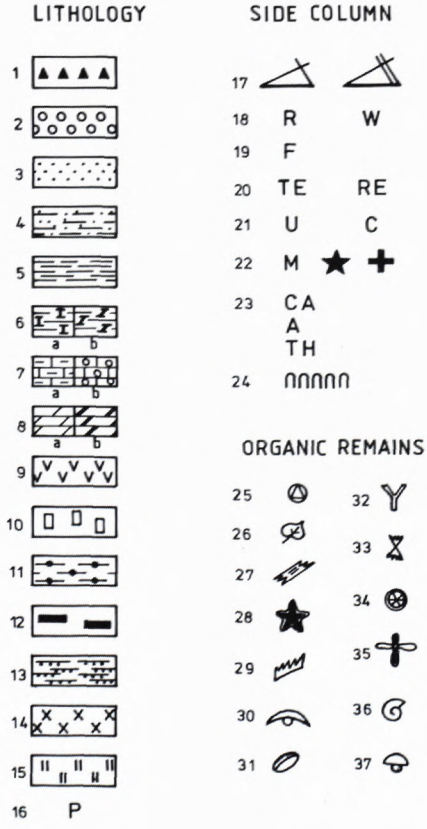
We correlate with the Ľubietová Group also Permian sediments of the cover Čierna Hora series (VOZÁROVÁ &

TAB. 1

## PERMIAN OF THE NORTHERN VEPORIC UNIT




comp. by A. VOZÁROVÁ




*Explanation to tables 1 - 9:*

***Lithology:*** *1 - breccias; 2 - conglomerates; 3 - sandstones; 4 - silts; alternating sandstones/shales; 5 - shales; 6 - a) shales with intercalation of limestones, b) shales with intercalation of dolomites; 7 - a) clayey carbonates, b) bioclastics carbonates; 8 - a) dolomites, b) magnesites; 9 - sulfates; 10 - halite; 11 - shales with abundant organic matter; 12 - coal; 13 - turbidites: s = siliciclastic, v = volcanoclastic, c = carbonatic; 14 - volcanics; 15 - volcanoclastics; 16 - phosphorite sandstones.*

*Note: All symbols are valid also for metamorhpic equivalents of the rocks*

***Side - column:*** *17 - low/high angle unconformity; 18 - rift/wrench induced; 19 - folding; 20 - transgression, regression; 21 - regional uplift/collapse; 22 - metamorphics, volcanics, intrusives; 23 - CA - calc-alkaline magmatic trend; A - alkaline magmatic trend; TH - tholeiitic magmatic trend; additional symbols: rhy - rhyolite; dac - dacite; and - andesite, bas - basalt; 24 - flysch troughs.*

***Organic remains:*** *25 - microfloral assemblages; 26 - plant fragments; 27 - fragments of stems, fragmental plant remains; 28 - crinoids; 29 - conodonts; 30 - trilobites; 31 - brachiopodes; 32 - bryozoas; 33 - bivalvia; 34 - corals; 35 - insects; 36 - nautiloids.*

*Additional symbols to depositional environment side-column*
*1 - mainly continental clastics:*
*c = coarse grained, f = fine grained, l = lacustrin, d = desertic, lateritic;*
*2 - evaporites: t = and clastics, c = and carbonates;*
*3 - deltaic, shallow marine, mainly sandstones;*
*4 - shallow marine, mainly shales;*
*5 - shallow marine, carbonates and clastics;*
*6 - deeper marine (turbidites).*

VOZÁR 1988). They are identical, as far as lithology and mineralogic composition, the superposition and probably (they have not been yet biostratigraphically dated) also stratigraphic range are concerned.

Separately there have been distinguished Permian sediments from the Starohorské vrchy Hills (Špania dolina Fm.), Branisko (Korytné Fm.) and Tribeč Mts. (Skýcov and Slopňa Fms.). They have been described in greater detail in the works of VOZÁROVÁ & VOZÁR (1988) and VOZÁROVÁ & VOZÁR in IVANIČKA et al. (1992). Common features of these occurrences are: 1. relatively monotonous lithological composition, i.e. predominantly arkosic detritus, of coarse-arenaceous to fine-conglomerate grain-size; 2. absence or only weak manifestations of syn-sedimentary volcanic activity of rhyolite composition (Tribeč Mts.); 3. in some places more significant proportion of fine-grained lithologic members in the upper part of the sequences (Tribeč, Starohorské vrchy Hills).

Generally, the sediments are poorly sorted, with variable lateral as well as vertical stratification and distinct fining-upward development and consequent change of colors (from greenish-gray and light-gray to violet-red and brownish-red). The sediments correspond to braided alluvia sedimentary environment passing in some places into ephemeral lake deposits.

Poor stratigraphic data are known only in the Starohorské vrchy Hills. The lower part of the Špania Dolina Fm. can be characterized by the microfloral species *Potonieisporites div.* sp., *Punctatisporites* sp., *Nuskoisporites* sp. as Saxonian (PLANDEROVÁ & ČILLÍK 1990). In the upper part of the formation, Upper Permian spore assemblages have been determined (PLANDEROVÁ 1974). The most frequent are bisaccate pollen *Karpatisporites gracilis* PLAND., *Karpatisporites minimus* PLAND., *Klausipollenites staplini* JANS., *Lueckisporites virkkiae* KLAUS, a.o.

The grade of metamorphism of the Northern Veporic Permian deposits did not exceed the lower - temperature part of greenschist facies.

## STEPHANIAN AND PERMIAN OF THE SOUTHERN VEPORIC UNIT

Alpine overthrust planes and steep faults separate the Southern Veporic basement and its Late Paleozoic and Mesozoic envelope from the Northern Veporic unit in the north (Muráň line) as well as from the Gemeric unit in the south (the Ľubeník-Margecany line). The Southern Veporic basement consists of several types of low- to medium-grade metamorphic rocks (phyllites, mica schists, albite-biotite gneisses, amphibolites). The occurrences of Al-Fe rich metasediments (KORIKOVSKIJ et al. 1989; KOVÁČIK 1991; MÉRES & HOVORKA 1991) and orthogneisses of magmatic arc provenance (HOVORKA et al. 1987) are special types. These rock complexes together with relics of migmatitized and strongly diaphtorized high-grade metamorphic complexes (?Lower Paleozoic/ ?Proterozoic; BEZÁK 1991) were distinguished as the Kohút Terrane (VOZÁROVÁ & VOZÁR 1996).

The Revúca Group (consisting of the Slatviná and Rimava Fms.) has been defined as the basal part of the envelope sequence of the Southern Veporicum (VOZÁROVÁ & VOZÁR 1982). Generally it represents the upward-coarsening sequence with mutual progradation from deltaic to fluvial environment (Tab. 2).

### *Stephanian*

Well preserved cyclical structure is the main lithological feature of the Slatviná Fm., in spite of its complicated metamorphic evolution during the Alpine orogeny. Multiple vertical alternation of gray metasandstones and dark-gray/black metapelites in low-order sedimentary cycles and their regional unification in two large coarsening-upward regressive cycles indicate a prograding fluvial environment. In reaches of stillwater there tended to develop anoxic bottom conditions, resulting in the formation of graphitic shales. Abundant carbonized plant detritus, relics of various organic remains including insects, tissue fragments, abundant spores of terrestrial plants are indicative of a shallow-water reservoir and proximity of a plant-covered continent. The cyclicity of sediments is the result of changes in the thickness of sandstone bodies, of a variable sandstone/shale ratio, decreasing or increasing grain size of sandstones.

Conspicuous stratification, sharp contacts of beds, tabular and relatively uniform sandstone strata are the main relic sedimentary features. Most others were destroyed by the polyphase Alpine metamorphism, caused by orogenic pressure and by consequent thermal relaxation connected with the intrusion of granitoids (VOZÁROVÁ 1990).

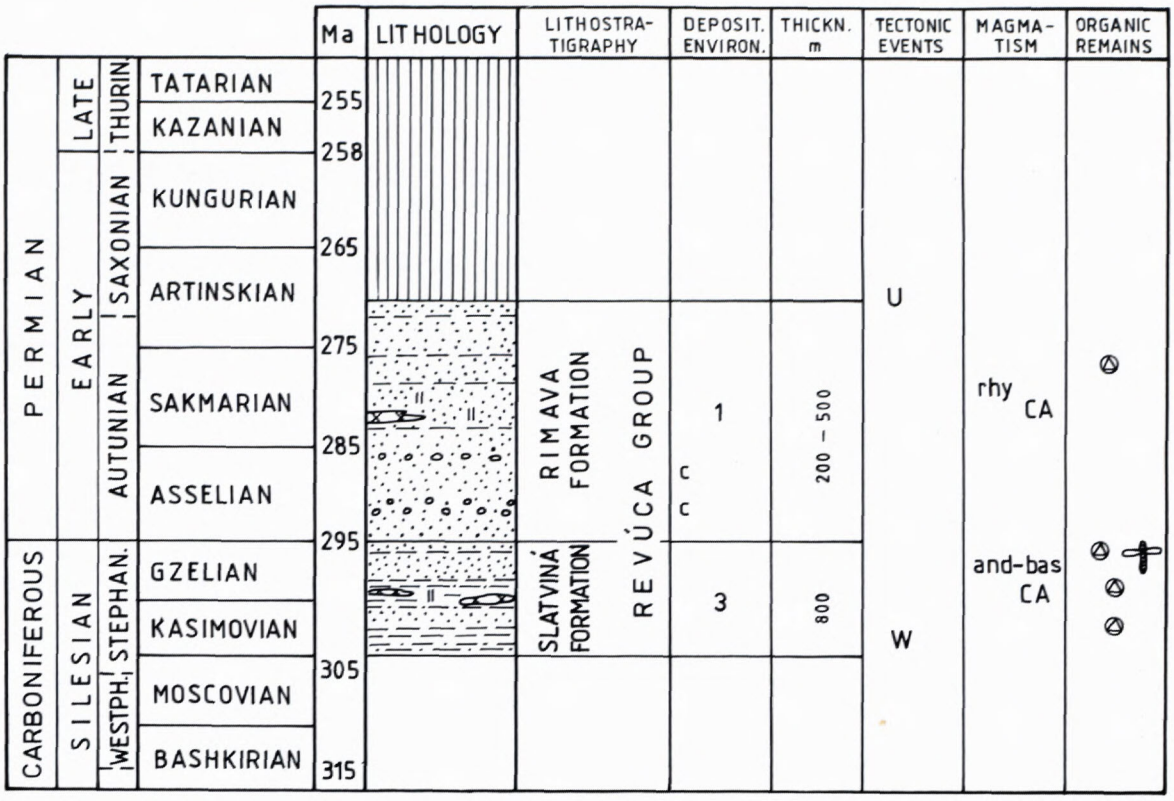
On the basis of abundant pollen of the genera *Potonieisporites*, *Illinites*, *Striatosaccites*, and spores of the genera *Florinites* and the species *Thymospora thiesenii* the Slatviná Fm. is classed with the Stephanian C-D (PLANDEROVÁ & VOZÁROVÁ 1978).

Manifestations of synsedimentary volcanism were not intensive. Dominant are redeposited volcanoclastics associated with local thin effusions of dacite-andesite and basalts.

### *Permian*

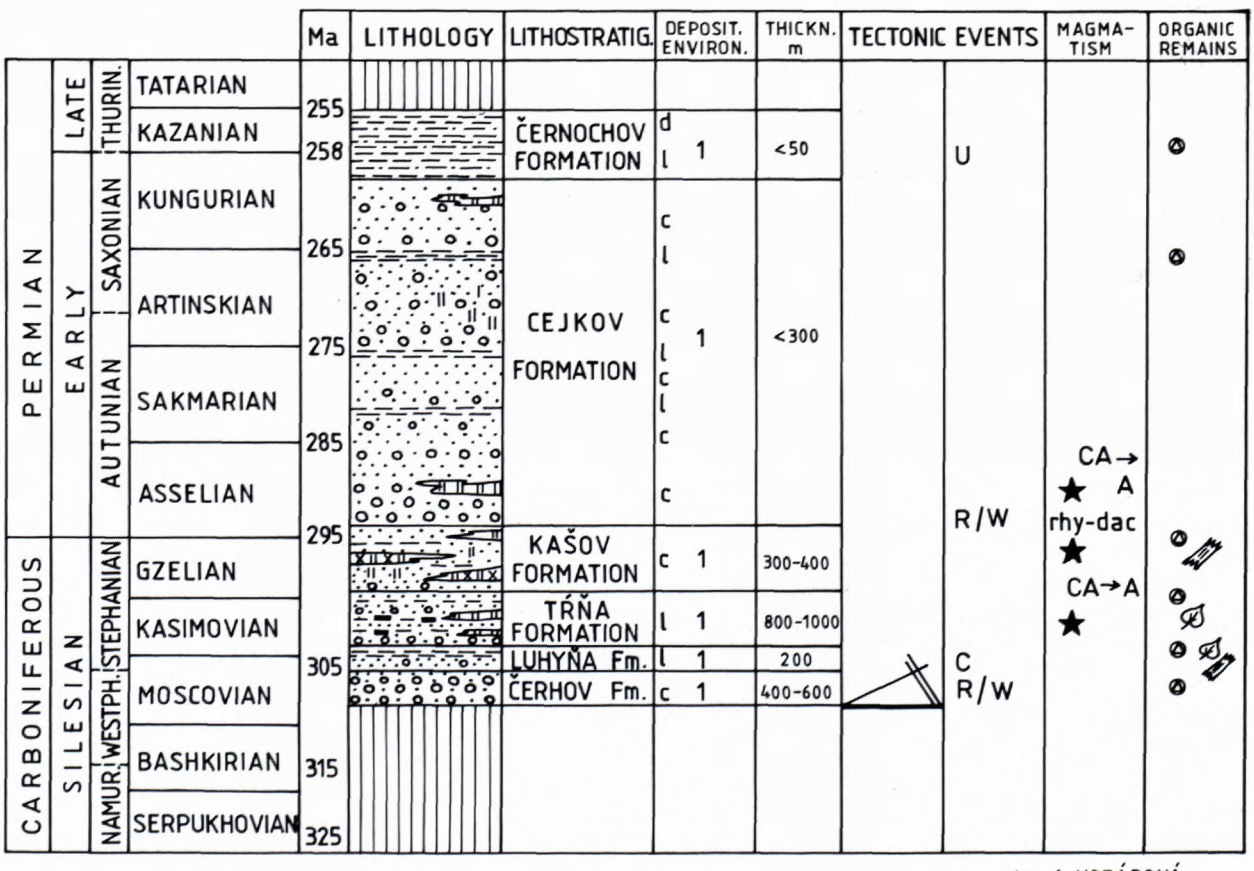
Metasediments of the Rimava Fm. do not display a distinctly cyclic fabric. They consist of thick progressive graded-bedded beds of metasandstones, sandy-metaconglomerates, very often with mutual erosive contacts. Metasediments contain abundant granitoid detritus, the prevalent metasandstones correspond to metaarkoses and arkosic metagraywackes. Discontinuous horizons of

TAB. 2 CARBONIFEROUS AND PERMIAN OF THE SOUTHERN VEPORIC UNIT




comp. by A. VOZÁROVÁ

TAB. 3 WESTPHALIAN-STEPHANIAN AND PERMIAN OF THE ZEMPLINIC UNIT




comp. by A. VOZÁROVÁ

well rounded medium-sized pebbles of quartz and granitoids are concentrated at the base of thick beds of sandstones. Fine-grained metasediments are only a minor component. They provide some spore species of the genus *Lueckisporites*, ranging the Rimava Fm. with the Lower Permian (PLANDEROVÁ & VOZÁROVÁ 1982).

Sequences of the Rimava Fm. comprise small bodies of rhyolites and rhyolite volcanoclastics. The contact of the Rimava Fm. and overlying Lower Triassic sediments is erosive, with an interruption of sedimentation.

## WESTPHALIAN-STEPHANIAN AND PERMIAN OF THE ZEMPLINIC UNIT

The crystalline rocks of the Zemplinic Unit, together with their Late Paleozoic and Mesozoic envelope, make up a NW-SE striking tectonic horst, uplifted from the basement of Tertiary filling of the East Slovakian (Transcarpathian) Basin. According to the character of crystalline rocks and mainly Mesozoic development it may be correlated with the other units of the Tatro-Veporic domain (VOZÁROVÁ 1991; FARYAD 1995; Byšta Susp. Terr., in VOZÁROVÁ & VOZÁR 1996).

### *Westphalian - Stephanian*

Overlapping unconformably the crystalline basement, the rocks represent a post-orogenic Late Variscan volcano-sedimentary complex documented in numerous drill-holes and by the composition of detritus. The Westphalian-Stephanian sequence consists of four partial lithostratigraphic units (Tab. 3; Čerhov, Luhyňa, Tŕňa, Kašov, Fms.; in BOUČEK & PŘIBYL 1959, GRECULA & EGYÜD 1982, VOZÁROVÁ 1986). Their stratigraphic range was established according to macro- and microfloral findings (NĚMEJC 1947, 1953; NĚMEJC & OBRHEL 1959, PLANDEROVÁ et al. 1981).

Polymict conglomerates, with grain-supported structure and relatively well-rounded pebble material are dominant lithofacies of the Čerhov Fm. They are interpreted mostly as braided-river deposits. The lithostratigraphic profile consists of repeated small fining-upward sedimentary cycles with prevalent conglomerate or sandy-conglomerate components. Minor black shale and siltstone intercalations occur in the upper part of the sequence. The dating, Westphalian D-Stephanian A, is based on dominant microflora: *Triquitrites* sp., *Microleticulatisporites sulcatus* (WILS. et KR.), *Tripartites* sp.

The gradually evolving Luhyňa Fm. consists of fine-grained lacustrine sediments - sandstones, mudstones and shales of gray to black color, interrupted by episodic events of distal-fan streams. The Stephanian A age was proved mainly by macroflora: *Calamites cisti* BRONGN., *Pecopteris cf. miltoni* ARTIS, *Alethopteris* sp., *Asterophyllites trichomonatus* STUR. Microfloral assemblages are indicative of the Stephanian A-B range. Dominant are spores of the species *Torispora securis* Balme, spores of the genus *Lycospora*, *Punctatisporites*, *Densosporites*, and bisaccate striate pollen of the genus *Vittatina*.

Cyclothems with thin coal seams represent the Tŕňa Fm. The Lower Stephanian age was inferred on the basis of plant findings: *Pecopteris cyathes, Cordaites borassifolius, Sphenophyllum emarginatus* BRONGN., *Asterotheca arborescens* BRONGN., *Alethopteris bohemica* FRANKE, *Calamites cisti* BRONGN., *Stigmaria ficoides* (STGB.) BRONGN., *Annularia pseudostellata* POTONIE, *Lepidophloios laricinus* STGB., *Lepidostrobophyllum majus* BRONGN.

The Tŕňa Fm. can be divided into two large cycles (several hundreds of m thick). The lower cycle contains seven limnic-fluvial cyclothems with coal seams of variable thickness (from several cm up to 160 cm). Generally, the sediments are rich in clastic mica, plant debris, fragments of tree trunks and barks. Distinct cyclicity of fining-upward type, with sets of layers of black shales with thin coal seams and occasionally dark limestones, indicate limnic-fluvial and swamp environments. The second large cycle is characterized by alluvial stream-channel lithofacies, with dominant sandstone members and absence of the coal-bearing association. Several levels of rhyolite-dacite, calc-alkaline volcanoclastics are typical for this part of sequence.

Thick layers of rhyolite-dacite volcanoclastics (including ignimbrites) and alluvial, stream-channel and flood plain sediments with dominant sandstones are predominant lithologies of the Kašov Fm. Based on the remnants of silicified trunks of araucarites, *Dadoxylon* sp. and microflora assemblages the Kašov Fm. was assigned to the Stephanian B-C. The following microflora assemblages were identified: *Thymospora perverrucosa* (ALP.) WILS.. et VEN., *Colluminisporites ovalis* PEPPER, *Latensina trileta, Vittatina ovalis* KLAUS, *Spinosporites* sp., *Disaccites striatiti* sp., *Cordaitina* sp.

Generally, geochemical data of volcanites based on bulk composition, trace elements and REE indicate the calc-alkaline magmatic trend. Results of zircon typology study show mainly higher temperature calc-alkaline to alkaline character (BROSKA et al. 1993).

### *Permian*

A sharp transition from humid to arid climate is characteristic for Permian sediments of the Zemplinic Unit. During the Permian sedimentary development the syn-sedimentary tectonics was less intensive compared to the Westphalian-Stephanian and as a consequence, the rate of sedimentation and volcanic activity were reduced. Generally, deposition proceeded in an alluvial environment with the features typical of a semi-arid and arid region. Multi-colored sedimentary complexes of the Cejkov Fm. comprise proximal and distal alluvial facies (polymict conglomerates and sandstones) alternating with deposits

of flood plains or of ephemeral arid lakes (mudstones alternating with shales and fine-grained sandstones and calcrete horizons). Characteristic, poorly sorted sediments resemble fossil mudstone and debris-flow. A part of this sequence includes several layers of rhyolite tuffs. The Lower Permian age is assigned to the Cejkov Fm. due to the abundance of the species from the genus *Potonieisporites* and *Vittatina*, as well as due to findings of bisaccate pollen of the genera *Jugasporites, Falcisporites* and *Klausipollenites.*

A complex of monotonous violet-red, vaguely schistose mudstones represents the youngest lithostratigraphic unit - the Černochov Fm. A relatively thin (max. 50 m) sequence of a monotonous playa association is unconformably overlain by light-gray quartzose conglomeratic sandstones of Lower Triassic age. Almost massive claystones and mudstones are rich in $Al_2O_3$ (20-21%) and ferric iron (7%). Poor microflora remains: *Lueckisporites, Striatites richteri, Jugasporites, Limitisporites* correspond most likely to the Thuringian.

Sedimentological and paleoecological data indicate that a short intra-Permian hiatus is possible. Sediments of both formations contain detritus derived from the underlying crystalline basement. The grade of their regional metamorphism did not exceed P-T conditions of anchizone/greenschist boundary.

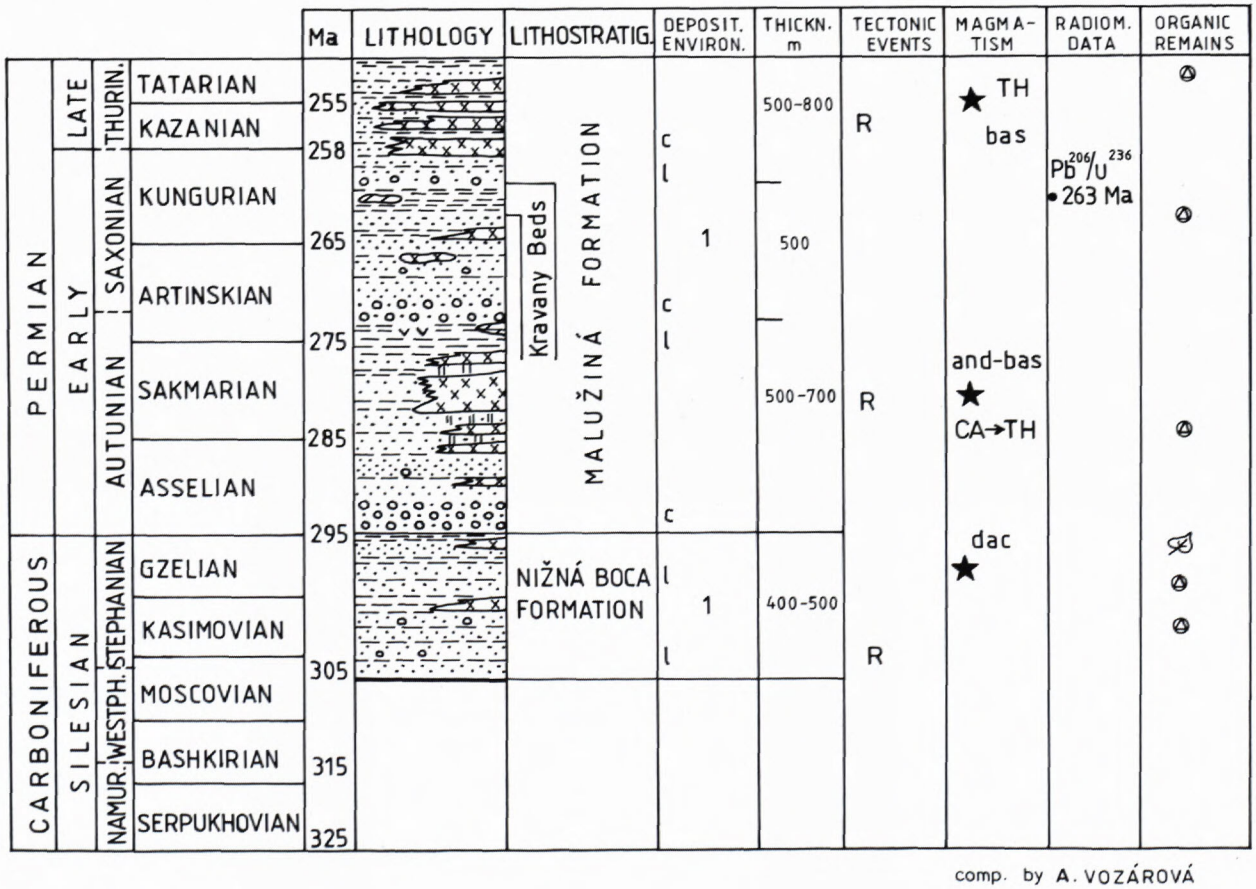
## STEPHANIAN AND PERMIAN OF THE HRONIC UNIT

The Hronic Unit has been defined as a rootless megastructural Alpine unit consisting of two partial nappes: the Šturec and Choč Nappes (accord. to ANDRUSOV et al. 1973). Due to their internal structure and mutual relations and facial characteristics the partial nappes have been distinguished as mainly Triassic complexes. Both Hronic nappe units contain Late Paleozoic volcano-sedimentary formations (Tab. 4), preserved variably as a consequence of tectonic reduction during the nappe thrusting. Remains of these sequences are known in many mountain ranges in the Western Carpathians.

### *Stephanian*

There is no evidence of either the underlying pre-Stephanian sediments or of the immediate basement. Tectonic slices of granitoid blastomylonites found in the

TAB. 4 STEPHANIAN AND PERMIAN OF THE HRONIC UNIT




comp. by A. VOZÁROVÁ

basal part of the Šturec nappe might be partly indicative of its composition (ANDRUSOV 1936, VOZÁROVÁ & VOZÁR 1979). Data obtained through petrofacial analysis of clastic sediments proved an affinity to a magmatic arc source area (the hypothetical Ipoltica Terr., VOZÁROVÁ & VOZÁR 1993).

The Stephanian - Nižná Boca Fm. - is generally a regressive clastic sequence with distinct tendency of upward coarsening (VOZÁROVÁ 1981). Numerous small repeating fining-upward sedimentary cycles are the most typical feature. Abundant graded-bedded sandstones with minor mudstone intercalations, as well as layers rich in plant detritus indicate a fluvial-lacustrine delta association. Sequences of fine-grained sandstones, mudstones and shales of gray to black color correspond to lacustrine lithofacies. Syngenetic, mostly subaerial dacite volcanism is represented by abundant redeposited volcanogenic material mixed with non-volcanic detritus, less by thin layers of dacitic tuffs and exceptionally with small bodies of dacite.

Macroflora from the uppermost part of the Nižná Boca Fm. indicates its Stephanian B-C age. SITÁR & VOZÁR (1973) described well preserved relics of *Asterotheca miltoni* ARTIS, *Asterotheca arborescens* BRONGN., *Cordaites palmaeformis* GOEPP. and *Callipteridium gigas* GUTT. Several fragments of Westphalian/ Stephanian flora were determined by NĚMEJC (in MAHEĽ 1954) in strongly tectonically reduced remains of the easternmost Nižná Boca Fm. occurrences (Slatviná and Vojkovce vill.): *Calamites* sp., *Lepidostrobophillum majus*, *Asterotheca miltoni*, *Stigmaria ficoides*, *Palmopteris furcata*. The palynological analysis of PLANDEROVÁ (1973) distinguished two microflora assemblages: the Stephanian A-B - *Torispora securis* BALM., *Lycospora pusilla* (IBR.) SOM., *Verrucosisporites pergranulatus* (ALP.) SMITH., *Crassispora kosankei* (POT. KREMP.) BHARADW., *Laevigatosporites vulgaris* (IBR.) ALP. DOUB., *Thymospora pseudothiessenii* (KOS.) ALP. DOUB., - the Stephanian C-D: *Laevigatosporites* div. sp., *Cyclogranisporites densus* BHARADW., *Lycospora pusilla* (IBR.) SOM., *Foevalatisporites junior* ROS., *Planisporites kosankei* (KNOX) POT. KR. *Cadiospora magna* KOS., *Allatisporites verrucosus* ALP., *A. hexalatus* ALP., *Potonieisporites* div. sp. and *Disaccites striatiti.*

### *Permian*

The Permian sequences of Malužiná Fm. are developed gradually from the underlying Nižná Boca Fm. They comprise a thick succession of red beds which consist of alternating conglomerates, sandstones and shales. Lenses of dolomites, gypsum and calcrete/ caliche horizons occur locally. Fining-upward cycles in the order of several meters, as well as three regional megacycles arranged above each other, are most typical. An important phenomenon is the polyphase synsedimentary andesite-basalt volcanism with continental tholeiitic magmatic trend (VOZÁR 1977, 1984).

Generally the sediments of the Malužiná Fm. originated in fluvial and fluvial-lacustrine environment, at permanently semiarid/arid climate. Basal parts of the three megacycles consist of channel-lag and point-bar deposits, associating laterally with flood plain and natural levee sequences. The upper part of the megacycles is characterized by a playa, scarcely inland sabkha and ephemeral lake associations.

The microflora proved the Lower and Upper Permian age of the Malužiná Fm. The following assemblages were described by PLANDEROVÁ (1973; in PLANDEROVÁ & VOZÁROVÁ 1982): - Autunian: *Spinosporites exiguus* UPTHAW - HEDL., *Thymospora* div.sp., *Punctatisporites speciosus* KALIB., *Cordaitina* div.sp., *Illinites unicus* KOS., *Vittatina* div. sp., a. o. - Autunian-Saxonian: *Latensina trileta* ALP., *Potonieisporites novicus* BHARADW., *P. radiosus* SCHWARZ, *Jugasporites delassaucei* KLAUS, *Vittatina ovalis* KLAUS, - Thuringian: *Calamospora nathorstii* KLAUS, *Klausipollenites* div.sp., *Carpathisporites sittleri* PLAND., *Lueckisporites parvus* KLAUS, *Vittatina angulistriata* KLAUS, *Monosulcites minimus* COOKSON, a.o.

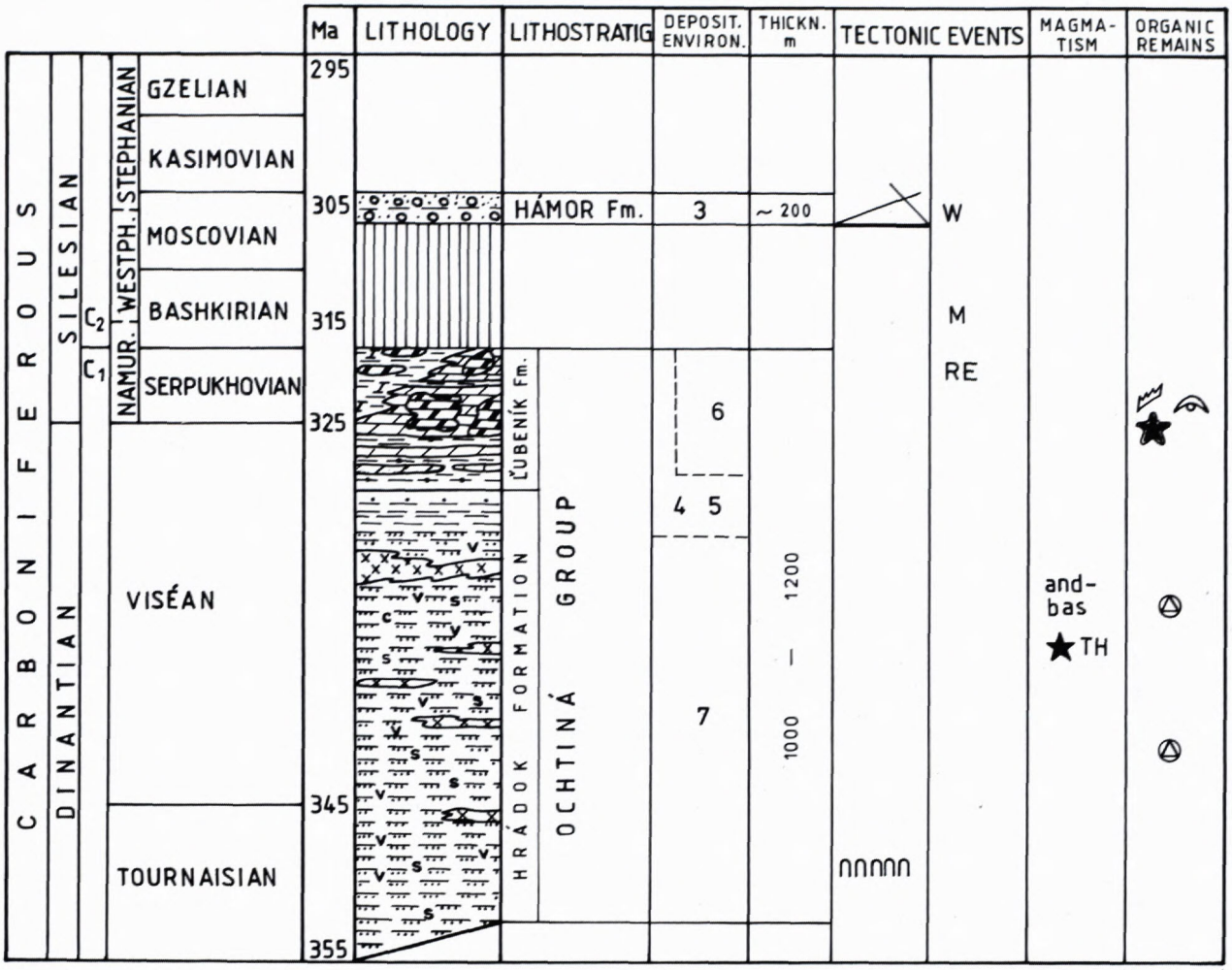
The Autunian-Saxonian microflora assemblages correspond approximately to the first and second megacycles. This assumption is supported by $^{206}Pb/^{238}U$ and $^{207}Pb/^{235}U$ dating of 263 and 274 Ma from uranium-bearing layers of the uppermost part of the 2nd megacycle (LEPKA in ROJKOVIČ et al. 1992).

Sediments of both formations contain detritus derived from: 1/granitoids and high-grade metamorphics, 2/ dacite and andesite/basalt synsedimentary volcanics, 3/ low-grade metamorphics. Generally the grade of regional metamorphism did not exceed P-T conditions of diagenesis/anchizone boundary.

## CARBONIFEROUS AND PERMIAN OF THE NORTHERN GEMERIC UNIT

The Alpine Northern Gemeric Unit contains two by the metamorphic development significantly differing pre-Carboniferous terranes - the Klátov and Rakovec Terranes (sensu VOZÁROVÁ & VOZÁR 1993, 1996). The Klátov Terrane is composed mostly of amphibolites, less gneisses, serpentinites and their hydrothermally-metasomatic derivatives, rarely Ca-silicate rocks (SPIŠIAK et al. 1985), as well as orthogneisses, plagiaplites, tonalites and granitoids found in fragments of Westphalian conglomerates (VOZÁROVÁ & VOZÁR l.c.). The Rakovec Terrane, on the other hand, contains basic metavolcanics and metavolcanoclastics associated with a minor amount of metapelites and metasandstones, with sporadic occurrences of intermediary and acid metavolcanics. While the grade of regional metamorphism reached in the Klátov Terrane the P-T conditions of the

TAB. 5 CARBONIFEROUS OF THE NORTHERN GEMERIC UNIT: SW part




higher-temperature amphibolite facies (HOVORKA & SPIŠIAK 1981, BAJANÍK & HOVORKA 1981 and others) of medium to high pressure (findings of retrograde-metamorphosed eclogitic rocks; HOVORKA et al. 1994), in the Rakovec did not exceed P-T conditions of greenschist facies. On the basis of their composition show a marked affinity to the oceanic and lower continental crust. Along with them, relics of the filling of Carboniferous-Permian, orogenic to post-orogenic sedimentation basins have been preserved in the Northern Gemeric Unit.

*Turnaisian - Visean - Serpukhovian*

Sedimentary sequences corresponding to this stratigraphic range have been preserved in the form of tectonically restricted relics at the SW and E-SE boundary of the Northern Gemeric Unit and they are tectonically strongly reduced due to its Alpine thrusting on the Southern Veporic Unit lying below (Tab. 5, 6). In spite of the tectonic reduction and the reduction of the original thickness due to regional metamorphism, present thickness of these sequences is estimated at 1000 m and more.

SW part of the Northern Gemeric Unit (Tab. 5): Lower Carboniferous sequences are in this part separated from the footwall (Southern Veporicum; Ľubeník-Margecany Line) as well as hanging wall (Southern Gemericum; Hrádok Line) tectonically, by thrust lines. This sequence was originally defined as the Ochtiná Fm. and included into the Dobšiná Gr. along with other Middle Carboniferous formations (VOZÁROVÁ in BAJANÍK et al. 1981). In view of its different tectonometamorphic development and stratigraphic position we distinguished this sequence from the Dobšiná Gr. and we define it as an independent lithostratigraphic unit of a higher order. While preserving the priority rule, we left the original name of the lithostratigraphic unit and we changed only the general part of the name - "group" instead of "formation". Within the

Ochtiná Group. we distinguish two formations - the lower Hrádok and upper Ľubeník Fm.

The Hrádok Fm. consists of flysch-like dark-gray and black clastic sediments - metaconglomerates, metasandstones, metapelites, interlayered with metabasalts, metadolerites and basaltic metavolcanoclastics. Very rare rocks, found only in thin layers are lydites and siliceous metapelites. Slabs of ultramafic rocks (?oceanic crust fragments) indicated by antigorite serpentinites and talc-tremolitic schists have been reported. Sedimentary structures indicate turbidity current flows, gravity slides and grain flows as a transport system.

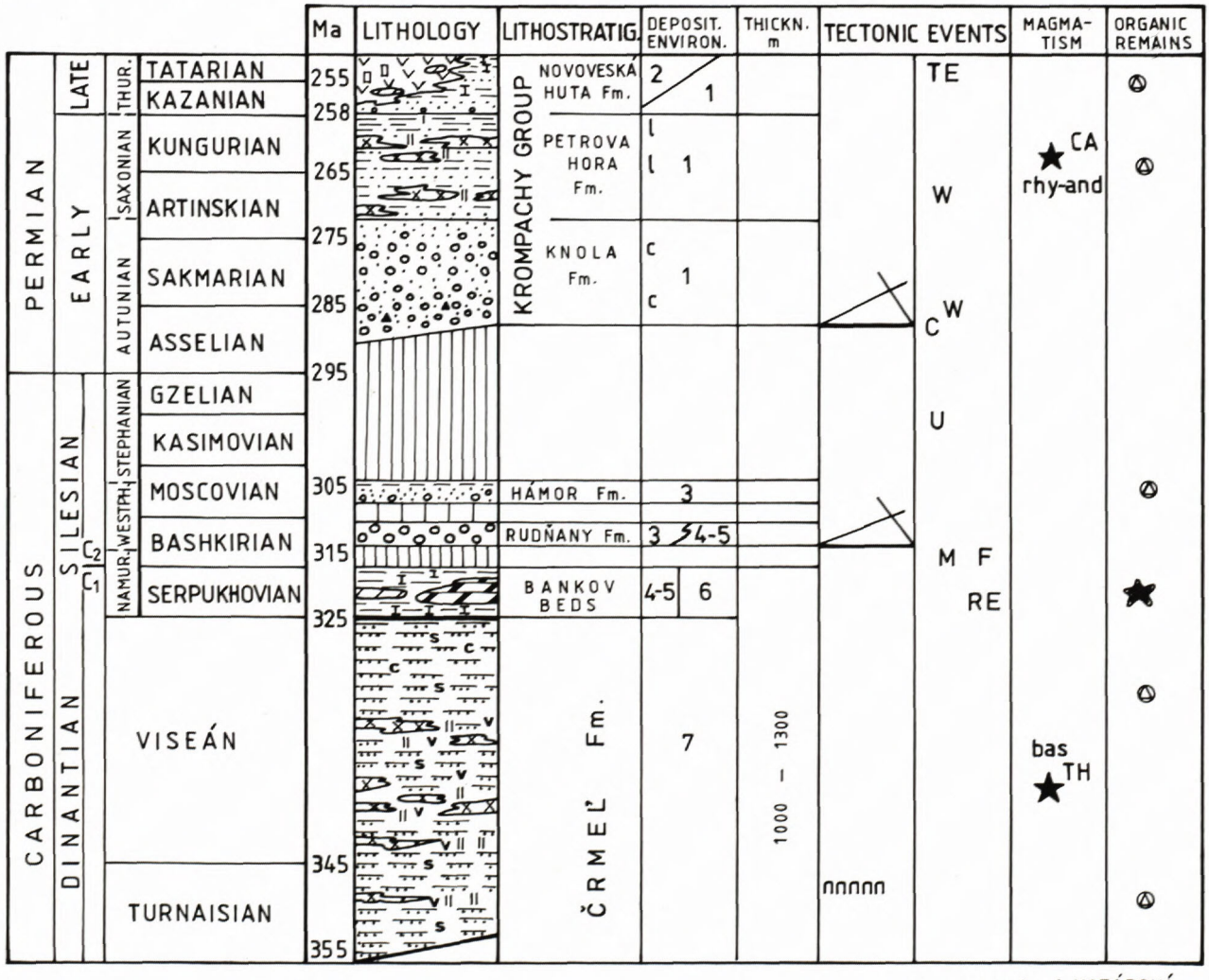
A monotonous complex of dark-gray metapelites, overlying relative coarse-grained basal part of the Hrádok Fm., yielded microfloral assemblages indicating Upper Turnaisian - Visean age (Planderová 1982, Bajaník & Planderová 1985). The following microfloral assemblages were described: *Tumulispora varituber culata* (Zieber) Pot. Naum., *Tetraporina glabra, Vallatisporites verrucosus* Hacque, *Lophosphaeridium finitimus* Tsch., *Dyctyotriletes submarginatus* Playf.

The basic volcanic rocks of the Hrádok Fm. belong to tholeiites with distinct N-MORB affinity.

Sedimentation in shallow-water neritic and littoral environment is a characteristic feature of the Ľubeník Fm. The sequence consists of black shales, dolomitic shales, well-bedded dolomites and massive coarse-grained magnesite. Most dolomites show pellintrabiosparite texture comprising pellets, intraclasts of micrite texture and bioclasts, consisting of fragments of Echinodermata, Lamellibranchiata, Foraminifera, Ostracoda, a.o.

On the basis of trilobite fauna, the age of the Ľubeník Fm. at the loc. Ochtiná was determined as Namurian B-C by Bouček & Přibyl (1960). Index forms of trilobites: *Phillipsia margaritifera* Roemer, *Paladin eichwaldi* (Fischer). Later, Kozur & Mock (in Kozur et al. 1976),

TAB. 6 CARBONIFEROUS AND PERMIAN OF THE NORTHERN GEMERIC UNIT: E-SE part




comp. by A. VOZÁROVÁ

based on the first findings of conodonts, holothurian sclerites and ostracods, classed the sediments from loc. Ochtiná with the uppermost Visean and Serpukhovian. In the lower part of the sequence, conodont fauna was found: *Paragnathodus commutatus* (BRANSON and MEHL 1957) and *Paragnathodus nodosus* (BISCHOFF 1957), in the upper part there was *Gnathodus bilineatus bollandensis.*

E and SE part of the Northern Gemeric Unit (Tab. 6): The Lower Carboniferous sequence of the Črmeľ Fm. was described as a distal flysch complex, consisting of alternating pelites, fine-grained sandstones, basic to intermediate volcanites and volcanoclastics, subsidiary carbonates and lydites. Small amounts of acid volcanoclastic detritus are unevenly dispersed in the sediments.

The Turnaisian-Visean age was indicated by microfloral assemblages (Snopková in BAJANÍK et al. 1984): *Convolutispora labiata* PLAYFORD, *C. subtriquetra* PLAYF., *Foveosporites oppositus* PLAYF., *F. insculptus* (PLAYF.) var. minor, *Schopfites claviger* SULIVAN, *Prolycospora claytonii* TURN., *Schulzospora* cf. *campyloptera* (WALTZ) HOFFM. STAPL. et MALL., a.o.

Lower Carboniferous sequences in the eastern and south-eastern part of the Northern Gemericum were originally defined and the Črmeľ Group. In view of the stratigraphic range and lithology equal to the sequences of the Ochtiná Group we assign the general part of the name "group" to the lower category - formation, and, under the name Črmeľ Formation, we incorporate this lithostratigraphic unit into the Ochtiná Group. The Črmeľ Fm. may be correlated, on the basis of the flysch development, the same type of basic volcanism (tholeiites with N-MORB affinity) with the Hrádok Fm. in the west. However, there are differences, such as the absence of fragments of ultrabasics and conglomerate turbidites, the substantially smaller number of graphitic shale horizons, considerably higher proportion of lenses of laminated crystalline limestones, allowing to distinguish this sequence as a separate formation within the Ochtiná Gr.

In the eastern part, there are preserved also shallow-marine sediments of the Ľubeník Fm., with magnesites. Its relationship to the Črmeľ Fm. is however in the eastern occurrences tectonic. Stratigraphically, the horizon with magnesites near Košice has not been documented by fauna. In view of certain lithological differences (the presence of beds with redeposited carbonate fragments; absence of horizons with fauna) we assign to this horizon the name Bankov Beds, classified as a member of the Ľubeník Fm.

Generally, Lower Carboniferous sequences in the Northern Gemericum were regionally metamorphosed in P-T conditions of the low temperature greenschist facies of lower-pressure type (illite crystallinity index, Šucha, p.c.; $b_o$ values of muscovites - SASSI & VOZÁROVÁ 1987 - estimated temperatures of 350-370°C at low pressures and high geothermal gradient of approx. 40°C/km).

*Westphalian A-D*

From the original definition of Carboniferous lithostratigraphic units of Gemericum, we left only Westphalian sequences in the Dobšiná Gr.. The most completely preserved ones are in the northern part (Tab. 7). In the eastern part, only two of them have been preserved (Rudňany and Hámor Fms., Tab. 6) and in the western part there are only relics of the Hámor Fm. (Tab. 5).

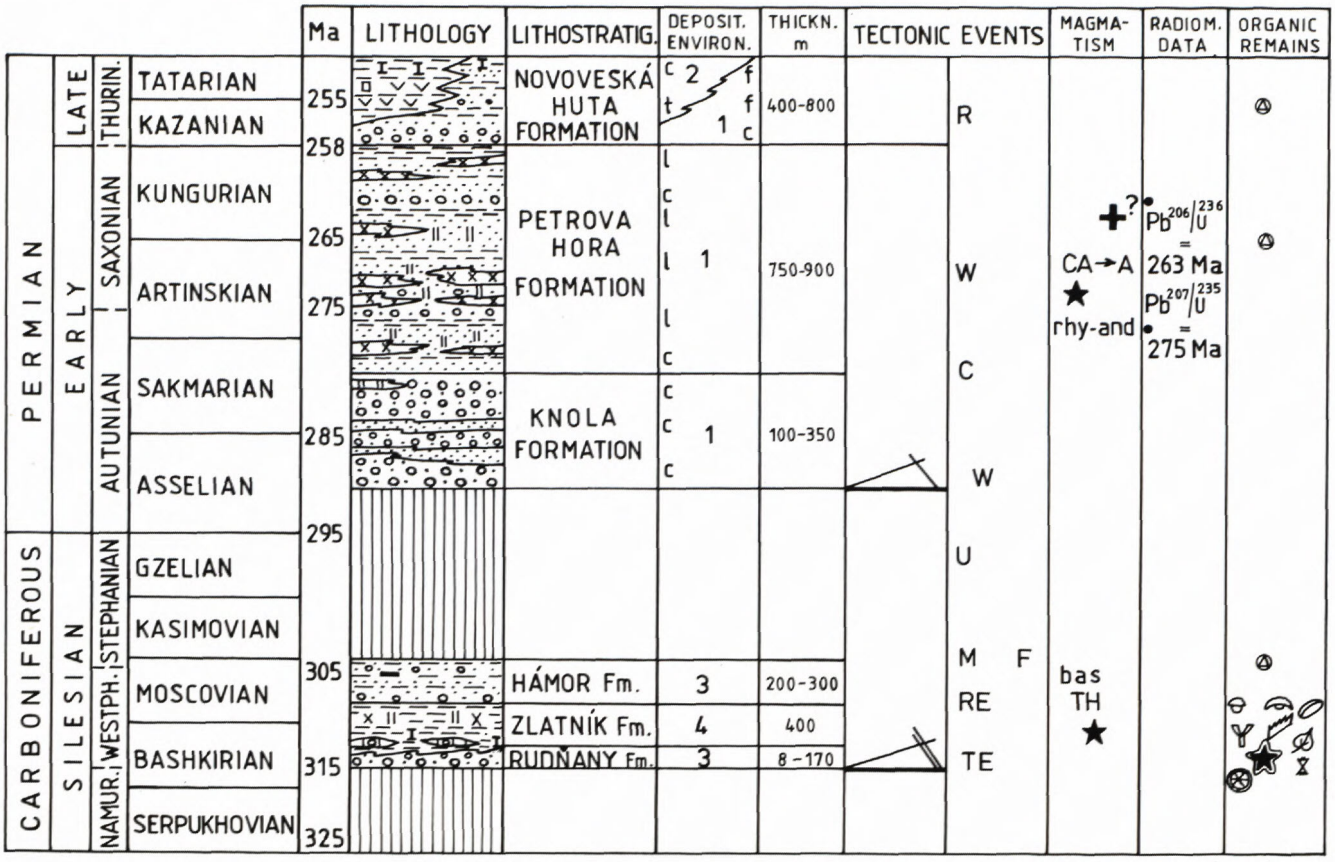
The Westphalian sequences are preserved within the paleo-Alpine North Gemeric Unit as tectonically reduced fragments. Their tectonic setting, related to continental collision, started in the Westphalian A by delta-fan, coarse-grained, very often boulder conglomerates, containing detritus derived from the underlying pre-Upper Carboniferous rock complexes. Direct contact of this basement rocks and basal part of the Westphalian deltaic-marine overstep sequences is preserved only in some places. Basal conglomerates of the Rudňany Formation unconformably overlap the gneiss-amphibolite complex of the Klátov Terrane in the vicinity of the Dobšiná town (Tab. 7), metasediments and metabasalts of the Rakovec Terrane in the wider area of the Rudňany village (Tab. 7), and the Lower Carboniferous flysch sequence of Črmeľ Fm. in the area between Margecany and Košická Belá (Tab. 6). Black shales and micaceous gray sandstone intercalations are a normal member of the upward fining Rudňany Fm. The floristic finds were determined by NĚMEJC (1947): *Cordaites palmaeoformis, Asterophyllites* cf. *grandis, Asterotheca miltoni, Neuropteris schützei, N. gigantea, N. gigantea abbreviata.*

After initial rapid sedimentation, the littoral to shallow-neritic limestones were associated with fine-grained clastic metasediments. This detritic-carbonate lithofacies corresponds to basal part of the Zlatník Fm., from which the Westphalian B-C age is indicated by rich trilobite fauna: *Griffithides rozlozsniki* RAKUSZ, 1932; *Cummingella* sp. aff. *balladoolensis* RED, 1942; *Palladin* sp. aff. *eichwaldi* FISHER, 1925 (in Rakusz 1932; BOUČEK & PŘIBYL 1960). Based on flora findings, NĚMEJC (1947; 1953) ranged this sequence to the Westphalian A-B: *Paripteris gigantea, Stylocalamites suckovi, Neuropteris heterophylla.* The conodont *Idiognatoides sinuatus* proved Westphalian A age (KOZUR & MOCK 1977).

The upper part of the Zlatník Fm. comprises fine-grained clastic metasediments associated with fine metabasaltic volcanoclastics and scarce effusions of high-K tholeiitic basalts. It reflects the deepening of the Westphalian sedimentary basin. Poor microfloral assemblages proved Upper Carboniferous age, but not an accurate division.

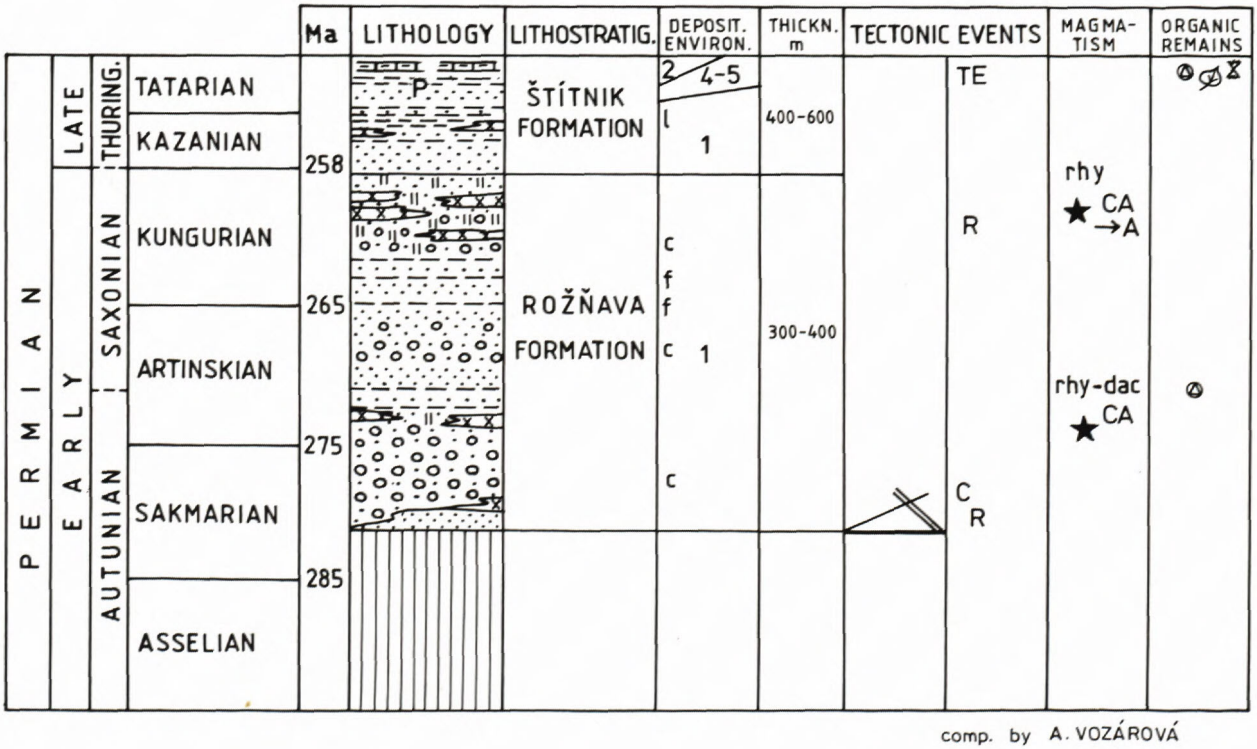
The termination of the Westphalian peripheral basin is reflected by the paralic sequence of the Hámor Fm. It is characterized by: 1. distinct cyclical, coarsening-upward arrangement of shally-sandy-conglomeratic sedi-

TAB. 7 CARBONIFEROUS AND PERMIAN OF THE NORTHERN GEMERIC UNIT: N part




comp. by A. VOZÁROVÁ

TAB. 8 PERMIAN OF THE SOUTHERN GEMERIC UNIT




comp. by A. VOZÁROVÁ

ments; 2. absence of synsedimentary volcanism; 3. local occurrence of a ribbed coal seam; 4. abundant mineralogical mature, quartz detritus. Poor microfloral assemblages proved the Westphalian D age: *Reticulatisporites irregularis* KOSANKE, *Thymospora thiessenii*, *Apiculatisporites raistrickii* (DYB.-JACH.), *Angulisporites splendidus* BHARADW., *Illinisporites elegans* KOS. (ILAVSKÁ 1961 in CHMELÍK et al. 1962; PLANDEROVÁ, manus. report).

The metamorphic grade in the Westphalian sequences did not exceed P-T conditions of the boundary between anchizone and lower limit of the greenschist facies.

### *Permian*

Continental Permian sequences overlapped slightly deformed relics of the Westphalian peripheral basin filling as well as all pre-Westphalian complexes of the Northern Gemeric zone with the exclusion of W and SW occurrences of the Ochtiná Group (see Tab. 5). Prevalent coarse-clastic sediments derived from the collision belt are associated with bimodal andesite/basalt-rhyolite volcanism. The development of the Permian depositional realm was connected with the post-Asturian transpression/transtension stage, as a result of extensional regime during the Late Permian-well as with Lower Triassic time.

The following are the characteristic features: 1/ multicoloured clastic sediments with dominant violet and violet-red; 2/ gradual upward fining; 3/ cyclicity manifested within the framework of small cycles as well as megacycles; 4/ bimodal calc-alkaline to alkaline volcanism.

The basal part (the Knola Fm.) contains mostly poorly sorted polymict conglomerates and breccias of extremely variable thickness, with pebble material reflecting the composition of the direct underlier. The coarse-grained sediments overlapped different parts of both pre-Carboniferous crystalline complexes as well as irregularly eroded surface of the Moscovian formations. They represent fossil mudflows, in some places partly reworked by flows, relieved by alluvial, mainly stream channel deposits. The age of these sediments has not been determined, due to a lack of fossils remains.

Volcanics and volcanoclastics of bimodal magmatic association are the main feature of the Petrova Hora Fm. The polyphase volcanic activity manifested a regional and time relationship with large sedimentary cycles. Sediments are characterized by a low degree of maturity and a mixture of syngenetic volcanic and non-volcanic detritus. Among the most striking features are the fining-upward alluvial cycles, with channel lag, pointbar and floodplain lakes facies alternating with playa subenvironment at the topmost part of large cycles.

The microflora found in the upper part of the Petrova Hora Fm. proved Saxonian age: *Limitisporites moesensis* (GREBEL) KLAUS, *Vittatina* div. sp., *Nuckoisporites dulhontyi* KLAUS (PLANDEROVÁ in BAJANÍK et al. 1977). This age is supported by isotopic analysis of sulfides from volcanogenic horizons: $^{206}Pb/^{236}U$ = 263 Ma; $^{207}Pb/^{235}U$ = 274 Ma (NOVOTNÝ & ROJKOVIČ 1981).

The Autunian-Saxonian terrigenous and terrigenous-volcanogenic sequences are overlapped by a relatively mature sandy-conglomerates horizon, with pebble material derived from the direct stratigraphic underlier. This could have been a consequence of the break in sedimentation after the Saxonian, but biostratigraphic evidence to support this assumption is missing. Alluvial, stream channel deposits prograde gradually upward to the inland sabkha and near-shore sabkha/lagoonal facies, with anhydrite-gypsum and salt breccia horizons (the Novoveská Huta Fm.). Isotopic analysis of sulfur shows results close to Upper Permian - lower part of the Lower Triassic (KANTOR et al. 1982). There are gradual transition up to the *Claraia clarai* horizon.

The grade of metamorphism of the Permian rock complexes did not exceed the P-T conditions of upper anchizone boundary.

### PERMIAN OF THE SOUTHERN GEMERIC UNIT

Late Variscan, post-orogenic overstep sequences of the Southern Gemeric Unit are represented only by the Permian to Lower Triassic continental and near-shore, lagoonal-sabkha formations (Tab. 8). They unconformably overlapped their Early Paleozoic basement, the volcano-sedimentary flysch of the Gelnica Gr. and metasediments of the Štós Fm. (defined together as the Gelnica Terr., VOZÁROVÁ & VOZÁR 1993, 1996). Generally, the Permian volcano-sedimentary complexes are characterized by a high content of mineralogically mature detritus, mainly in their basal part. Conspicuous upward fining is accompanied by a relative decrease of mineralogical maturity. Sediments represent the relics of sedimentary basin filling which originated in a transpression/transtension regime, which prograded to the initial stage of post-Variscan rifting. The whole sequence is subdivided into two lithostratigraphic units: the Rožňava and Štítnik Fms.

Characteristic lithotype of the Rožňava Fm. are oligomict, quartzose conglomerates, with indistinct stratification. The whole sequence is dismembered vertically into two large cycles, with conglomerate horizons at the base of each and a sandstone-shale member between them. Dominant are stream channel and sheet-flood deposits, with unimodal transport system. Both conglomerate horizons are connected with rhyolite-dacite subaerial volcanism. Their chemical composition corresponds to calc-alkaline magmatic type. The Lower Permian age of the Rožňava Fm. is assumed on the basis of microflora, with the predominant species of the genera *Potonieisporites, Striatodisaccites, Guetaceapollenites, Vittatina* sp., *Urtemis trigonius* and mainly the form *Triquitrites additus* WILS.. et HOFM.. (PLANDEROVÁ 1980).

The gradually prograded Štítnik Fm. is a monotonous complex of cyclically alternating sandstones, siltstones and shales. Lenses of carbonate sandstones and dolomitic limestones with intercalations of shales occur only in its upper part. Thin lenses of phosphatic sandstones and sediments with extremely high content of albite (albitolites) are exceptional. Sediments contain a relatively high amount of rhyolite/dacite detritus (? synsedimentary or redeposited from the Rožňava Fm.). The sedimentary environment is interpreted as alluvial-lacustrine and lacustrine, with high-alkaline lakes in some places, prograding into near-shore, lagoonal-sabkha facies. Age determinations are known only from the uppermost part. The Upper Permian was proved on the basis of a cone slice and twig of *Pseudowoltzia liebeana* (GEIN) FLOR., and leaves of the genus *Sphenozamites*, as well as remains of bivalvian shells of the genus *Carbonicola* MCCOY 1855 (ŠUF 1963). Microfloral assemblages confirm the Lower Triassic age of this horizon (PLANDEROVÁ 1980).

Generally, sequences of the Southern Gemeric Permian are distinctly dynamometamorphically deformed, with metamorphic grade reaching P-T conditions of anchizone to low-temperature part of greenschist facies.

### PERMIAN OF THE MELIATIC UNIT (BÔRKA NAPPE)

Tectonic slices of volcano-sedimentary sequences intensively pressure-deformed, lying in tectonic position on the Southern Gemeric basement and its cover, were recently assigned to the Bôrka Nappe (in Geol. map of the Slovak Karst, MELLO et al. 1996). The Permian age of these sequences has no been biostratigraphically supported, it is estimated only on the basis of their lithologic development. Two formations have been distinguished, classified previously as higher-metamorphosed members of the Permian cover of the Southern Gemericum, although their thrust tectonic position has been known (REICHWALDER 1973, BAJANÍK et al. 1984).

The Bučina Fm. is composed of a set of rhyolite volcanoclastics and felsitic rhyolites mixed with a small amount of non-volcanic quartzose detritus, of psammitic or psephitic grain-size.

The Jasov Fm. is composed predominantly of clastic sediments - oligomict conglomerates, sandstones and shales, with only a small amount of acid volcanics and volcanoclastic at the basal part. It is characterized by considerable decrease of the grain-size towards the upper parts.

Based on $b_o$ muscovite values (MAZZOLI, SASSI & VOZÁROVÁ 1992), P-T conditions of regional metamorphism correspond to medium/high-pressure greenschist facies (T = 400-450°C; P = 9-10 kbar; geothermal gradient approx. 10°C/km). The measurements were made on phyllites from the upper part of the Jasov Fm., in which the metamorphic assemblage quartz + muscovite + paragonite + albite, with a small amount of pyrophyllite and chlorite has been determined. They are associated with muscovite-chlorite-chloritoid phyllites.

### CARBONIFEROUS AND PERMIAN OF THE TURNAIC UNIT

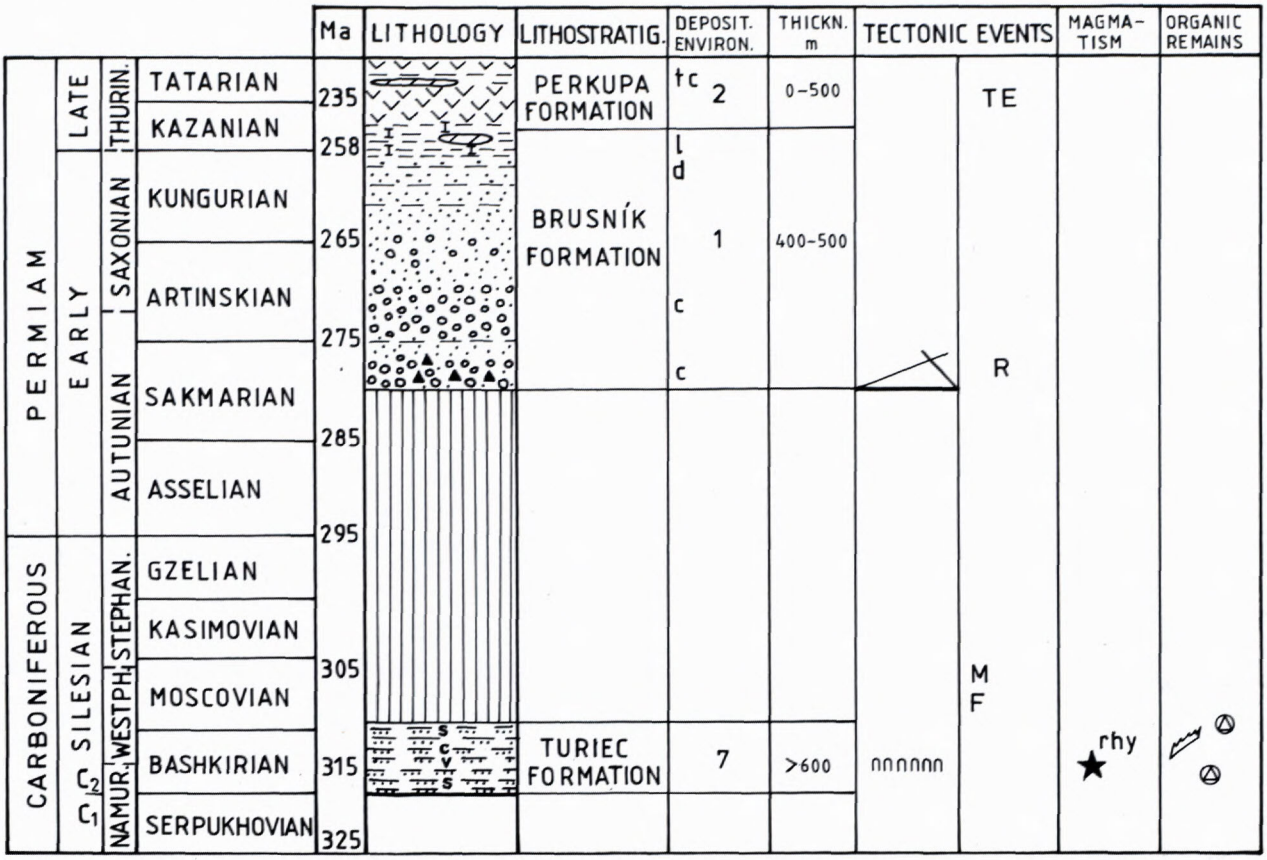
Late Paleozoic sequences assigned to the Turnaic Unit (Tab. 9) emerge to the surface from the tectonic underlier of the Silica Nappe in the southern part of the Slovenské rudohorie Mts., in the anticlinal structure near Brusník. The borehole BRU-1 (VOZÁROVÁ & VOZÁR 1990, 1992 a, b) allowed to determine their thrust tectonic position on the Upper Jurassic olistostrome sequence of Meliaticum. In the southern part of the Slovenské rudohorie Mts., they occur thus only in the form of nappe outliers in the tectonic overlier of Meliaticum (outliers of the Bôrka Nappe or Meliaticum s.s.) and in the tectonic underlier of the Silica Nappe.

#### *Namurian B - Westphalian A*

The sequence of black phyllites, metasiltstones and metasandstones with structural features of distal turbidite sedimentation, interrupted by episodic deposits of gravitational slides and a gravity current, including the carbonate olistostrome body, were defined as the Turiec Fm. (VOZÁROVÁ 1992). From the entire turbidite sequence only the Bouma facies $T_{d-e}$ have been preserved. Horizontal lamination, positive-graded within a small rhythm, is predominant. Associated there are thin graded-bedded metasandstone interbeds (maximum thickness 10-15 cm). Gravity current deposits are represented by layers of redeposited acid volcanoclastics and paraconglomerates. The bulk chemical composition of redeposited volcanoclastics shows their relationship to the rhyolite-dacite group of the subalkaline magmatic series. The paraconglomerate beds show positively graded bedding, with erosional contact with the underlying beds and predominant content of intraformational detritus.

The olistostrome consists of carbonate olistoliths ranging from tens of meters to decimeters in size. They are composed of limestones of two types: medium- to light-gray recrystallized limestones; black-gray clayey, unevenly recrystallized ones. Olistoliths of dark-gray limestones from the borehole BRU-1 contain conodonts whose age corresponds to the Zone "Idiognathoides" i.e. Namurian B - Westphalian A (EBNER et al. 1990). The dating is based on remains of *Idiognathoides* cf. *corrugatus* (HARRIS and HOLLINGSWORTH 1933); *Streptognathodus* sp., *Idiognathoides* sp. Mixed conodont fauna was found in the lower part of this olistostrome: *Idiognathoides* sp. (Namurian B - Westphalian A) and *Polygnathus* sp. (Emsian - Tournaisian).

TAB. 9 CARBONIFEROUS AND PERMIAN OF THE TURNAIC UNIT




comp. by A.VOZÁROVÁ

Sporomorph assemblages of the Namurian B - Westphalian A from the matrix of the olistostrome were determined by PLANDEROVÁ (in VOZÁR et al. 1989): *Tripartites vetustus*; *Anulatisporites bacatus* DYB., JACH.; *Cingulizonates loricus*; *Securisporites locatus*; *Densoisporites crassigranifer* are the most typical.

Metasediments of the Turiec Fm. underwent low-pressure greenschist-facies regional metamorphism (Mazzoli & VOZÁROVÁ 1989).

## *Permian*

Variegated, polymict coarse-clastic sediments resting unconformably on dark phyllites and containing phyllite fragments at their base, have always been considered to be of Permian age because of their continental red-beds type of deposits. They were described as a separate lithostratigraphic unit, denoted as the Brusník Fm. (VOZÁROVÁ & VOZÁR 1988).

The Brusník Fm. is characterized by dominant coarse-clastic sediments, a distinct tendency to fining upwards and dominant violet and gray-violet colors. In its internal structure three large sedimentary cycles were distinguished, each of them exceeding 100 m in thickness. Basic lithological types at the base of cycles are represented by polymict conglomerates in the middle part by lithic sandstones, in the upper part by sandstones alternating with siltstones and sandy shales. Among clastic sediments there are scarce irregular layers of redeposited acid volcanoclastic material, and in the upper part of the third large cycle there are small lenses of carbonates.

The assumed age of the Brusník Fm. is Lower Permian, in view of the fact that it is associated, with gradual transitions, with the evaporite Perkupa Fm. (borehole DRŽ-1, MELLO et al. 1994), which, on the basis of analogy with other evaporite occurrences in this zone, is most probably of Upper Permian age.

The Perkupa Fm. is composed of a complex of red and greenish-gray shales, with dolomite concretions on their base and beds of gypsum/anhydrite and dolomites in the upper parts.

### PERMIAN OF THE SILICIC UNIT

Locally preserved evaporite sequences of the Perkupa Fm., assumed to be Upper Permian, are the oldest known sediment on the base of the Silica Nappe.

They are connected with the overlying, biostratigraphically documented Lower Triassic sediments by gradual transitions. The Perkupa Fm. is composed of greenish-gray, less gray to dark-gray shales, gypsum/anhydrite and dolomites. A characteristic feature is the presence of anhydrite-arenites and evaporite sedimentary breccias, indicating mobile sedimentation conditions, redeposition of evaporites into relatively deeper part, most probably a tectonically formed rift sedimentation basin.

## Reconstruction of collision and post-collision variscan orogeny stage

The majority of sedimentary basins may be classified from the point of view of crust type, on which the basin originated, further, on the basis of the relative position to the plate margin and character of plate interaction taking place during filling up of the sedimentary basin (BALLY & SNELSON 1980, MIALL 1984). The plate tectonics theory shows that all these three fundamental parameters are changing with time. That implies that to the same mobile belt basins of various structural foundation and origin may be linked.

From the point of view of these criteria Carboniferous-Permian basins of the Western Carpathians belong to the type of peri- and epi-sutural basins, which were associated with formation of a compression megasuture. They were founded on continental or transitional to oceanic crust in a time and space succession depending on final closure of the Variscan mobile zone. It is evident that the Epi-Variscan continental crust formed by gradual accretion of terranes in the subduction-collision process, which at the beginning was finalized in Devonian - Lower Carboniferous and later terminated in Upper Carboniferous - Permian times. This process was accompanied at first by transpression/transtension and then extension regime associated with the origin of tectonically active sedimentary basins, located on both sides of the supposed Variscan suture.

Lithostratigraphic and sedimentologic analysis of Late Paleozoic basins suggests that the Variscan Terranes, recognized in the Paleo-Alpine Tatra-Veporic Domain, were gradually colliding from intra-Devonian to Middle Carboniferous time. The period of colliding is reflected by syn-collision magmatites, which had inherited VAC (CAG) features, related to previous subduction processes (HOVORKA & PETRÍK 1992, BROSKA & GREGOR 1992, KOHÚT 1992, 1996, PETRÍK et al. 1994, a.o.). These Variscan Terranes have been a part of the continental, overriding plate, composed of torn relics of Pre-Variscan crust (probably Precambrian) and of Caledonian-Variscan volcanic/magmatic arcs and convergent basins (represented by the Tatra T. including Byšta susp. T. and the Kohút and hypothetical Ipoltica T.). As a consequence of syn- and post-collisional magmatism a thickened continental crust formed, on which sedimentary basins were founded in a strike/slip and extensional regime in two stages.

The older, Westphalian-Stephanian ones are represented by huge wedges of clastogenic formations deposited in a continental or deltaic/shallow-water sedimentary regime. They are accompanied by acid to intermediate ensialic volcanism. The sedimentary basins of this stage are represented by volcanic-sedimentary formations preserved in Alpine-formed units of the Zemplinicum, Southern Veporicum and Hronicum (formations of the Zemplín, Ipoltica and Revúca Groups). The sedimentary regime continued in Westphalian-Stephanian basins, and gradually also in the Permian. A distinct change of climatic conditions was, however, taking place when the warm and humid climate was replaced by dry arid and semiarid climate. In the Permian generally clastic alluvial, fluvial-lacustrine formations of "red-beds" type formed in these basins. The determining feature of these basins is synsedimentary volcanism, mostly alkaline to calc-alkaline, and in zones of maximum extension of continental tholeiite type (Ipoltica Group; VOZÁR 1977).

A further group of graben and half-graben type basins was founded in Permian times (Autunian-Saxonian) and originated as a result of post-collision intra-plate extension. Their substratum were magmatic and crystalline massifs of the Tatra Terrane. The filling relics of these Permian basins are preserved in Alpine-formed units of the Tatricum and Northern Veporicum. In sedimentary basins founded in Permian times syngenetic volcanic activity was relative to previous group weak or not manifesting at all. From lithofacies representing preserved filling relics of Permian basins mostly wedges of coarse-clastic sediments coming from the environment of alluvial fans or braided rivers are found.

The model of most sedimentary basins founded on the Late Paleozoic Tatroveporic Domain respectively the Slovak Superterrane (name derived from the "Slovak block" MÁŠKA & ZOUBEK in BUDAY et al. 1960; "Slovakides" MAHEĽ 1983; "Slovakic Terrane" PLAŠIENKA 1991) is characterized by:

I. Prevailingly medium and small dimensions of sedimentary basins, in which intense tectonic activity at fault margins is indicated by conglomerate wedges. An exception, as to size and shape, is the Ipoltica Group rift trough, at which a considerably long (350-500 km) and well developed system of transversal and longitudinal transportation is supposed;

II. Manifestations of synsedimentary tectonics, as proved by development of megacycles of regional extension and of local intraformation disconformities, also by volcanic activity, mostly polyphase;

III. Clastic detritus coming from the immediate substratum bordering the margin of sedimentary basins or from synsedimentary volcanic centers;

| VARISCAN orogene | INTERNIDES | | | | | | EXTERNIDES | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| relics in paleo-Alpine units | T | NV | SV | Z | H | NG | SG | M | TU | S | U | SZ | B |
| character of substratum of Late Paleozoic basins | continental crust | | | | | thrust wedges of ceanic crust | consuming plate boundary fore-arc basin filling | | disrupted continental crust, attenuated in places | | | | |
| tectono-thermal development | Devonian - Carboniferous tectono-thermal activity with maximum deformation, magmatism and metamorphism | | | | | | weak or/lack of symptoms of magmatism; metamorphism more advanced than anchimetamorphism/low temperature greenschist facies | | | | | | |
| main collision events | Bretonian - Sudetian | | | | | | Asturian | | | | | | |
| depositional system | continental: Permian → Upper Carboniferous → marine: shallow-water Moscovian and Serpuchovian → deep-water post-Bretonian flysch → | | | | | | continental to sabcha-lagoonal: Permian → .sabcha to shallow-water: Permian → .marine: shallow-water Stephanian → deep-water post-Sudetian flysch → | | | | | | |
| provenance | continental block prov. → cut magmatic arc prov. → orogen. provenance → | | | | | | continental block provenance mixed - with recycled orogen provenance → | | | | | | |

**Explanation to symbols:**

T - Tatric Unit; NV - Northern Veporic U.; SV - Southern Veporic U.; Z - Zemplinic U.; NG - Northern Gemeric U.; SG - Southern Gemeric U.; M - Meliatic U.; TU - Turnaic U.; S - Silicic U.; U - Upponyi Mts.; SZ - Szendrö Mts.; B - Bükk Mts.

*Tab. 10 Scheme of tectono-sedimentary evolution of the Western Carpathian Carboniferous-Permian basins.*

IV. The petrofacial analysis of clastic sediments indicates a double provenance from the rejuvenated continental basement and truncated volcanic arc;

V. High-rate sedimentation.

The Late Paleozoic basins included into the Paleo-Alpine Gemeric Domain originated not only on two different types of the substratum, but also in different time.

Basins, the substratum of which was the Spiš Composite Terrane, originated on the oceanic crust and destroyed ensialic arc as well as high metamorphic fragments of lower continental crust. Lower Carboniferous remnant basins were of specific intrasutural position, represented by sequences of the Ochtiná Group. They are characterized by flysch type of sedimentation, with slabs of serpentinized ultrabasites (? of oceanic crust), upward shallowing and gradual replacement of flysch formations by shallow-water, littoral-neritic sediments. The filling of these basins was deformed and metamorphosed towards the end of the Lower Carboniferous (VOZÁROVÁ 1993), probably due to Sudetian movements (finds of the Črmeľ Fm. rock fragments in pebbles of Westphalian conglomerates; VOZÁROVÁ 1973). The development of Lower Carboniferous basins was terminated with the origin of the Variscan compression suture. In the Variscan orogeny, the Spiš Composite Terrane represented a intricate relic of oceanic/continental crust, on which at first the Lower Carboniferous flysch basins, and then shallow-marine peripheral basin formed in the Westphalian A-B. At the base it contains coarse-clastic deposits of delta-fan type, in which there are found detritus coming from Spiš Composite T. rock complexes, but also fragments of granitoids orthogneisses, tonalites, mica schists and mineralogically mature metasandstones. This exotic fragmentary material came from a newly forming collision suture, in which also parts of the active continental margin were destroyed. As a consequence of transform movements along the suture zone the peripheral basin changed its boundary and its sedimentation was interrupted. Shallow-marine sedimentation was terminated in the Westphalian D by a paralic sequence. Due to the supposed transform movements the basin was moderately deformed and the sediments weakly metamorphosed. Continental Permian sediments are resting unconformably on various lithological members of Westphalian formations and have all features of sedimentation in transtensional zone originated on the thickened continental crust with calc-alkaline to alkaline bimodal volcanism. Tectonic stabilization of the whole region was terminated by development of Upper Permian - Lower Triassic evaporite formations.

Quite a different development in the termination of the Variscan orogeny is reflected in the sedimentary basin formed on the Gelnica Terrane. The relic of its sedimentary filling is represented by formations of the

Gočaltovo Group, generally of Lower Permian to Upper Permian - Lower Triassic age (ŠUF 1963, PLANDEROVÁ 1980). The basin was founded in a strike/slip fault regime, in which distinct extension was predominating in later development. The sedimentary filling, which is prevailingly continental and only in the upper parts transitional, lagoonal-marine, therefore has some features of rift formations. It is mainly high mineralogical maturity of sediments, which is in contradiction with their structural immaturity. A further feature is distinct decrease in the maturity grade of sediments in upward direction (VOZÁROVÁ 1977). The associated volcanism is subaerial, highly siliceous. Although at the beginning of the development of the Gočaltovo Group sedimentary basin transpression/transtension forces (pebbles of quartz and blastomylonite deformed cataclastically) were active, extensional tectonic later prevailed, continuing also in the Early Alpine stage. Mineralogically mature sediments of the Gočaltovo Group were compared with the Alpine - Mediterranean "Verrucano" formations, defined by CASSINIS et al. (1979) as riftogenic tectonofacies of the Alpine cycle. For this reason we suggest that the Permian sedimentary basin originated on the basement of the Gelnica Terrane as a post-collision basin, distinctly linked with Alpine rifting culminating with the formation of the Meliata ocean.

Of particular importance for reconstruction of the Variscan orogene is therefore the occurrence of the Middle Carboniferous flysch tectonic slice (Turiec Formation; VOZÁROVÁ 1992), which was identified in borehole BRU-1 (VOZÁR et al. 1989) in the Brusník anticline. This flysch sequence was correlated lithologically (VOZÁROVÁ & VOZÁR 1990, 1992a, b) and stratigraphically (EBNER & VOZÁROVÁ et al. 1990) with the Szendrö Phyllites Formation in northern Hungary and with other Southern Alpine Middle Carboniferous flysch occurrences. The stratigraphic range of the Turiec Formation is Namurian B - Westphalian A (Bashkirian). It is a formation not compared with other Carboniferous occurrences in the Western Carpathians, as the Namurian B-C is missing in the Western Carpathians and the Westphalian A is in the development of the Post-Sudetian marine molasse. Regarding to the Turiec Formation containing a carbonate olistostrome (olistoliths of carbonates from the passive continental margin and also volcanoclastic rhyolite turbidites - island-arc detritus?) we may suppose that there is a relic of flysch trough genetically connected with the termination of the Western Carpathian Variscan externides. We may put the closing of this trough in connection with Asturian movements, its filling being deformed and metamorphosed in greenschist facies of low-pressure type (Mazzoli & VOZÁROVÁ 1989). The Post-Asturian molasse is represented by continental Permian conglomerates of the Brusník Formation.

## Conclusion

1. The origin of Carboniferous-Permian basins in the Western Carpathians is associated in time and space with collision events of the Variscan orogeny.
2. The distribution of Carboniferous-Permian basins in time as well as the lithofacial character of their filling documents the southern polarity of the Variscan orogene in the Western Carpathians.
3. The Carboniferous-Permian basins originated in three zones differing in the type of crust and position regarding to Variscan orogene polarity.

They are:

a) The Slovak Superterrane in which there formed terranes belonging to the upper continental plate with maximum manifestations of magmatism and metamorphism connected with convergent regime. In present-day Alpine structure the Tatra, Kohút and hypothetical Ipoltica Terranes are relics of this continental plate, which besides probable fragments of Precambrian crust contained also element of converging margins - relics of magmatic arcs or back-arc basins connected with Variscan orogeny. In this innermost zone of the Variscan orogeny only continental Upper Carboniferous-Permian molasse basins associated with transform fault and extensional regime have been preserved.

b) The Spiš Composite T., composed of the Klátov and Rakovec Terranes, which represents a relic of a plate with loer continetal and oceanic to transitional crust (perhaps of the type of developed back-arc basin in the sense of the interpretation of IVAN et al. 1994). The sedimentary basins, which originated in this zone, reflect the succession of Variscan collision. This relic of the Variscan suture is composed of tectonically pressed slices of oceanic crust, probably also including the destroyed ensimatic island arc and relics of continental crust and destroyed collision and post-collision Carboniferous-Permian basins. The latter are represented by filling relics of ?deep- to shallow-marine Post-Bretonian intrasutural basins and a shallow-marine Post-Sudetian peripheral basin. They are unconformably covered by Post-Asturian continental molasse.

c) The Gelnica Terrane represents a relic of forearc basin filling, associated with an ensialic arc on an active continental margin. On its basement a Post-Asturian continental basin originated in extensional regime. It is very probable that the Gelnica Terrane was palinspastically connected with a flysch trough, the relics of which were found in the form of a tectonic nappe outlier in borehole BRU-1 and its continuation is in the Szendrö Mts. If this assumption is correct, the Middle Carboniferous flysch trough represented by the Turiec Formation and Szendrö Phyllites Formation was linked with a convergent regime of the Western Carpathian Variscan externides. The closing of this basin was connected with Asturian movements. This zone is palinspastically di-

rectly connected with the South Alpine-Dinaride flysch zone, connections of which with lagoonal - shallow-marine formations of the African plate passive margin are evident.

4. On the basis of filling relics of Carboniferous-Permian basins in the Western Carpathians, two zones of continental collision differing in time were identified:

a) Inner branch, with termination of collision during Bretonian-Sudetian events. It consist of two main domain: the Slovak Superterrane, which reflects intense dynamo-metamorphism, deformation and magmatism resulting in a long-lasting and strong uplifting and preserved only post-collisional Upper Carboniferous and/or Permian continental cover; the Spiš Composite T. inside of which Lower Carboniferous synorogenic flysch, Upper Carboniferous and Permian marine to continental post-collisional cover as well as slices of the multi-stage metamorphosed oceanic and lower continental crust have been preserved.

b) Outer branch, with termination during Asturian events. It is represented by the Early Paleozoic Gelnica T. volcanogenic fore-arc flysch and rifting-related its Permian cover with palinspastic relations to the Bashkirian flysch trough in the Turnaic Unit.

Both sutures represented zones of extension and crustal shortening in the Alpine orogeny. Especially the Asturian suture represented the zone of maximum extension and rifting, which led eventually to the origin of the future Meliata Ocean.

## References


ANDRUSOV, D. 1936: Subtatric nappes in Western Carpathians. Carpathica, 1, Praha, 5-50.

ANDRUSOV, D., BYSTRICKÝ, J. & FUSÁN, O. 1973: Outline of the Structure of the West Carpathians - Guide-book for Geol. Excur. X. Congr. of CBGA, D.Š. Inst. of Geol., Bratislava, 1-44.

BAJANÍK, Š. & HOVORKA, D. 1981: The amphibolite facies metabasites of the Rakovec Group of Gemericum (the West Carpathians). Geol. Zborn. Geol. Carpath., 32, 6, Bratislava, 679-705.

BAJAMÍL, Š., IVANIČKA, J., VOZÁROVÁ, A. & DOVINA, V. 1977: Explanation to geological map, sheet Gelnica, M. 1 : 25 000. Archives, D. Š. Geol., Bratislava, manuscr. report (In Slovak).

BAJANÍK, Š., VOZÁROVÁ, A. & REICHWALDER, P. 1981: Lithostratigraphic classification of the Rakovec Group and Late Paleozoic of the Spišsko-gemerské rudohorie Mts. Geol. Práce, Spr. 75, Bratislava, 19-53 (in Slovak).

BAJANÍK, Š., VOZÁROVÁ, A., SNOPKOVÁ, P. & STRAKA, P. 1984: Lithostratigraphy of the Črmeľ Group. Manuskript, Archives D. Š. Inst. of Geol., Bratislava (in Slovak).

BAJANÍK, Š., IVANIČKA, J., MELLO, J., PRISTAŠ, J., REICHWALDER, P., VOZÁR, J. & VOZÁROVÁ, A. 1984: Geological map of the Slovenské rudohorie Mts., 1:50.000. D. Š. Inst. of Geol., Bratislava.

BAJANÍK, Š. & PLANDEROVÁ, E. 1985: Stratigraphic position of the Lower part of the Ochtiná Fm. (between Magnezitovce and Magura). Geol. Práce, Spr. 82, D.Š. Inst of Geol., Bratislava, 67-76 (in Slovak).

BALLY, A.W. & SNELSON, S. 1980: Realms of subsidence. In A.D. Miall (ed.): Facts and principles of world petroleum occurrence. Can. Soc. Petrol. Geol. Mem., 6, 9-94.

BEZÁK, V. 1991: Metamorphic conditions of the Veporic unit in the Western Carpathians. Geologica Carpathica, 42, 4, Bratislava, 219-222.

BOUČEK, B. & PŘIBYL, A. 1959: Geological conditions of Zemplínske vrchy Hills in Eastern Slovakia. Geol. Práce, Zošit 52, Bratislava, 185-222 (in Czech).

BOUČEK, B. & PŘIBYL, A. 1960: Revision der Trilobiten aus dem slowakischen Oberkarbon. Geol. Práce, Spr. 20, Bratislava, 5-50 (in Czech).

BROSKA, I. & GREGOR, T. 1992: Allanite-monazite antagonism and monazite-ilmenite granite series in the Tribeč Mts. In J. VOZÁR (ed.): Spec. Vol. IGCP Pr. No. 276 - The Paleoz. Geodyn. Dom. in their Alp. Ev., D.Š. Inst of Geol., Bratislava, 25-36.

BROSKA, I., VOZÁR, J., UHER, I. & JAKABSKÁ, K. 1993: Zircon typology from the Permian rhyolite-dacites and their pyroclastics (Western Carpathians). M. Rakús, J. VOZÁR (eds.): Geodyn. vývoj a hlbinná stavba Záp. Karpát, Zborn. konf., symp., sem., D.Š. Inst. of Geol., Bratislava, 151-158 (in Slovak).

BUDAY, T., KODYM, O., MAHEĽ, M., MÁŠKA, M., MATĚJKA, A., SVOBODA, J. & ZOUBEK, Vl. 1960: Tectonic development of Czechoslovakia. Praha, ČSAV, 245.

CASSINIS, G., ELTER, G., RAU, A. & TONGIORGI, M. 1979: Verrucano: a tectofacies of the Alpine-Mediterranean Southern Europe. Memoires Societa Geologia Italiana, 20, Pisa, 135-149.

EBNER, F., VOZÁROVÁ, A., STRAKA, P. & VOZÁR, J. 1990: Carboniferous conodonts from Brusník Anticline (South Slovakia). In: D. MINAŘÍKOVÁ - H. LOBITZER (eds.) "Thirty years of geological cooperation between Austria and Czechoslovakia", Vienna - Prague, 249-252.

FARYAD, Sh.W. 1995: Geothermobarometry of metamorphic rocks from the Zemplinicum (Western Carpathians, Slovakia). Geol. carpath., 46, 2, Bratislava, 113-126.

GRECULA, P. & EGYUD, K. 1982: Lithostratigraphy of Upper Paleozoic and Lower Triassic strata of the Zemplínske vrchy Mts. (SE Slovakia). Miner. slov., 14, 3, 221-239 (in Slovak).

HOVORKA, D. & SPIŠIAK, J. 1981: Coexisting garnet and amphiboles metabasites from Rudňany area (the Paleozoic, the Spišsko-gemerské rudohorie Mts., the Western Carpathians). Miner. slovaca, 13, 6, Alfa, Bratislava, 509-525.

HOVORKA, D., DÁVIDOVÁ, Š., FEJDI, P., GREGOROVÁ, J., HATÁR, J., KÁTLOVSKÝ, V., PRAMUKA, S. & SPIŠIAK, J. 1987: The Muráň Gneisses - the KOHÚT Crystalline Complex, the Western Carpathians. Acta Geolog. Geogr. Univ. Com., Geol. 42, Bratislava, 5-101.

HOVORKA, D. & PETRÍK, I. 1992: Variscan granitic bodies of the Western Carpathians: the back bone of the mountain chain. In J. VOZÁR (ed.): Spec. Vol. IGCP Pr. No. 276. The Paleozoic Geodynamic Domain in their Alpidic evolution. D. Š. Inst of Geol., Bratislava, 57-66.

HOVORKA, D., MÉRES, Š. & IVAN, P. 1994: Pre-Alpine Western Carpathians Basement Complexes: Lithology and Geodynamic setting. Mitt. Österr. Ges., 86, Wien, 33-44.

ILAVSKÁ, Ž. 1961 in CHMELÍK, J. et al. 1962: Geologické vyhodnotenie vrtu G-37, Dobšiná - Hámor. Manuscript, Geofond, Bratislava (in Slovak).

IVAN, P. 1994: Early Paleozoic of the Gemeric Unit (Inner Western Carpathians): Geodynamic setting as inferred from metabasalts geochemistry data. Mitt. Österr. Geol. Ges., 86, Wien, 23-31.

IVANIČKA, J., HÓK, J., POLÁK, M., HATÁR, J., GREGUŠ, J., KOVÁČIK, M., VOZÁR, J., VOZÁROVÁ, A., NAGY, A., KERNÁTS, G., BRLAY, A., JÁNOVÁ, V. & VRANOVSKÁ, A. 1992: Explanation to the geological map 1:25.000, sheet Partizánske-3. Manuscript, Archives D.Š. Inst of Geol., Bratislava (in Slovak).

KANTOR, J., ĎURKOVIČOVÁ, J., RYBÁR, M., GARAJ, M., FERENČÍKOVÁ, E. & HAŠKOVÁ, A. 1982: Genesis of Western Carpathian evaporites based on sulphur isotopes. Manuscript. Geofond, Bratislava (in Slovak).

KOHÚT, M. 1992: The Veľká Fatra granitoid pluton - an example of a Variscan zoned body in the Western Carpathians. In J. VOZÁR (ed.): Spec. Vol. IGCP Pr. No. 276 - The Paleoz. Geodyn. Dom. in their Alpidic Evol., D.Š. Inst of Geol., Bratislava, 79-92.

KOHÚT, M. 1996: The geology of the Ľubochňa granitoid massif of the Veľká Fatra Mts. Geol. Surv., Bratislava (dis. thes.).

KORIKOVSKIJ, S.P., DUPEJ, J. & BORONIKHIN, V.A. 1989: High-ferrugineous metasediments from Kokava nad Rimavicou (Veporicum). Miner. slovaca, 21, Alfa, Bratislava, 251-258 (in Slovak).

KOVÁČIK, M. 1991: High Al and Fe micaschists from the southeastern Veporicum: protolith and regional metamorphism. Miner. slovaca, 23, Alfa, Bratislava, 23-32 (in Slovak).

KOZUR, H., MOCK, R. & MOSTLER, H. 1976: Stratigraphische Neuenstufung der Karbonatgesteine der unteren Schichtenfolgen von Ochtiná (Slovakei) in das oberste Vise-Serpukhovian (Namur A). Geologische Palaeontolog. Mitt., 6, 1, Innsbruck, 1-29.

KOZUR, H. & MOCK, R. 1977: Erster Nachweis von Conodonten im Paleozoikum (Karbon) der Westkarpaten. Čas. pro miner. a geol., 22, 3, Praha, 299-305.

MAHEĽ, M. 1954: Stratigraphic and tectonic setting of Western Gemerides Paleozoic complexes. Geol. sbor. SAV, 5, Bratislava (in Slovak).

MAHEĽ, M. 1983: Proposal for tectonic nomenclature. Miner. slovaca, 15, Alfa, Bratislava, 559-565 (in Slovak).

MAZZOLI, C. & VOZÁROVÁ, A. 1989: Further data concerning the pressure character of the Hercynian metamorphism in the West Carpathians (Czechoslovakia). Rend. Soc. It. Min. Petr., 43, 3, 635-642.

MAZZOLI, C., SASSI, R. & VOZÁROVÁ, A. 1992: The pressure character of the Alpine metamorphism in the Central and Inner Western Carpathians (Czecho-Slovakia). In J. VOZÁR (ed.): Special Vol. IGCP Pr. NO. 276, D. Š. Inst of Geol., Bratislava, 109-117.

MELLO, J., VOZÁROVÁ, A., VOZÁR, J., GARGULÁK, M., HANZEL, V., KÁČER, Š., KAROLI, S., MOLÁK, B., ŠUCHA, V. & SIRAŇOVÁ, V. 1994: Evaluation of the structural borehole DRŽ-1 (Držkovce). Manuscript, Archives D. Š. Inst of Geol., Bratislava (in Slovak).

MELLO, J. (ed.), ELEČKO, M., PRISTAŠ, J., SNOPKO, L. & VOZÁROVÁ, A. 1996: Geological map of the Slovak karst 1:50.000. Geol. Surv., Bratislava.

MÉRES, Š. & HOVORKA, D. 1991: Geochemistry and metamorphic evolution of the Kohút crystalline complex mica schists (the Western Carpathians). Acta geol. geogr. Univ. Com., Geol., 47/1, Bratislava, 15-66.

MIALL, D.A. 1984: Principles of Sedimentary Basin Analysis. Springer-Verlag, New York - Berlin - Heidelberg - Tokyo, 1-468.

NĚMEJC, F. 1947: Contribution to knowledge of floral remnants and stratigraphical division of Permo-Carboniferous of Slovakia. Rozpravy II. tř. Čes. Akad. Věd, roč. 56, č. 15, Praha, 1-34 (in Czech).

NĚMEJC, F. 1953: Introduction to stratigraphy of coal basins of ČSR based on macroflora. ČSAV, Praha, 1-173 (in Czech).

NĚMEJC, F. & OBRHEL, J. 1958: Evaluation of some plant impressions from Permian-Carboniferous of Slovakia. Zprávy o geol. výzk. v roce 1957, Ústř. Úst. Geol., Praha, 165-166 (in Czech).

NOVOTNÝ, L. & ROJKOVIČ, I. 1981: Uran-mineralization in Western Carpathians. In: M. MAHEĽ (Ed.): Vážnejšie problémy geol. vývoja a stavby Československa. Smolenice 1979. D.Š. Inst. of Geol., Bratislava, 327-347 (in Slovak).

PETRÍK, I., BROSKA, I. & UHER, P. 1994: Evolution of the Western Carpathian granite magmatism: age, source rock, geotectonic setting and relation to Variscan structure. Geol. Zbor. Geol. Carpath., 45, Bratislava, 283-291.

PLANDEROVÁ, E. 1973: Palinological research in the melaphyre series of the Choč Unit in the NE part of the Nízke Tatry between Spišský Štiavnik and Vikartovce. Geol. Práce, Spr. 60, Bratislava, 143-168 (in Slovak).

PLANDEROVÁ, E. 1974: On the age of Staré Hory Paleozoic based on palynology. Miner. slovaca, 6, 1, Alfa, Bratislava, 63-72 (in Slovak).

PLANDEROVÁ, E. 1980: New results about age of "Rožňava - Železník Group". Geol. Práce, Spr. 74, Bratislava, 113-128 (in Slovak).

PLANDEROVÁ, E. 1982: First finding of Visean microflora in Gemerides (Slovakia). Západ. Karpaty, sér. paleont., 8, D. Š. Inst of Geol., Bratislava, 111-126 (in Slovak).

PLANDEROVÁ, E. & VOZÁROVÁ, A. 1978: Upper Carboniferous in the Southern Veporicum. Geol. Práce, Spr. 70, D.Š. Inst. of Geol., Bratislava, 129-141 (in Slovak).

PLANDEROVÁ, E., SITÁR, V., GRECULA, P. & EGYÜD, K. 1981: Biostratigraphical evaluation of graphite shales of Zemplín island. Miner. slov., 13, Bratislava, 97-128 (in Slovak).

PLANDEROVÁ, E. & VOZÁROVÁ, A. 1982: Biostratigraphical correlation of Late Paleozoic Formations in the West Carpathians. Newsletter, 4, IGCP No. 5, Eds.: F.P. Sassi and I. Varga, Košice - Padova, 67-71.

PLANDEROVÁ, E. & ČILLÍK, I. 1990: The age of variegated sandy shales from the area of cooper deposits in the Špania dolina, Middle Slovakia. Miner. slovaca, 22, 5, Alfa, Bratislava, 411-416 (in Slovak).

PLAŠIENKA, D. 1991: Mesozoic tectonic evolution of the epi-Variscan continental crust of the Central Western Carpathians - a tentative model. Miner. slovaca, 23, Bratislava, 447-457.

RAKUSZ, Gy. 1932: Die oberkarbonischen Fosilien von Dobšiná und Nagyvisnyo. Geolog. Hungarica, Ser. Paleont., 8, Budapest, 1-219.

REICHWALDER, P. 1973: Geologische Verhältnisse des jüngeren Paläozoikums im SÖ Teil des Zips-Gemer Erzgebirges. Západ. Karpaty, 18, D.Š. Inst. of Greol., Bratislava, 99-140 (in Slovak, German res.).

ROJKOVIČ, I., FRANCÚ, J. & ČÁSLAVSKÝ, J. 1992: Association of organic matter with uranium mineralization on the Permian sandstones of the Western Carpathians. Geol. carpath., 43, Bratislava, 27-34.

SASSI, F.P. & VOZÁROVÁ, A. 1987: The pressure character of the Hercynian metamorphism in the Gemericum (West Carpathians, Czechoslovakia). Rend. Soc. Ital. Min. Petr., 42, 73-81.

SITÁR, V. & VOZÁR, J. 1973: Die ersten Makrofloren Funde in dem Karbon der Choč Einheit in der Niederen Tatra (Westkarpaten). Geol. Zborn. Geol. carpath., 24, 2, 441-448.

SPIŠIAK, J., HOVORKA, D. & IVAN, P. 1985: Klátov Group the representative of the Paleozoic amphibolite facies metamorphites on the Inner Western Carpathians. Geol. Práce, Spr. 82, D. Š. Inst of Geol., Bratislava, 205-220 (in Slovak).

ŠUF, J. 1963: Ergebnise der geologischen Untersuchungen im Gebiete von Štítnik. Geol. Práce, Spr. 27, Bratislava, 63-68 (in Czech).

VOZÁR, J. 1977: Tholeiitic magmatic rocks in the Permian of the Choč Nappe (Western Carpathians). Miner. slov., 9, 4, Bratislava, 241-258 (in Slovak).

VOZÁR, J. 1984: Permian volcanic activity in the Variscan molasse evolutions in the West Carpathians. In: "Magmatism of the molasse-forming epoch". Ed. J. VOZÁR, D. Š. Inst. of Geol., Bratislava, 147-156.

VOZÁR, J., VOZÁROVÁ, A., BODIŠ, D., EBNER, F., GARGULÁK, M., HANZEL, V., ONDREJIČKOVÁ, A., PLANDEROVÁ, E. & STRAKA, P. 1989: Results from the borehole BRU-1. Manuscript, Archives D. Š. Inst of Geol., Bratislava (in Slovak).

VOZÁROVÁ, A. 1973: Pebble analysis of the Late Paleozoic conglomerates in Spišsko-gemerské rudohorie Mts. Západ. Karpaty, 18, D. Š. Inst. of Geol., Bratislava, 7-98 (in Slovak).

VOZÁROVÁ, A. 1977: Petrography of Late Paleozoic sediments in southeastern part of Spišsko-gemerské rudohorie Mts. (West Carpathians). Západ. karpaty, sér. miner., petrograf., geochém., lož., 3, Bratislava, 147-174 (in Slovak).

VOZÁROVÁ, A. 1979: Lithofacial characteristic of the Permian in NW part of the Veporic. Západ. Karpaty, sér. miner., petrogr., geochém., metalogen., 6, Bratislava, 61-116 (in Slovak).

VOZÁROVÁ, A. 1981: Lithology and Petrology of Nižná Boca Fm. Západ. Karpaty, sér. miner., petrol., geochém., metal., 8, D. Š. Inst. of Geol., Bratislava, 143-199 (in Slovak).

VOZÁROVÁ, A. 1986: Problems of lithostratigraphical division of Permo-Carboniferous of Zemplínske vrchy Hills and characterization of Luhyňa Fm. Reg. geol. Západ. Karpát, 21, Bratislava, 39-45 (in Slovak).

VOZÁROVÁ, A. 1990: Development of metamorphism in the Gemeric/Veporic contact zone (Western Carpathians). Geol. Zborn. Geol. Carpathica, 41, 5, Bratislava, 475-502.

VOZÁROVÁ, A. 1991: The petrology of crystalline rocks of Zemplinicum (West Carpathians). Západ. Karpaty, sér. miner., petrograf., geochém., metal., 14, D. Š. Inst. of Geol., Bratislava, 7-60 (in Slovak, Engl. res.).

VOZÁROVÁ, A. 1992: New lithostratigraphic units in the Brusník anticline. Geol. Práce, Spr. 96, D.Š. Inst of Geol., Bratislava, 25-32 (in Slovak).

VOZÁROVÁ, A. 1993: Variscan metamorphism and crustal evolution in the Gemericum. Západ. Karpaty, sér. miner., petrol., geochém., metal., 16, D.Š. Inst of Geol., Bratislava (in Slovak, Engl. res.).

VOZÁROVÁ, A. & VOZÁR, J. 1979: Nižná Boca and Malužiná Fms. - new lithostratigraphic units in Late Paleozoicum in Hronicum. Miner. slov., 11, 5, Alfa, Bratislava (in Slovak).

VOZÁROVÁ, A. & VOZÁR, J. 1982: New lithostratigraphic units in Southern part of Veporicum. Geol. Práce, Spr. 79, D.Š. Inst. of Geol., Bratislava, 27-54 (in Slovak).

VOZÁROVÁ, A. & VOZÁR, J. 1988: Late Paleozoic in West Carpathians. Monography. D. Š. Inst of Geol., Bratislava, 1-314.

VOZÁROVÁ, A. & VOZÁR, J. 1990: Olistostromes and gravitational slidings in borehole BRU-1 sequence (Brusník Anticline; Rimava Depression). Miner. slovaca, 22, Alfa, Bratislava, 381-382 (in Slovak).

VOZÁROVÁ, A. & VOZÁR, J. 1992a: Middle Carboniferous flysch in the Western Carpathians: contribution to tectonics of the southern part of the Slovenské rudohorie Mts. based on results of the borehole BRU-1, Brusník. Miner. slovaca, 24, Alfa, Bratislava, 53-62 (in Slovak).

VOZÁROVÁ, A. & VOZÁR, J. 1992b: Tornaicum and Meliaticum in borehole Brusník, BRU-1, Southern Slovakia. Acta Hungarica, Vol. 35/2, Budapest, 97-116.

VOZÁROVÁ, A. & VOZÁR, J. 1993: Pre-Alpine terranes in Western Carpathians: reconstruction of colision and post-colision stage of Variscan orogene. In: Geodynamický vývoj a hlbinná stavba Západ. Karpát. Eds.: M. RAKÚS and J. VOZÁR, Bratislava, 129-143 (in Slovak).

VOZÁROVÁ, A. & VOZÁR, J. 1996: Terranes of West Carpathians - North Pannonian Domain. Slovak Geol. Mag., 1/96, D. Š. Publ., Bratislava, 61-83.

SLOVAK GEOLOGICAL MAGAZINE

# Upper Triassic - Lower Jurassic sediments of the Lučatín Unit in the Northern Veporicum: facial diversity and tectonic stacking

JÁN SOTÁK[1] & DUŠAN PLAŠIENKA[2]

[1] Geological Institute, Slovak Academy of Sciences, Severná 5, 974 01 Banská Bystrica, Slovakia
[2] Geological Institute, Slovak Academy od Sciences, Dúbravská cesta 9, 842 26 Bratislava, Slovakia

*Abstract* . The Lučatín unit is a transitional tectonic element between the Krížna nappe and the Veporic superunit, analogous to the Veľký Bok unit. It consists of three partial nappe subunits differing in structural positions and lithofacial characteristics of especially the Lower Jurassic syn-rift sediments. The lowermost subunit crops out only in small tectonic windows and it facially closely approaches the Zliechov basinal succession of the Krížna nappe, the structurally highest subunit is confined to the North Veporic basement. The paper concentrates on the middle, Farbište subunit, with peculiar Upper Triassic - Lower Jurassic strata. Middle to Upper Liassic variegated limestones point to the deposition in an elevated and dissected domain rapidly subsiding during the Middle and Late Jurassic. Several facies uncommon in the Western Carpathians (Rhaetian reefal Jakub Limestones, lowermost Dogger Neptunian dykes filled up with Bositra Limestones) indicate "southern" affinities of the Lučatín shelf.

*Key words:* Central Western Carpathians, Lučatín unit, Upper Triassic, Lower Jurassic, facial diversity, partial nappes

## Introduction

The Lučatín Unit has been defined by Maheľ (in MAHEĽ et al., 1967) as a marginal rear element of the Krížna nappe, analogous to the Veľký Bok Unit of the Nízke Tatry Mts. Similarly as the Veľký Bok Unit in the Liptovská Teplička district (PLAŠIENKA, 1995), the Lučatín Unit is composed of several superimposed, flat-lying partial nappes or recumbent folds, the higher ones clearly confined to the pre-Alpine crystalline basement of the Northern Veporicum.

Three subunits form the structure of the Lučatín Unit between Poniky, Slovenská Ľupča and Ľubietová villages (PLAŠIENKA,1981,1983).The lowermost Driekyňa subunit (or the basal structure sensu MAHEĽ, 1977), has a deep-water development of Jurassic formations and it is characterised by slight metamorphic imprint. The higher, Farbište subunit, has a complete stratigraphic succession from the Lower Triassic to the Lower Cretaceous, with the most remarkable Upper Liassic and Lower Dogger variegated limestone formation (for a detailed lithofacial characterisation and description of Ammonite fauna see MIŠÍK, 1962, 1964; MIŠÍK & RAKÚS, 1964; RAKÚS, 1964). The uppermost Hutná subunit is formed of Middle and Upper Triassic dolomite complexes, strongly reduced Jurassic members and a thick Neocomian marly limestone formation. Some complementary data on stratigraphy and lithofacial content of the Lučatín Unit have been provided by the study of new boreholes realised in the area of the Driekyňa Valley and Farbište Hill. Continuous borehole profiles (up to 100 m) have been obtained especially from the Upper Triassic-Jurassic formations of the Farbište subunit. The knowledge achieved indicates substantial facial variety and contrasts of the Lower Jurassic sedimentation, both within the Farbište subunit itself, and especially between individual partial nappes of the Lučatín Unit.

## Lithostratigraphy of the Upper Triassic - Lower Jurassic formations of the Farbište subunit

### *Carpathian Keuper Formation*

The Carpathian Keuper Formation consists of grey massive or brecciated dolomites, with intercalations of brick-red, violet and greenish marlstones (Fig. 1). In some boreholes, the variegated marlstones ("bunte Keuper-Mergel") are predominant. The transition of Keuper into the overlying Rhaetian beds is usually sharp, locally however with repeated appearance of dolomite beds in sediments of the Fatra Formation. The thickness of the Keuper Formation reaches 50-100 m in boreholes.

### *Fatra Formation*

Rhaetian sediments are in the Farbište subunit represented mostly by the Fatra Formation displaying a cyclic character. The base of each cycle is formed of co-

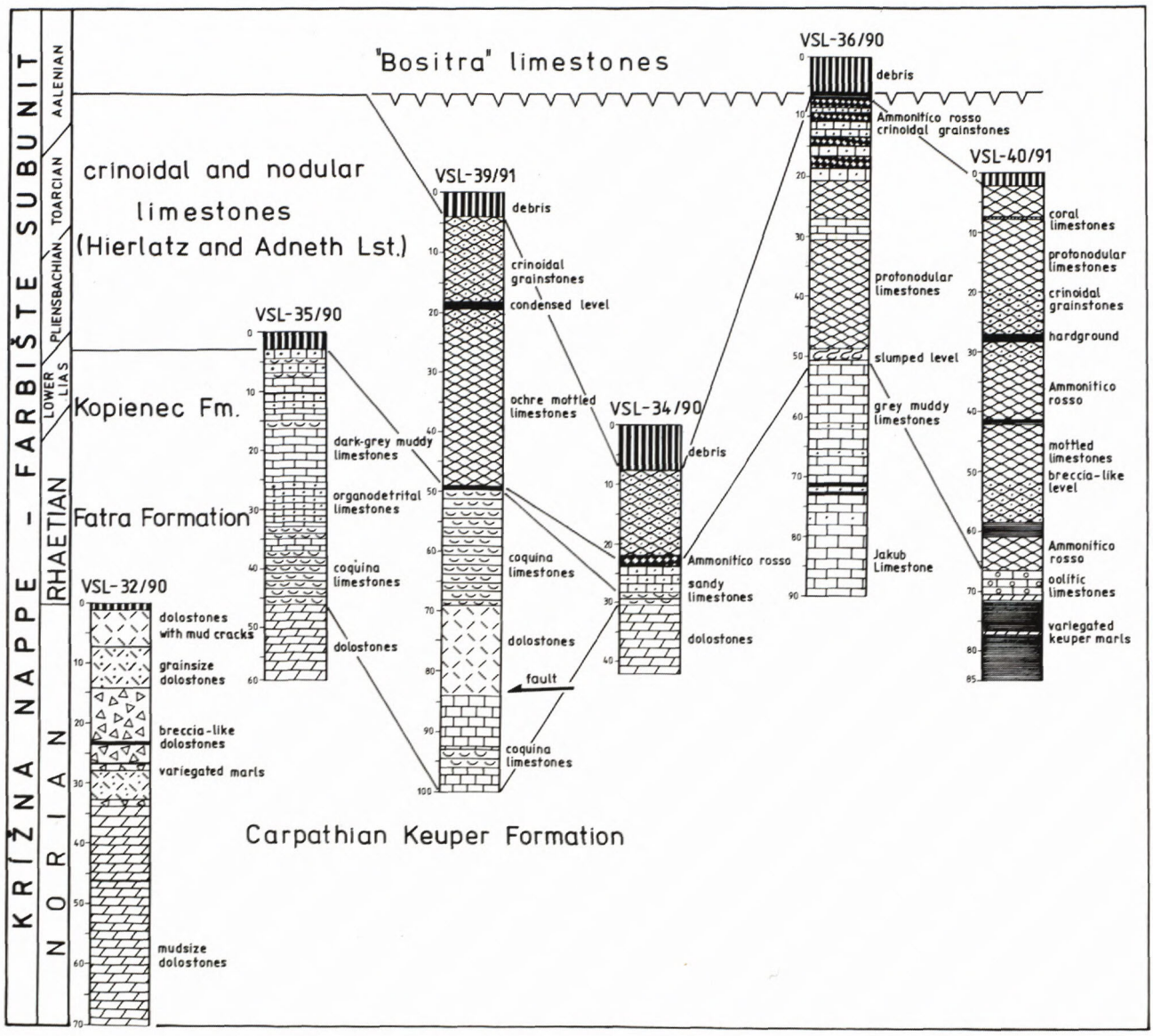



*Fig. 1. Lithostratigraphic sequence and spatial diversity of the Upper Triassic - Lower Jurassic sediments of the Farbište subunit, constructed from the field and borehole profiles.*

quina limestones with *Rhaetavicula contorta* and the grain size decreases upwards. The interphases of cycles consist of biodetritic and oolitic limestones and the muddy cycles end with ooze or marly limestones (Fig. 1). Limestones of the Fatra Formation contain abundant bivalvians, brachiopods, crinoids and corals (also in the form of patch reefs). Microfauna is represented by forams *Agathammina inconstans* (MICHALÍK, JENDREJÁKOVÁ & BORZA), zoospores *Globochaete tatrica* RADWANSKI, fragments of thallophytic algae etc.

### *Jakub Limestone*

The Jakub Limestones appear in the uppermost parts of the Fatra Formation below sandy limestones of the Kopienec Formation (Fig. 1). They occur only locally, probably in places of paleotopographic elevations with reef buildups. They are grey massive limestones with cavities filled with layered-fibrous calcite. Microstructurally, the biomicritic matrix contains numerous sparitised foraminifer tests of *Aulotortus sinuosus* WEYNSCHENK, *Angulodiscus communis* KRISTAN *Gandinella falsofriedli* ZANINETTI, dating the Jakub Limestones as Rhaetian.

### *Kopienec Formation*

The basal part of the Liassic sequence of the Farbište subunit is represented by the Kopienec Formation de-

tritic sediments, Hettangian to Sinemurian in age. Lithologically they are very similar to the Fatra Formation, however they contain a greater proportion of sandy and marly material and less coquina layers. In the borehole profiles, we recorded also intervals of "Gresten-type" black shales. Coeval shallow-water carbonate sedimentation in the Driekyňa Valley is represented by so-called cyanophyte limestones (MIŠÍK, 1964).

### *Crinoidal and nodular limestone formation*

The detrital-carbonate sediments of the Kopienec Formation are followed by varied sedimentation of crinoid and nodular limestones in the Farbište Unit. They are characterised by considerable lateral changes of thickness, from thin, strongly condensed layers to thick intervals with manifestation of slope accumulation (up to 60 m - Fig. 1). Their lithofacies vary from red nodular limestones with residual clay of the "Ammonitico rosso" type, indistinctly nodular and mottled limestones of ochre, beige and pink colour with abundant stylolites, as well as pseudobreccia limestones. The nodular facies alternates in the borehole profiles with layers of violet-red and grey crinoidal limestones (Fig. 1). Lithological variability is documented also by the presence of coral-bearing layers, ferrolitic crusts (hardgrounds), limestones with Fe-ooids and allochems of "black pebbles" type etc. Microfacies of nodular limestones is characterised especially by echinoderm segments, filaments, zoospores of *Globochaete*, segments of ophiurians and thick-walled forams of the genus Involutina (*I. liassica* JONES and *I. farinacciae* BRONNIMANN & KOEHN-ZANNETTI). In layers of stronger condensation, tests of nodosarian foraminifers concentrate in a great quantity (representatives of *Dentalina, Nodosaria, Marginulina, Falsopalmula* etc.). In variegated limestones, there are often cavities with isopachous and pseudospar calcite fillings. The texture and isotopic composition ($\delta^{18}O$: 1.9 - 3.1 ‰, $\delta^{13}C$: -2.3 to 3.3 ‰) documents the marine character of the cavity cement. Varied nodular and crinoidal limestones contain also rich ammonite fauna, represented mostly by the Domerian species *Partschiceras* cf. *monestieri*, *Calliphyloceras nilsoni*, *Juraphyllites limatus* and others (RAKÚS, 1964, 1989; MIŠÍK & RAKÚS, 1964).

### *Bositra Limestones*

The varied Liassic limestones are immediately overlain by the light Bositra Limestones in the Driekyňa Valley (Fait's quarry). Their position in the succession is not quite clear, however. They may be a normal sequence member, but they may also represent fillings of Neptunian dykes penetrating the Liassic substratum. Limestones are actually coquinas of the bivalvian shells *Bositra buchi* (ROEMER). The limestones are very pure, washed and recrystallised. Observed in thin-sections, their biodetritic texture is overprinted by strong sparitisation - only outer periostracum layers have been mostly preserved from the shells.

Bositra coquinas from the Driekyňa Valley remind of bivalvian necrocenoses concentrating dead shells washed down into open fissures in the sea bottom ("Efekt postmortaler Verfrachtung", "trap for fossils"). Therefore, it is possible to accept the dyke character of these limestones, at least partly. The described Bositra Limestones represent Lower Dogger member of the Farbište subunit (Aalenian - Bajocian), overlain by basinal violet-red laminated siliceous and marly limestones.

### *Upper Jurassic formations of the Farbište Unit*

During the Late Jurassic, grey platy cherty limestones, siliceous and marly limestones and red radiolarites were deposited. Uppermost Jurassic and Lower Cretaceous are represented by red, grey and green marly slates and thick complex of grey calcareous phyllites.

### *Structural pattern of the Lučatín Unit*

The Driekyňa subunit, as the lowermost one within the Lučatín stack, crops out only in one larger and one small tectonic window in the upper part of the Mokrá Driekyňa valley (Fig. 2). It is built up of a deep-water Jurassic to Lower Cretaceous succession, slightly metamorphosed and intensively folded. Dark grey marly slates with scarce turbiditic beds of sandy crinoidal limestones represent probably the Lower to Middle Jurassic Allgäu formation, overlain by the Upper Jurassic black-brown siliceous limestones and silicites and Lower Cretaceous grey-green marly slates. We parallelize the Driekyňa succession with the Fatric (Krížna) Zliechov-type units. The Neocomian marlstones of the Driekyňa subunit are overridden by the Scythian quartzose clastics and middle Triassic Ramsau dolostones of the higher Farbište subunit (Fig. 2). Thin lenses of clastic Lunz beds intercalate the upper part of the dolomite complex, being overlain by a considerably thick sequence of varicoloured dolomites, shales and sandstones of the Carpathian Keuper Formation. Fossiliferous Rhaetian Fatra Formation and the lowermost Liassic clastic Kopienec Formation underlie the Middle to Upper Liassic massive limestone body containing various lithologies close to the Hierlatz and Adnet facies, the main subject of the present study. Middle to Upper Jurassic variegated marly and cherty limestones and red radiolarites are overlain by Neocomian grey marly shales. The Farbište subunit is strongly folded in a macroscopic scale (Fig. 2), recognizable from the spatial distribution of the competent layer of Liassic limestones embedded amidst incompetent shally and marly sequences. The first macrofold set is formed by two northward-facing recumbent anticlines (Fig. 2) with cores filled with soft Keuper rocks detached

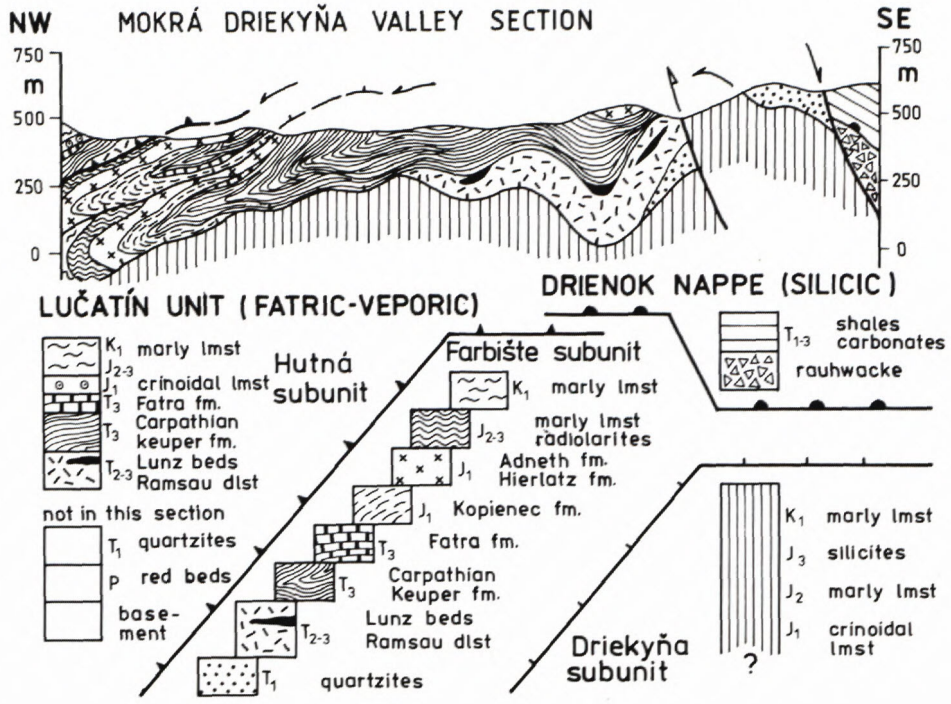



*Fig. 2. Geological profile of the Lučatín Unit along the Mokrá Driekyňa valley, east of Poniky village.*

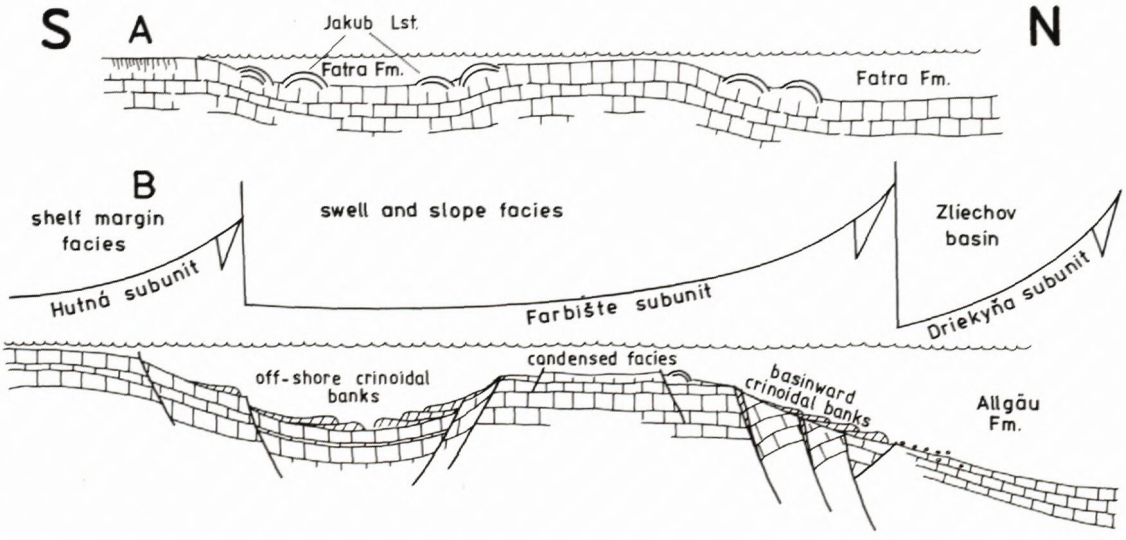



*Fig. 3: Late Triassic - Early Jurassic paleogeography of different sedimentary areas of the Lučatín unit. A - Upper Triassic carbonate platform, B - post-collapse configuration of the North Veporic slope facing the Zliechov basin with suggested original positions of the Lučatín subunits.*

from their Ramsau dolomite substratum. Recumbent folds are refolded by two perpendicular sets (SW-NE and NW-SE trending) of symmetrical open upright macrofolds, giving rise to a very complex structure of the Farbište subunit in the map view. The highermost Hutná subunit is rimming the Farbište half-window, composed of complete Permian to Lower Cretaceous succesion confined to the pre-Alpine basement of the north Veporic Ľubietová Zone. Unlike the Farbište subunit, the Hutná succession includes only a very thin, mostly marly Jurassic sequence and considerably thick Neocomian marlstones.

*Paleogeography and tectonic stacking of the Lučatín Unit*

The Lučatín Unit of the Northern Veporicum is characterised especially by a varied development of Liassic sedimentation, starting after the collapse of the Triassic carbonate platform. This variety documents the substantial topographic differentiation of a shelf domain at the transition from the Veporic margin into the Zliechov Basin. The considerable contrast in Liassic formations is thus manifested among the partial nappes of the Lučatín Unit, ranging from the shelf margin (Hutná subunit), foot of the shelf slope (Farbište subunit) and the basinal plain (Driekyňa subunit - Fig. 3). The Lučatín Unit, as a vertically differentiated system of nappe subunits, formed in the rear part of the Krížna thrust stack before its final emplacement as a cover nappe overriding the Tatricum (PLAŠIENKA, 1983). The subunits originated by inversion of original marginal extensional halfgrabens formed due to the Lower Jurassic rifting event (Fig. 3). Their transformation into recumbent macrofold structures included domino-type rotation of halfgraben blocks and progressive contraction, macroscopic folding and flattening of their partly detached sedimentary successions (PLAŠIENKA & PROKEŠOVÁ , 1996).

*Acknowledgements*

The paper conributes to the research project "Geodynamic evolution of the Western Carpathians" and to the Academic grant project No. 1081. The Geological Survey of the Slovak Republic and the Scientific Grant Agency are thanked for the financial support.

## References

MAHEĽ, M., 1977: Niektoré závažnejšie otázky stavby kryštalinika a mezozoika tatríd a veporíd. Miner. Slov., 9, 1, 1 - 9.

MAHEĽ, M., BUDAY, T. et al., 1967: Regional geology of Czechoslovakia. Part II - The West Carpathians. Academia, Praha, 723 p.

MIŠÍK, M., 1962: Litofaciálny výskum liasu Veľkej Fatry v západnej časti Nízkych Tatier. Geol. Práce, Zoš. 62, Bratislava, 229 - 232. (In Slovak).

MIŠÍK, M., 1964: Lithofazielle Studien im Lias der Grossen Fatra und im westlichen Teil der Niederen Tatra. Západné Karpaty 1, Geol. Úst. D. Štúra, Bratislava, 8 - 88.

MIŠÍK, M. & RAKÚS, M., 1964: Bemerkungen zu räumlichen Beziehungen des Lias und zur Paläogeographie des Mesozoikum in der Grossen Fatra. Západné Karpaty 1, Geol. Úst. D. Štúra, Bratislava, 159 - 185.

PLAŠIENKA, D. 1981: Tectonic position of some metamorphosed Mesozoic series of the Veporicum. Thesis, Geol. Inst. Slov. Acad. Sci., Bratislava, 153 p.

PLAŠIENKA, D., 1983: Kinematic assessment of some structures of the Northern Veporic in relation to the generation of the Krížna nappe (in Slovak, English summary). Mineralia Slov., 15, 217 - 231.

PLAŠIENKA, D., 1995: Cleavage and folds in changing tectonic regimes: The Veľký Bok Mesozoic cover unit of the Veporicum (Nízke Tatry Mts., Central Western Carpathians). Slov. Geol. Mag., 2/95, 97 - 113.

PLAŠIENKA, D. & PROKEŠOVÁ , R., 1996: Towards an evolutionary tectonic model of the Krížna cover nappe (Central Western Carpathians). Slov. Geol. Mag., this volume.

RAKÚS, M., 1964: Paleontologische Studien im Lias der Grossen Fatra und Westteil der Niederen Tatra. Západné Karpaty 1, Geol. Úst. D. Štúra, Bratislava, 95 - 154.

RAKÚS, M., 1989: Paleobiografia amonitov pliensbachu Západných Karpát. In. MICHALÍK, M. & SAMUEL, O. (eds.) : Zborník z paleontologickej konferencie - Súčasné problémy a trendy v československej paleontológii. Geol. Úst. D. Štúra, Bratislava, 111-116. (In Slovak, Engl. res.).

SLOVAK GEOLOGICAL MAGAZINE

# Towards an evolutionary tectonic model of the Krížna cover nappe (Western Carpathians, Slovakia)

DUŠAN PLAŠIENKA[1] AND ROBERTA PROKEŠOVÁ[2]

[1]Geological Institute, Slovak Academy of Sciences, Dúbravská 9, 842 26 Bratislava, Slovakia
[2]Faculty of Science, Matej Bel University, Tajovského 40, 974 01 Banská Bystrica, Slovakia

*Abstract.* The Krížna nappe, belonging to the Fatric system, is an areally extensive, but relatively thin allochthonous sheet composed of Mesozoic sediments detached from a disappeared substratum and overthrusting the Tatric basement and cover units. The principal Zliechov unit was formed at the expense of a wide basinal area floored by continental crust strongly stretched and thinned during Early Jurassic rifting. In Mid-Cretaceous times, the Zliechov basin was progressively shortened through underthrusting of its basement and tegument complexes below the Veporic thrust wedge. The sedimentary filling was detached along the horizon of Upper Scythian shales and evaporites and formed an initial fold-and-thrust stack prograding outwards. After the complete elimination of the Zliechov basin substratum, its southern Tatric and northern Veporic margins came into collision and the Krížna stack was pushed over the frontal southern Tatric ramp, from which the frontal Fatric elements with slope and ridge-related sedimentary successions were torn off. Finally, in the Late Turonian, the Fatric nappe elements gravitationally glided northwards in a diverticulation manner from the southern Tatric elevation over the unconstrained basinal northern Tatric areas.

*Key words*: Central Western Carpathians, Krížna cover nappe, paleotectonic evolution, emplacement mechanisms

## Introduction

The Krížna nappe group, or "stem nappe" (MAHEĽ, 1983), redefined as Fatricum consisting of the Vysoká and Krížna principal nappes by ANDRUSOV et al. (1973), is a tectonic unit representative of the Central Western Carpathians (CWC). It overlies various Tatric cover units and it is overlain by another important group of cover nappes - the Choč and higher nappes (the Hronic and Silicic systems). The Krížna nappe is a relatively thin (1-3 km), but widespread (more than 12,000 km$^2$ - JACKO & SASVÁRI, 1990) overthrust sheet composed of Lower Triassic to mid-Cretaceous sediments of diverse, although mostly carbonatic lithologies. They were sheared off their mostly disappeared original basement and tegument along décollement horizons of Werfenian and Keuper shales and evaporites to form a far-reaching allochthonous body. The nappe consists of numerous dismembered slices, recumbent folds and imbricates, but sections with relatively undisturbed stratigraphic successions are present as well. The CWC nappe system is assumed to be a lateral continuation of the Austroalpine system of the Eastern Alps. Both were primarily shortened during the Cretaceous paleo-Alpine (eo-Alpine) orogenic contraction.

As it appears today, the Krížna unit is a complex overthrust sheet exposed from its "roots" in the rear part (Veľký Bok unit related to the north Veporic basement wedge), positioned between the Tatric and Veporic basement thick-skinned sheets, through a wide central allochthonous body resting on the Tatric substratum, up to frontal subunits with a complicated structure in the Periklippen zone. The Krížna nappe is a uniquely preserved early Alpidic, thin-skinned overthrust body for which hardly any analogue can be found in the European Alpides (MAHEĽ, 1983). Therefore, a relevant tectonic reconstruction of the generation and final emplacement of the Krížna nappe might provide a world-wide applicable model for the development of extensive superficial nappe sheets.

From the lithostratigraphical point of view, the Krížna nappe is generally subdivided into the Vysoká and Zliechov-type units. The Vysoká units contain shallow-water Jurassic successions similar to the Tatric (High Tatra-type successions), while the Zliechov is an antagonistic, deep-water Jurassic-Cretaceous succession. In central Slovakia, both units form independent nappe bodies, the Vysoká-type forming slices or duplexes (Belá, Ďurčiná, Havran) at the sole of the huge Zliechov nappe. At the western (Malé Karpaty Mts.) and eastern (Branisko and Humenské vrchy Mts.) termination of the CWC the Vysoká type becomes to be the main constituent of the Fatricum and the Zliechov type gradually wedges out.

There are several crucial problems in the interpretation of the frontal parts of the Krížna nappe. Some

authors (e.g. MAHEĽ, 1978, 1983, 1986 etc; MICHALÍK et al., 1987) consider the important Manín unit of the Periklippen belt (the zone between the northern edge of the Tatricum and the Pieniny Klippen belt itself) as a partial, Vysoká-related unit of the Krížna nappe group because of the resemblance or even correspodence of its Jurassic-Lower Cretaceous sequence to the Vysoká type, while the majority of other authors (e.g. ANDRUSOV, 1968; RAKÚS, 1977; MARSCHALKO, 1986; SALAJ, 1994a, b, 1995) stress the continuation of the Middle to Upper Cretaceous succession and they place the Manín unit paleogeographically north of the Tatricum. If the Manín unit is really a constituent of the Krížna nappe group, one cannot exclude that also some other Periklippen units, such as the Drietoma, Bošáca, Kostelec and even the Klape unit, presumably their pre-Upper Turonian formations, also belong to the Krížna system (PLAŠIENKA, 1995a).

The southern extension of the Krížna nappe is limited by the northern edge of Veporicum, an important crustal-scale sheet of the Central Western Carpathians. No wonder that the boundary fault of the Tatricum and Veporicum - the Čertovica line - has been considered for decades the suture, the "root zone" of the Krížna nappe (e.g. BIELY & FUSÁN, 1967). The sedimentary cover of the northern Veporic basement, the Veľký Bok unit, displays some similarity to the Krížna (Zliechov) type of successions, although its southernmost zones show clear shallowing of their Jurassic formations (PLAŠIENKA, 1983, 1995b; SOTÁK and PLAŠIENKA, 1996).

Lithostratigraphy, structural position and tectonic prominence of the Krížna unit were treated by numerous authors, e.g. ANDRUSOV (1968), JAROŠ (1965,1969, 1971, 1980), VOZÁR (1965) MAHEĽ (1983, 1986), or BIELY (1978, 1989). The emplacement mechanism of the Krížna nappe was discussed by BIELY and FUSÁN (1967), MAHEĽ (1983), JACKO & SASVÁRI (1990) and JAROSZEWSKI (1982). A more detailed paleotectonic scenario of the generation of the Krížna unit was reconstructed by JAROŠ (1971), PLAŠIENKA (1983, 1987, 1991, 1995a), PLAŠIENKA et al. (1989), and HÄUSLER et al. (1993), based on the interpretation of sedimentary-lithostratigraphic, metamorphic and structural rock records especially in the rear part of the nappe (Veľký Bok unit). However, the central and frontal nappe parts have only scarcely been subjects of thorough structural studies, with the exception of important papers by BAC (1971), BUJNOVSKÝ (1979), BAC-MOSZASZWILI et al. (1981), JAROSZEWSKI (1982), BUJNOVSKÝ & LUKÁČIK (1985), HÓK et al. (1994) and PROKEŠOVÁ (1994).

This contribution deals with the most important geometrical, mechanical and temporal signatures of the Krížna nappe formation and outlines the main aspects of its evolutionary tectonic model. Interpretative assumptions presented here outline a strictly tentative working hypothesis which will be tested by several independent analytical procedures during further research.

## Main points of the tectonic model

For the elaboration of an updated tectonic model of the Krížna nappe, all the available and relevant information which can be read from the rock record has to be taken into account. This includes analyses of the material (lithostratigraphic, sedimentologic, volcanic, metamorphic) and structural records, as well as paleogeographic assumptions. As the extent of the present paper is limited, all the extensive dataset sources will not be quoted here and readers are recommended to the review articles by ANDRUSOV (1968), ANDRUSOV et al. (1973), BIELY & FUSÁN (1967), BIELY (1978, 1989), JAROŠ (1971, 1980), MAHEĽ (1982, 1983, 1986), PLAŠIENKA (1983, 1991, 1995a, b, c), PLAŠIENKA et al. (1989), HÄUSLER et al. (1983) and to the references cited therein. In the next paragraphs, only the most important (from the authors' viewpoint) aspects of the structure and evolution of the Krížna nappe system will be stressed.

### *Paleogeographic setting*

The original homeland of the Fatric (Krížna s.l.) units was a basinal area (Zliechov basin) some 100 km wide, flanked by elevated domains from its subaequatorial sides (in the present coordinates): the Tatra swell, or South Tatric ridge in the north with the adjacent, dissected shelf margin originally occupied by the Vysoká and Manín-type units, and the North Veporic (Veľký Bok - Lučatín) continental margin in the south. The basin was floored by a thinned, strongly stretched continental crust. Westward lateral wedging out of the Zliechov unit points to a lozenge-shaped basin formed by transtensional movements during Jurassic rifting. The along-strike length of the basin was at least 250 km.

### *Pre-contractional paleotectonic evolution*

The Zliechov basin was formed by Early Jurassic rifting and distension of the European crust composed of the deeply denuded crystalline basement of inner Variscan zones and its Permotriassic continental and shelf carbonate platform sedimentary cover generally approaching developments of the Germanic basin. After the Upper Jurassic period of thermal subsidence, renewed rifting events are recorded, especially in the Barremian and Aptian. Lithospheric-scale extension is revealed by extrusions of basanitic lavas, followed by mid-Cretaceous shortening period heralded by Aptian olistostromes and then by coarsening-upward Albocenomanian siliciclastic flysch.

### *Mechanical stratigraphy*

Most of the sedimentary infill of the Zliechov basin has been detached from its substratum along the horizon

of Upper Scythian shales and evaporites. The underlying Permoscythian clastic sequence, the tegument, remained attached to the pre-Alpine crystalline basement and both were largely underthrust during shortening of the Fatric area. The complete detached Zliechov succession, originally some 3 to 4 km thick, is composed of:

– slices of Upper Scythian (Werfenian) shales at the nappe sole;
– huge competent complex of Middle to lower Upper Triassic carbonates (mostly Gutenstein and Ramsau formations), up to 1,000 m thick, intercalated by thin Lunz beds in the upper part;
– weak Upper Triassic (Norian) Carpathian Keuper formation of variegated shales, sandstones and evaporitic dolomites and gypsum, with variable thickness up to 300 m;
– Rhaetian fossiliferous Kössen (Fatra) formation;
– Lower Liassic shales and sandy limestones of the Kopienec fm.;
– variable complex of Middle and Upper Liassic biodetritic and sandy limestones, sandstones, spotted (Allgäu) and nodular (Adnet) limestones, marlstones etc. of rapidly changing thicknesses (syn-rift strata), relatively competent;
– thick-bedded Allgäu limestone-marlstone formation (basinal syn-rift) with the thickness reaching several hundreds of metres in some sections;
– well-bedded Upper Jurassic radiolarites, siliceous, nodular and biancône-type limestones form a comparatively weak, easily foldable (but not décollement) complex some 50-200 m thick;7
– Lower Cretaceous marlstones and marly limestones attain thicknesses in excess of 1,000 m (probably not primary), it is an incompetent sequence often partly detached from its underlier;
– the uppermost Albocenomanian flysch sequence (Poruba fm.) is usually detached, even not present in large areas of the dorsal and inner nappe parts; since it was deposited immediately before and during thrusting, sediments were probably still not lithified, but water-saturated, hence mechanically very weak.

This generalized mechanostratigraphy includes three most important potential decoupling layers. The lower one occurs within the Werfenian formation, the middle in the Carpathian Keuper formation, and the upper at the base of unconsolidated mid-Cretaceous flysch sequence. Corresponding décollement horizons are present also in the Manín and Vysoká-type successions, though these are generally stronger due to prevalence of massive or thick-bedded limestone bodies. In the direction of the translation path, the importance of higher detachments increases. From the rheological point of view, the Fatric successions may be regarded as a multilayer, with downward increasing competence and upward increasing ability of folding and decoupling.

## *Crustal shortening processes*

The contraction of the Fatric realm prograded in mid-Cretaceous times from the south to the north (in present coordinates). The southern flanks of the Zliechov basin were inverted to form an orogenic wedge with a set of superimposed large-scale recumbent folds and partial nappe units at its toe. The cover (Veľký Bok and Lučatín units) was only partly stripped off the northern Veporic basement and each partial subunit contains a lithostratigraphic succession differing to some extent from the neighbouring subunit (Fig. 1, see also SOTÁK & PLAŠIENKA, 1996). This feature can be attributed to the pre-existing depositional diversities in individual fault-bounded marginal halfgrabens. Special geometrical characteristics of recumbent folds (intact overturned limbs, but sheared-off normal upper limbs) would imply development of folds by horizontal-axis rotation, tightening and distributed non-coaxial shearing of halfgraben blocks at the tip of compressional wedge (Fig. 2).

Most of the Zliechov basin substratum (basement and its tegument) disappeared by underthrusting beneath the northern Veporic thrust wedge. However, a part of this substratum was detached to form a thin-skinned imbricated duplex thrust over the southern Tatric basement and cover (Staré hory Mts. - JAROŠ, 1971; Rázdiel block of the Tríbeč Mts. - HÓK et al., 1994; VOZÁROVÁ & VOZÁR 1988). The roof thrust transported the whole Zliechov succession further towards the foreland. It might be speculated that this basement duplex represents upper crustal slivers torn off the southern Zliechov basin floor in front of the developing northern Veporic basement wedge (Fig. 2).

## *Detachment of sedimentary successions*

The above-described décollement horizons represent rheologically predisposed layers of high strain rates enabling differential movements of inserted stronger rock units. At the incipient stage of the cover detachment, the lower "Werfenian" décollement was operating. In the course of underthrusting of the Zliechov basin substratum, the detached sedimentary complexes created an imbricated fold-and-thrust belt and the upper two detachments became active during ramp-flat thrusting.

The Vysoká and Manín-type units, located originally at the Tatric-Fatric transitional basinal slope dissected by basinward dipping normal faults (Fig. 2), were detached in two ways: (1) more commonly along the middle "Keuper" décollement; (2) some partial nappes (e.g. Belá) involve also basal slices of substratum (basement and tegument), these are probably torn off edges of tilted extensional blocks truncated by footwall-shortcuts during inversion and ramping in front of the Zliechov stack.

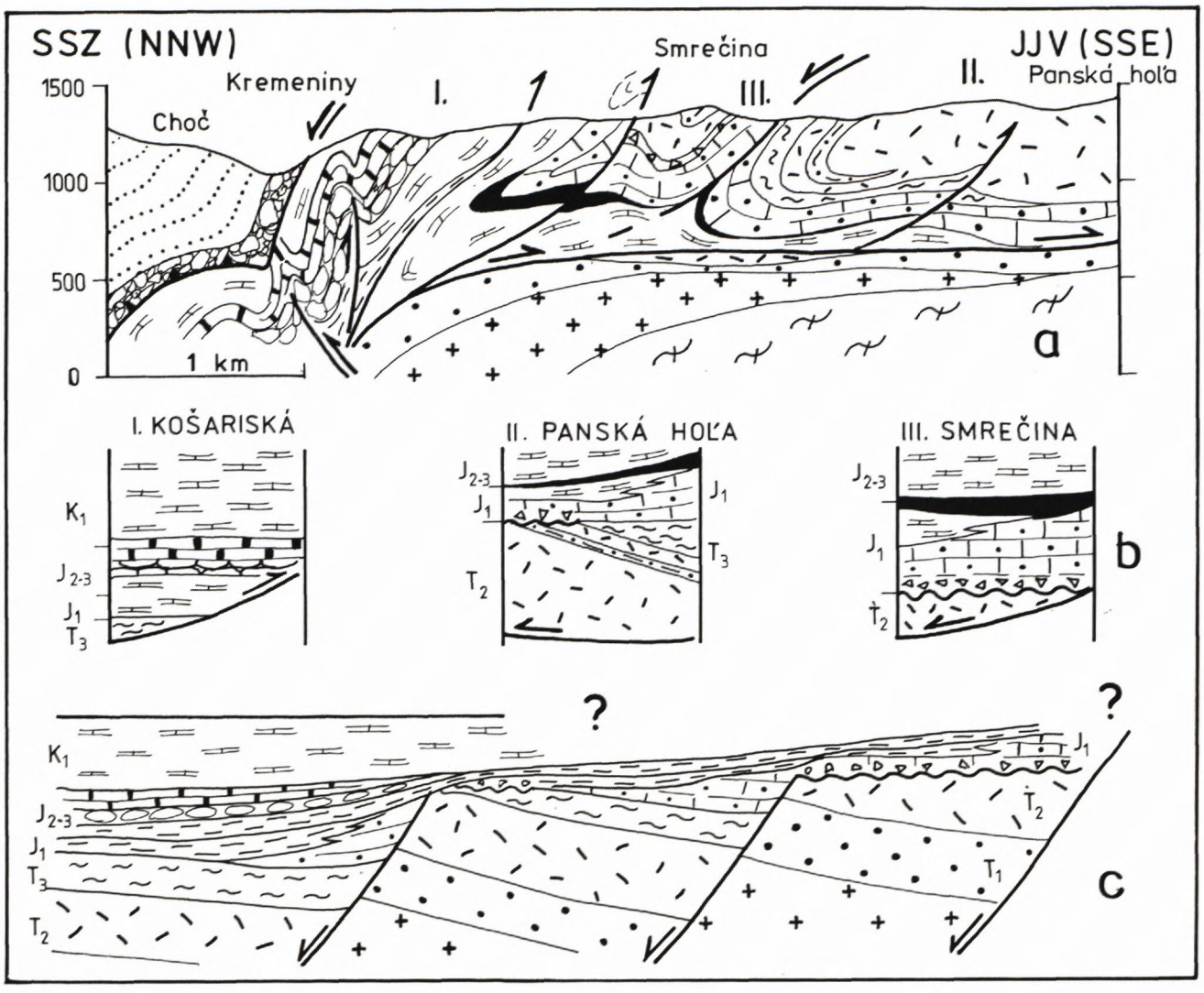



*Fig. 1 Structure and lithology of the Veľký Bok unit on northern slopes of the Nízke Tatry Mts. (cf. PLAŠIENKA 1995b)*
*a- tectonic profile with three principal subunits; b - Košariská subunit (I.) approaches basinal Zliechov succession, the Panská hoľa (II.) and Smrečina (III.) subunits represent faulted basin flanks with thick Lower Jurassic syn-rift deposits and deep erosion of the original position of the Triassic substratum; c - tentative reconstruction of the original position of the Veľký Bok subunits based on structural and lithostratigraphic signatures. $J_{2-3}$-$K_1$ post-rift deposits.*

## Structural evolution

The conspicuous structural record, especially in the rear part of the Krížna system (Veľký Bok and related units), has been studied by few authors (cf. PLAŠIENKA, 1983, 1995b and references therein). Numerous small-scale structures have been grouped into several deformation stages (PLAŠIENKA, l.c.), the first two being intimately related to the generation and emplacement of the Krížna unit. The AD1 stage records thrust stacking, the AD2 additional collisional shortening of a weak suture zone between the Tatric and Veporic crustal sheets, after the principal body of the Krížna nappe was expulsed and translated northwards.

At the passage from the rear to the central parts of the Krížna nappe body, the AD1-2 structural associations are overprinted by flat-lying extensional structures (PROKEŠOVÁ, 1994). The dorsal nappe elements exhibit mostly layer-parallel extensional structures superimposed on scarcely preserved older compressional ones, the whole nappe body is thinned and stripped off its uppermost mid-Cretaceous flysch complexes.

The frontal nappe parts show complicated structure with often pervasive mesoscale fold structures especially in the higher, well-bedded formations. The lower structural complex (Middle Triassic carbonates) is often doubled, forming at least two superimposed recumbent or northward-plunging "digitations" (MAHEĽ, 1983). However,

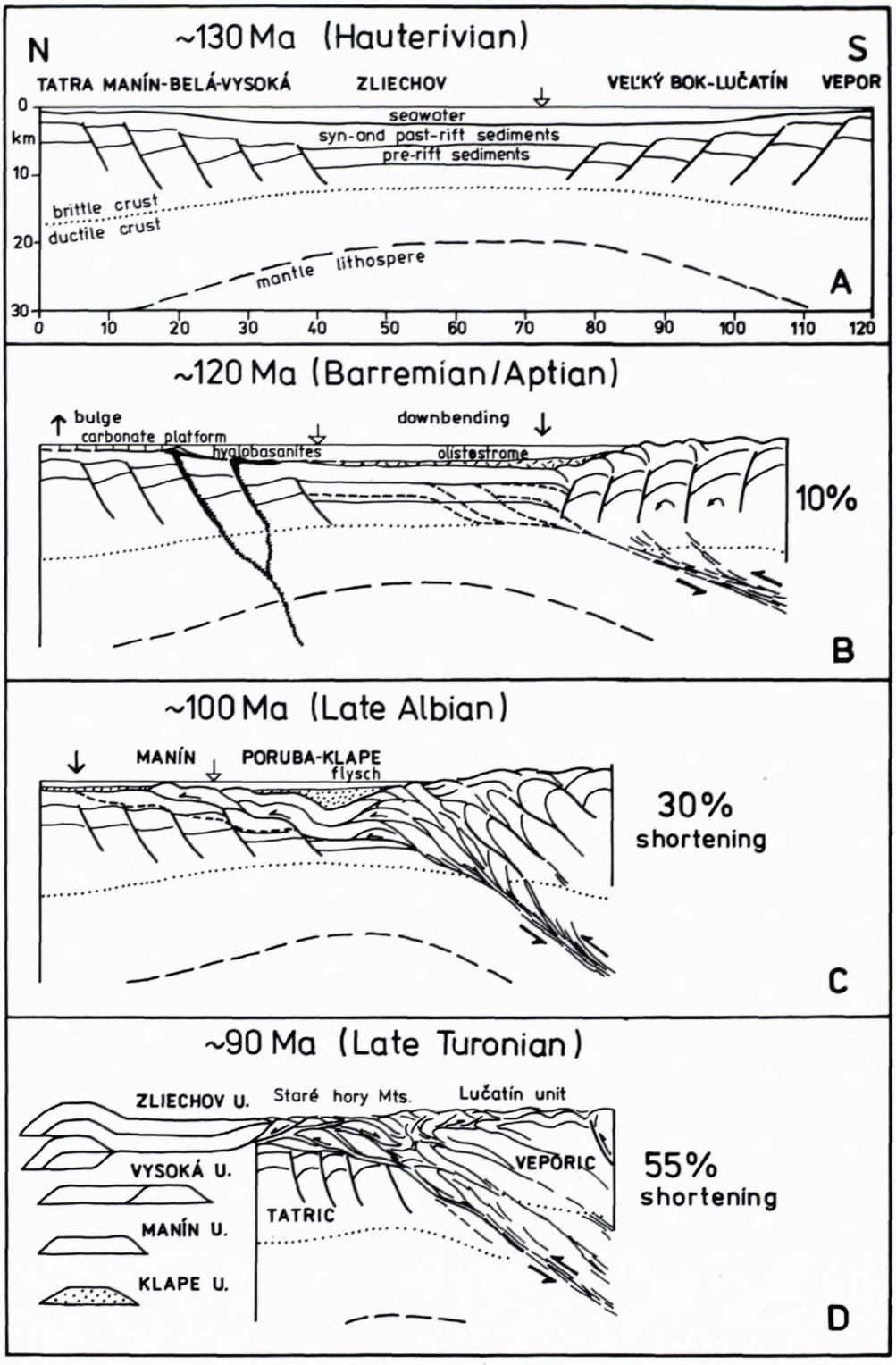



*Fig. 2. Paleotectonic scenario of the Krížna nappe origin. A - general pre-compression architecture of the Fatric realm with principal isopic zones. B - incipient shortening of the Fatric-Veporic margin. C - stacking of detached units of the Zliechov basin, piggy-back flysch sedimentation. D - elimination of the Zliechov trough, collision of the Tatric and Veporic crustal superunits, foreland-ward diverticulation gliding of individual Fatric units (Krížna nappe s.l.).*

according to preliminary structural observations, these digitations are in fact original thrust imbrications formed during the initial shortening of the Zliechov basin. They were passively transported towards the nappe fronts, suffering only flattening and some additional forelandward gliding of the upper subunit with respect to the lower one to form false synclines.

The emplacement-related structures in the frontal Fatric units are strongly overprinted by younger transpressional deformation and are hardly recognizable without a careful analysis. Nevertheless, the AD1 thrusting-related structural record is still preserved, e.g. in the Manín unit.

### *Final emplacement mechanisms*

Where the Krížna nappe is in a clear allochthonous position above the Tatric units, structures at the nappe base provide an insight into the ways of its final emplacement. There is one aspect of the mechanical paradox often mentioned in connection with large-scale superficial décollement cover nappes that their overthrusts apparently have not considerably affected the structures of the substratum (e.g. BAC-MOSZASZWILI et al., 1981; JAROSZEWSKI, 1982). Unlike other famous thrust and nappe systems (e.g. Helvetic), there are no signs of ductile straining within the Krížna nappe or its substratum which might be ascribed to the overthrust event. On the contrary, only brittle crushing and cataclastic flow within a narrow layer at the nappe sole can be observed. This horizon is formed by carbonate tectonic breccias, often rauhwackized. Brecciation should have been triggered by high pore-fluid pressure during thrusting (JAROSZEWSKI, 1982; PLAŠIENKA & SOTÁK, 1996) to reduce friction within the brittle shear zone loaded by the whole nappe. Overpressured sole permitted more-or-less free, most probably gravity-driven nappe gliding towards the foreland. The necessary topographic downslope (however moderate required) was produced by the compressional uplift of the rear nappe parts, thereby accompanied by pushing up the Krížna stack over the south Tatric margin as a frontal ramp. Afterwards, individual Fatric units glided gravitationally in a "diverticulation" manner to spread over the unconstrained, basinal Tatric foreland (PLAŠIENKA, 1995c). The frontal and uppermost units (Klape, Manín, Vysoká) had the potential for the farthest translation.

There is a remarkable relationship between the character of the discrete nappe sole and lithology of the underlying Tatric cover. If the substratum is composed of mid-Cretaceous flysch sediments, the layer of rauhwackized carbonate breccia often occurs at the nappe sole. This signature has been tentatively explained by PLAŠIENKA & SOTÁK (1996) as an indication of a subaqueous overthrusting, when the nappe overrode in large areas unconsolidated, water-saturated flysch sediments. Tectonic load and aquathermal pressuring caused devolatization of substratum sediments and produced continuously excess fluid pressures in a contact horizon, possibly up to lithostatic values, thereby enabling almost free nappe movement. However, where the overpressured layer superposed the lithified substratum, the water influx ceased and fluids were released from the nappe sole. The brecciated layer was sometimes entirely dissolved together with some wall rocks (mostly underlying) to form a "macrostytolitic" discrete Tatric-Krížna contact (JAROSZEWSKI, 1982) of apparently non-tectonic origin. This inevitably led to the inhibition of any further movement along this rugged contact, consequently a new thrust plane had to be formed, or the movement relocated to some of the higher décollement horizons. These features are typical for the inner central nappe parts, above the South Tatric ridge, which at least partly emerged in the course of thrusting due to internal shortening (relief nappe - BUJNOVSKÝ, 1979).

Summing up, the Krížna nappe should have been finally translated gravitationally along an extremely weak overpressured cataclastic breccia horizon supporting the nappe weight and allowing frictionless gliding. The weak sole accomodated most of or all thrusting-related shear stresses, therefore mostly extensional structures accompanied the final emplacement event: brittle fracturing and veining, meso- to macroscale boudinage of competent units, or reactivation of décollement horizons.

### *Post-emplacement deformation*

Immediately after its emplacement onto the Tatric substratum (for the temporal considerations about the nappe thrusing events see PLAŠIENKA, 1996), the Krížna unit had to be overridden by the higher Hronic superficial cover nappe system (the Choč and related nappes). Similarly as the Fatric vs. Tatric, also the Hronic vs. Fatric is of apparently non-tectonic nature, being formed by (often even missing) rauhwackized tectonic breccias again (cf. PLAŠIENKA & SOTÁK, 1996). Obviously, the final emplacement of the Hronic nappes had comparable characteristics to that of the Fatric nappes.

A variety of deformation features postdating the final nappe emplacement event is frequent especially in the frontal parts of the Fatric system, which is incorpoarted into a broad wrench corridor in the Periklippen zone active in the Tertiary. Superimposed structures are not always unambiguously distinguishable from the thrusting-related, therefore a thorough structural analysis has to be applied in this area.

## Aspects of the geodynamic model

After a relevant tectonic model of the Krížna nappe origin is elaborated, a comprehensive lithospheric-scale

geodynamic model should be the next step. It has to include physical evaluation of extensional and contractional processes, first of all isostatic and thermal modelling, rheological considerations and reconstruction of driving forces of operative processes. The whole-Carpathian context should be taken into consideration.

## Conclusions

The above outlined aspects impose significant constraints to any viable tectonic model of the Krížna nappe origin. Though our data base is not complete and straightforward, a lot of indications points to:

* the Krížna nappe was formed at the expense of a wide basinal domain floored by attenuated continental crust, which was mostly underthrust below the hinterland orogenic wedge (Veporicum);
* the sedimentary filling of this basin was detached along the Upper Scythian décollement horizon to form an initial fold-and-thrust complex;
* after the elimination of the basin substratum, the detached imbricated sedimentary complex was pushed over the frontal ramp (Fatric-Tatric basin flanks) and the basal marginal Vysoká and Manín-type imbrications were sheared off this ramp;
* the Krížna nappe was finally emplaced by the gravity gliding mechanism from the topographic elevation towards unconstrained foreland basinal domains, where it spread out to create a thin blanket covering the Tatric units.

*Acknowledgements*

The paper conributes to the research project "Geodynamic evolution of the Western Carpathians" and to the Academic grant project No. 1081. The Geological Survey of the Slovak Republic and the Scientific Grant Agency are thanked for the financial support.

## References

ANDRUSOV D., 1968: Grundriss der Tektonik der nördlichen Karpaten. Verlag Slov. Akad. Wissensch., Bratislava, 188 p.

ANDRUSOV D., BYSTRICKÝ J. & FUSÁN O. 1973: Outline of the structure of the West Carpathians. Guide book, X Congress CBGA, Geol. Úst. D. Štúra, Bratislava, 44 p.

BAC M., 1971: Tectonics of the Bobrovec unit in the Western Tatra Mts. (in Polish, English summary). Acta Geol. Pol., 21, 279–317.

BAC-MOSZASZWILI M., GAMKRELIDZE I.P., JAROSZEWSKI W., SCHROEDER E., STOJANOV S. S. & TZANKOV TZ. V., 1981: Thrust zone of the Krížna nappe at Stoly in the Tatra Mts. (Poland). Stud. Geol. Pol., 68, 61–73.

BIELY A., 1978: Problem of location of the Krížna nappe sedimentation area in the light of new knowledge on the structure of the eastern part of the Nízke Tatry and Slovenské rudohorie Mts. (in Slovak, English summary). In J. VOZÁR (ed.): Paleogeographical evolution of the West Carpathians. Conf., Symp., Sem., D. Štúr Inst. Geol., Bratislava, 221–231.

BIELY A., 1989: The geological structure of the West Carpathians. In M. RAKÚS, J. DERCOURT & A. E. M. NAIRN (eds.): Evolution of the northern margin of Tethys, Vol. II. Mém. Soc. Géol. France, Nouvelle Série No. 154 (II), Paris, p. 51–57.

BIELY A. & Fusán O., 1967: Zum Problem der Wurzelzonen der subtatrischen Decken. Geol. Práce, Zprávy, 42, 51–64.

BUJNOVSKÝ A., 1979: Geological profiles and structural elements of nappes in the NW part of the Low Tatra Mts. and Revúca fault zone (in Slovak, English summary). In M. MAHEĽ (ed.): Tectonic profiles through the West Carpathains. Konferencie, Sympóziá, Semináre, Geol. Úst. D. Štúra, Bratislava, 85–97.

BUJNOVSKÝ A. & LUKÁČIK E., 1985: Geology of NW parts of Nízke Tatry Mts. and adjacent part of Veľká Fatra Mts. (in Slovak, English summary). Západ. Karpaty, Geol., 10, 39–65.

HÄUSLER H., PLAŠIENKA D. & POLÁK M., 1993: Comparison of Mesozoic successions in the Central Eastern Alps and the Central Western Carpathians. Jahrb. Geol. B-A, 136, 715–739.

HÓK J., IVANIČKA J. & KOVÁČIK M., 1994: Geological structure of the Rázdiel part of the Tríbeč Mts.: new knowledge and discussion (Western Carpathians; in Slovak, English summary). Miner. slov., 26, 192–196.

JACKO S. & SASVÁRI T., 1990: Some remarks to an emplacement mechanism of the West Carpathian paleo-Alpine nappes. Geol. Zbor. Geol. carpath., 41, 179–197.

JAROSZEWSKI W., 1982: Hydrotectonic phenomena at the base of the Krížna nappe, Tatra Mts. In M. MAHEĽ (ed.): Alpine structural elements: Carpathian-Balkan-Caucasus-Pamir orogene zone. Veda, Bratislava, 137–148.

JAROŠ, J., 1965: Über den tektonischen Charakter der Krížna-Einheit in der Umgebung von Banská Bystrica (in Czech, German summary). Geol. práce, Zprávy 35, 41-52.

JAROŠ J., 1969: Setting of the root zone of the Krížna nappe in the West Carpathians. Čas. Miner. Geol., 14, 141–149.

JAROŠ J., 1971: Tectonic styles of the homelands of superficial nappes. Rozpr. Čs. Akad. Věd, Ř. Mat. Přír. Věd, 81, 6, 1–59.

JAROŠ J., 1980: Tectonic styles, ophiolites and Paleoalpine subduction: implications for palinspastic reconstructions of the West Carpathians. Geol. Zbor. Geol. carpath., 31, 441–449.

MAHEĽ M., 1978: Manín tectonic unit: relations of the Klippen Belt and Central West Carpathians. Geol. Zbor. Geol. carpath., 29, 197–213.

MAHEĽ M., 1983: Krížna nappe, example of polyfacial and polystructural unit (in Slovak, English summary). Miner. slov., 15, 193–216.

MAHEĽ M., 1986: Geological structure of Czechoslovak Carpathians: Paleoalpine units (in Slovak). Veda Publ., Bratislava, 503 p.

MARSCHALKO R., 1986: Evolution and geotectonic significance of the Klippen Belt Cretaceous flysch in the Carpathian megastructure (in Slovak, English summary). Veda Publ., Bratislava, 139 p.

MICHALÍK J., BORZA K. & VAŠÍČEK J., 1987: Lithological, biofacial and geochemical characterization of the Lower

Cretaceous pelagic carbonate sequence of Mt. Butkov (Manín Unit, West Carpathians). Geol. Zbor. Geol. carpath., 38, 323–348.

PLAŠIENKA D., 1981: Tectonic position of some metamorphosed Mesozoic series of the Veporicum (in Slovak). Unpublished thesis, Geol. Inst. Slov. Acad. Sci., Bratislava, 153 p.

PLAŠIENKA D., 1983: Kinematic assessment of some structures of the Northern Veporic in relation to the generation of the Krížna nappe (in Slovak, English summary). Miner. slov., 15, 217–231.

PLAŠIENKA D., 1987: Paleoalpine dynamics of the North Veporic thrust wedge. Abstr. Int. Conf. "Structural development of the Carpathian-Balkan orogenic belt", Bratislava, 117–118.

PLAŠIENKA D., 1991: Mesozoic tectonic evolution of the epi-Variscan continental crust of the Western Carpathians - a tentative model. Miner. slov., 23, 447–457.

PLAŠIENKA D., 1995a: Mesozoic evolution of Tatric units in the Malé Karpaty and Považský Inovec Mts.: Implications for the position of the Klape and related units in western Slovakia. Geol. carpath., 46, 101–112.

PLAŠIENKA D., 1995b: Cleavages and folds in changing tectonic regimes: the Veľký Bok Mesozoic cover unit of the Veporicum (Nízke Tatry Mts., Central Western Carpathians). Slov. Geol. Mag., 2/95, 97–113.

PLAŠIENKA D., 1995c: Passive and active margin history of the northern Tatricum (Western Carpathians, Slovakia). Geol. Rundschau, 84, 748–760.

PLAŠIENKA D., 1996: Mid-Cretaceous (120-80 Ma) orogenic processes in the Central Western Carpathians: brief review and interpretation of data. Slovak Geol. Mag., this volume.

PLAŠIENKA D. & SOTÁK J., 1996: Rauhwackized carbonate tectonic breccias in the West Carpathian nappe edifice: introductory remarks and preliminary results. Slovak Geol. Mag., this volume.

PLAŠIENKA D., JANÁK M., HACURA A. & VRBATOVIČ P., 1989: First illite-crystallinity data from Alpine metamorphosed rocks of the Veporicum, Central West Carpathians. Miner. slov., 21, 43–51.

PROKEŠOVÁ R., 1994: Structural analysis of the Krížna nappe in its near-root and superficial position (in Slovak, English summary). Miner. slov., 26, 347–254.

RAKÚS M., 1977: Supplements to the Jurassic and Cretaceous lithostratigraphy and paleogeography of the Manín series in the middle Váh valley (in Slovak, English abstract). Geol. Práce, Spr., 68, 21–38.

SALAJ J., 1994a: Geology of Middle Váh valley. Klippen and Periklippen belt, Súľov Paleogene and Mesozoics of northern part of Strážovské vrchy hills - part 1 (in Slovak, English summary). Zem. Plyn Nafta, 39, 195–291.

SALAJ J., 1994b: Geology of Middle Váh valley. Klippen and Periklippen belt, Súľov Paleogene and Mesozoics of northern part of Strážovské vrchy hills - part 2 (in Slovak, English summary). Zem. Plyn Nafta, 39, 297–395.

SALAJ J., 1995: Geology of Middle Váh valley. Klippen and Periklippen belt, Súľov Paleogene and Mesozoics of northern part of Strážovské vrchy hills - part 3 (in Slovak, English summary). Zem. Plyn Nafta, 40, 3–51.

SOTÁK J. & PLAŠIENKA D., 1996: Upper Triassic - Lower Jurassic sediments of the Lučatín unit in the Northern Veporicum: facial diversity and tectonic stacking. Slovak Geol. Mag., this volume.

VOZÁR J., 1965: Metamorphietes Mesozoikum im westlichen Teile der Veporiden (in Slovak, German Summary). Geol. práce, Zprávy 35, 33-40.

VOZÁROVÁ A. & VOZÁR J., 1988: Late Paleozoic in West Carpathians. GÚDŠ, Bratislava, 314 p.

SLOVAK GEOLOGICAL MAGAZINE

# Rauhwackized carbonate tectonic breccias in the West Carpathian nappe edifice: introductory remarks and preliminary results

DUŠAN PLAŠIENKA[1] & JÁN SOTÁK[2]

[1]Geological Institute of the Slovak Academy of Sciences, Dúbravská 9, 842 26 Bratislava, Slovakia
[2]Geological Institute of the Slovak Academy of Sciences, Severná 5, 974 01 Banská Bystrica, Slovakia

*Abstract.* Based on the provenance of diagnostic clasts, four types of rauhwackized carbonate tectonic breccias occuring at the West Carpathian cover nappe soles are distinguished and characterized. Four types are combinations of two most distinctive signatures of the clast provenances: their derivation from either the nearby juxtaposed carbonate complexes (intraclasts) or the distant sources (extraclasts), and from either the hangingwall or footwall units. Some consequences for the thrusting mechanisms, e.g. subaqueous vs. subaerial, are also discussed.

*Key words:* Central Western Carpathians, cover nappe soles, carbonate tectonic breccias, emplacement mechanisms

## Introduction

Carbonate tectonic breccias are penetratively (in the meso-scale) brittlely deformed original sedimentary carbonates (limestones and dolostones). Carbonate tectonic breccias are formed through fracturing and crushing with dominant role of percolating solutions under intricate fluid regimes by multiple pressure solution, chemical alteration, recrystallization and precipitation processes. They are influenced also by subrecent recalcification, chemical alterations, leaching, weathering with concentration of Fe-hydroxides causing the typical ochre colour and karstification. The end members of these processes are rocks designated by German terms "Rauhwacke" or "Zellendolomit" (e.g. CORNELIUS, 1927; MÜLLER, 1982; LEINE, 1971), French "cornieules" or "cargneules" (e.g. MASSON, 1972; WARRAK, 1974; JEANBOURQUIN, 1988), and Italian "calcare cavernoso" (MASI & TUCCI, 1993; CARTER et al., 1994).

In the international structural geological literature, the problematics of carbonate tectonites has been widely discussed during the last two decades, forced by the introduction of new methodical procedures. In the case of study of rauhwackes, the classical petrographic observations in thin sections (e.g. LEINE, 1971; MASSON, 1972; WARRAK, 1974; MÜLLER, 1982; JEANBOURQUIN, 1988) have been improved by studies of cathodoluminiscence, fluid inclusions and stable isotopes (RYE & BRADBURY, 1988; BURKHARD & KERRICH, 1988; AMIEUX & JEANBOURQUIN, 1989; CARTER ET AL., 1992; MASI & TUCCI, 1993; CROS et al., 1996, etc.). These works have clearly shown that rauhwackes may provide important information about the rheological, pressure and fluid regimes operating during their formation, and even the age constraints of their emplacement event can be defined.

In the Western Carpathian literature, only short notes about rauhwackes can be found in papers by MIŠÍK (1972), PLAŠIENKA (1981), and JAROSZEWSKI (1982), who emphasized the extraordinary importance of the fluid-driven deformation processes in thrust terrains. The role of fluids in the emplacement mechanisms of the Carpathian cover nappes was discussed also by JACKO and SASVÁRI (1990).

The present paper aims at tectonic systematization of rauhwackized carbonate tectonic breccias and at the formulation of a working hypothesis of their origin and significance for the nappe tectonics. This hypothesis should serve as a basis for the choice of the most appropriate research methods and analytical procedures which might provide new information about the genesis of these so important, but often disregarded rocks.

## Rauhwackes confined to stratigraphic successions

Rauhwackes are usually considered to be rocks formed from carbonate (mainly dolostone, less limestone) and associated sulphate (gypsum or anhydrite), and possibly also halite precursors. The extreme competence contrast and strain rate differences between these two rock types result in brittle brecciation of dolomitic and ductile flow of sulphate rocks even at temperatures below 100° C (MÜLLER, 1982; SCHMID, 1982). Moreover, the volume changes during the gypsum to anhydrite and vice-versa transformations contribute significantly to the brecciation of the accompanying carbonate rocks, enhanced also by hydraulic fracturing ini-

tiated by fluid overpressure in the system trapped in non-permeable wall rocks (shales). These rauhwackes may be termed dilation (collapse and/or expansion) breccias. Layer-parallel shearing along weak evaporitic horizons accelerated the development of rauhwackes. In spite of the content of various rock fragments (carbonates, shales), these always represent only the local intraformation or wall sediments. Both monomict and polymict rauhwackes in the sense of LEINE (1971) are present.

Evaporitic dolomite- and gypsum-bearing sedimentary sequences are commonly present amidst Permoscythian or Norian (Keuper) red beds of several Western Carpathian units. Rauhwackes often occur on peripheries of sulphate bodies and, if sulphate is completely dissolved, they resemble breccia layers of originally sedimentary origin (e.g. MAHEĽ & BIELY, 1956 - regression breccias). We have investigated intrastratal dilation breccias in the Carpathian Keuper formation of the Krížna nappe at the locality Rybô in the Veľká Fatra Mts. and in the Permoscythian evaporites from the borehole VŠDL-18, Špania Dolina.

## Rauhwackized tectonic breccias

Since gypsum- and/or anhydrite-bearing rocks concentrate deformation due to high strain rates, evaporitic formations often serve as décollement horizons. Large-scale décollements result in generation of allochthonous units with soles commonly composed of rauhwackized carbonate breccias, the witnesses of former evaporites. Thrust planes, as zones of high shear stresses, evidently need a weak "lubricant" layer to accomodate most of the shearing strain during overthrusting. Evaporites and rauhwackes, especially overpressured, are ideal rocks for such a role. In the Western Carpathians, evaporite-containing décollement layers occur in the Upper Permian red-bed sequences (Silicic nappes), Upper Scythian variegated shales (Hronic and Fatric nappes) and Upper Triassic Keuper formation (Fatric units). Nevertheless, some nappes are floored by carbonate tectonic breccias which obviously were formed at the expense of footwall or hangingwall non-evaporitic carbonate complexes (though they can include originally evaporitic matrix as well), and they even contain "exotic" fragments derived from rock complexes currently not present in the nearby structure.

Based on the composition and provenance of the rock fragments in the nappe-sole rauhwackes, their tentative classification from the tectonic point of view is presented (Tab. 1, Fig. 1). The four types distinguished are not ultimately defined, and transitional varieties commonly occur in the field. Nevertheless, the presence of some diagnostic clasts might, in our opinion, contribute to the tectonic interpretation of their origin and of the affiliation, transport direction and mechanisms of the overlying nappe unit.

The type **1A** contains dominantly intraclasts from the juxtaposed hangingwall complexes, mostly carbonates. They usually form the nappe bases, especially where the nappe sole lacks non-carbonatic complexes. In the Western Carpathians, these are mainly frontal parts of Fatric and Hronic nappes (not floored by Permoscythian clastic formations), or overthrust planes of internal partial nappes. Evaporites often played a negligible role in the formation of the 1A-type rauhwackes. Moreover, we have sometimes observed original unaltered carbonate cataclastic breccias at bases of the Choč nappe (Majerova skala hill, Veľká Fatra Mts.) and the Fatric Bujačí subunit (Belianske Tatry Mts.). These are monomict dolocataclasites to mylonites showing indistinct semiductile flow foliation and lineation with dolostone porphyroclasts rimmed by pressure shadows. They were formed by brittle crushing and grain-size reduction up to rupturing of individual crystals to form a "pseudomicrite". Other 1A-type rauhwackes are ordinary cavernous calcitic rocks (boxwork-rauhwacke) with dedolomitized and leached original dolostone clasts.

All rauhwacke types described were fundamentally formed by brittle fragmentation of carbonate precursors, their possible mixing with highly mobile sulphates (usually calcitized or leached later - WARRAK, 1974), chemical alterations by percolating fluids, possibly overpressured (hydraulic fracturing - MASSON, 1972) and by late dissolution. High pore-fluid pressure might have led to "hydrotectonic" phenomena (JAROSZEWSKI, 1982), such as complete dissolution of the carbonate breccia bodies in the course of thrusting resulting in a "macrostylolite" contact (Fig. 1) between carbonates of the autochthonous Tatric substratum and allochthonous Krížna nappe (Tatra Mts. - JAROSZEWSKI, 1982).

The **1B** rauhwackes contain distinctive extraclasts obviously not derived from the actually juxtaposed footwall and hangingwall complexes (though these can be present as well). Based on their compositions, the provenance of some unaltered clasts may be inferred. In the case of the sole of the Hronic Choč nappe on northern slopes of the Nízke Tatry Mts., the rauhwackized carbonate breccias are wedged between the underlying low-grade metamorphosed Neocomian marlstones of the north Veporic-Fatric Veľký Bok unit and the overlying, unmetamorphosed Upper Paleozoic clastic formations of the Hronic Ipoltica group (Fig. 1). However, the prevalence of carbonate clasts is formed by unmetamorphosed Triassic dolostones and limestones, which otherwise occur in a much more higher structural position above the up to several thousands of metres thick Ipoltica group. This fact may be tentatively explained in two ways: (1) rauhwackized breccias represent the lower sheared-off limb of the Choč fold-nappe, or tectonically reduced and brecciated lower Hronic partial unit; (2)

Tab. 1 An attempt to the tectonic classification of carbonate crush breccias and rauhwackes occuring at the West Carpathian cover nappe soles, based on the composition and inferred provenance of the most distinctive rock fragments. Examples are depicted in Fig. 1.

| TYPE | INFERRED PROVENANCE OF DIAGNOSTIC CLASTS IN TECTONIC BRECCIAS | EXAMPLES |
|---|---|---|
| 1A | internal hangingwall-derived rocks fragments from the immediately overlying complexes (mostly carbonates) | soles of the Krížna and Choč nappes (without Ipoltica) |
| 1B | external hangingwall-derived rocks fragments from distant complexes of the nappe unit (mostly carbonates) | sole of the Choč nappe with the Ipoltica group |
| 2A | internal footwall-derived rocks fragments of the immediate substratum (mostly metacarbonates) | soles of the Muráň and Drienok nappes |
| 2B | external footwall-derived rocks "exotic" fragments or slices of metamorphic and ophiolitic complexes | soles of the Stratená and Silica nappes |

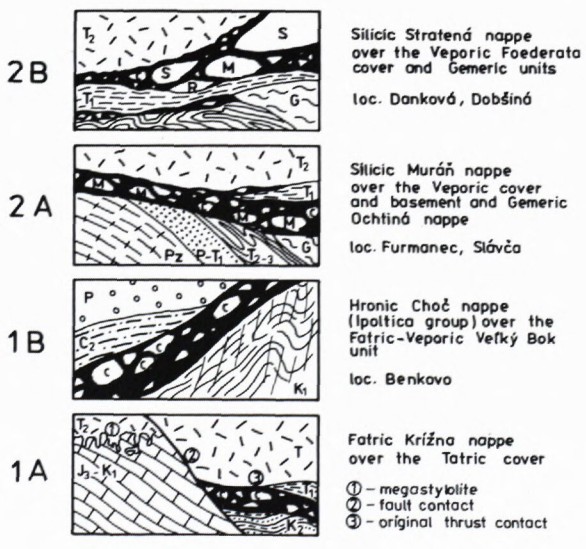



*Fig. 1. Schematic position of rauhwackized, dominantly carbonate tectonic breccias at soles of the Carpathian superficial nappes. Not to scale. G – Gemeric units. Important fragments in rauhwackes: C – unmetamorphosed carbonates (hangingwall-derived), M – metamorphosed carbonates (footwall-derived), S – serpentinite, R – radiolarite. Note a considerable structural discordance at the rauhwacke vs. substratum contact in the upper three examples.*

breccias are of tectono-sedimentary origin - formed from the carbonate erosional debris of the overthrust allochthonous sheet deposited in its advancing front, later overridden by the lowermost nappe parts and crushed and altered as other carbonate tectonic breccias. At the time being, we prefer the second possibility, as the first one does not correspond to the overall structure of the Hronic nappe system.

The **2A** type carbonate breccias have been observed at the base of the Silicic Muráň nappe. They contain various clasts, among them fragments of their immediate substratum - the strongly metamorphosed and ductilely strained Middle and Upper Triassic limestones, and scarcely also Lower Triassic quartzites, of the footwall Veporic Foederata cover unit. In addition to these, clasts of Scythian shales, Triassic unmetamorphosed carbonates, dark metamorphic slates of unknown provenance and other rocks occur as well. PLAŠIENKA (1981) reported also clasts of speleothems. MILOVSKÝ (1996) found authigenic potassium feldspars in the matrix of rauhwackes. The genesis of 2A rauhwackes was, at the starting phase of their development, probably connected with basal truncation and disintegration of footwall carbonate rocks, which possibly built up a subaerial rugged karstified relief in the time of thrusting of Silicic nappes.

Another type of 2A rocks are rauhwackized carbonate breccias occuring below the Drienok nappe. They have been recently interpreted as Upper Cretaceous to Paleocene sedimentary breccias, later overridden by the south-vergent Drienok nappe (SLAVKAY & ROHÁLOVÁ, 1993). However, they exhibit features typical for other rauhwackized carbonate tectonites and belong probably to our 2A type, being dominantly composed of clasts of the underlying Triassic carbonates of the Choč unit and, less frequently, of slightly metamorphosed rocks of the Lučatín (Veľký Bok) unit from its deeper substratum. Hangingwall-derived clasts are also occurring. These breccias might have had sedimentary precursors deposited in karstic depressions and later mixed with tectonically originated material. Such karst rauhwackes were described by JEANBOURQUIN (1988).

The last, **2B** type rauhwacke is distinctive due to occurences of rock fragments derived from "exotic" units, currently not present either in footwall or hangingwall complexes. However, based on regional assumptions, they are inferred to come from distant footwall units. Clasts and blocks of ophiolites, predominantly serpentinites, less frequently marbles and radiolarites, are of special interest. They are chaotically distributed in a rauhwacke matrix. 2B-type rocks approach some characteristics of ophiolite mélanges. In the case of being incorporated into evaporitic matrix, they have been termed "salinar mélange" by KOZUR (1991). These rocks occur at soles of higher Juvavic nappes in the Northern Calcareous Alps ("Haselgebirge") and at soles of the Silicic Stratená (cf. JAROŠ et al., 1981) and Silica-Aggtelek

nappes (Perkupa formation). Ophiolitic rocks, especially highly mobile serpentinites, were incorporated into basal carbonate-sulphate nappe tectonites probably during the translation of Silicic nappes across or along an ophiolitic suture in their substratum.

## Discussion and conclusion

The above outlined characteristic features and distribution of the Western Carpathian rauhwackes confined to the overthrust planes of far-reaching superficial cover nappes indicate that the types distinguished can be attributed to the individual nappe systems or their parts. The types 1A, involving preferably hangingwall-derived intraclasts, are most frequent in frontal parts of the Fatric and Hronic nappes and at bases of their internal subunits. However, they are often completely dissolved to form a large-scale stylolitic contact of apparently non-tectonic origin. This indicates high activity of interstitial fluids bound to the breccia bodies and their more-or-less free possibility to release in the course of thrusting. In spite of its escape, the fluid influx seems not to have been limited. It might be speculated that continuous fluid supply was fed by compactional dewatering of the underlying Tatric and/or Fatric mid-Cretaceous flysch sediments deposited immediately before being loaded by the overriding nappes. This would indicate a subaqueous character of the nappe emplacement. Stable isotope studies should either confirm or deny this assumption.

The 1B rauhwackes with hangingwall-derived extraclasts have been found below the Choč nappe floored by the Ipoltica group. Their probable tectono-sedimentary origin has been already mentioned, but not yet confirmed by direct lithological observations. There is a well pronounced structural and metamorphic discordance between the rauhwacke and the underlying Veľký Bok metasedimentary complexes. In the case studied in the Nízke Tatry Mts., this discordance is expressed by the lack of three penetrative deformation stages within the Hronic complexes, which are recorded in the Veľký Bok rocks, and by the skip in estimated PT conditions of deformation in the order of some 5 to 10 km of missing rock column removed from the footwall autochthonous units (cf. PLAŠIENKA, 1995). A conclusion may be drawn that the rear (Veľký Bok) parts of the Krížna unit were already exposed to subaerial erosion and denudation in times when its frontal nappe elements glided subaqueously, on condition that a simultaneous emplacement event of the Hronic nappe system in both areas is assumed (about the time constraints of thrusting events see PLAŠIENKA, 1996). In contrast to 1A tectonites, the overpressured fluids were trapped within the breccia layer bounded by impermeable complexes. Overpressured rauhwacke "pillows" then could reduce vertical stresses and support the weight of the overlying nappe, which facilitated its "smooth" emplacement without any considerable affect on the basement structures.

The 2A-type rauhwackes differ from the previous types by extensive disintegration of the footwall carbonate complexes and their incorporation into the basal nappe crush breccias. The structural-metamorphic discordance at the Muráň nappe sole is even exceeding that of the case of 1B-type contact, indicated by more than 15 km of missing original footwall tectonic overburden (cf. PLAŠIENKA, 1996). We can only hypothesize that the Muráň relief nappe invaded a deeply denuded area with rugged karstic morphology developed in Triassic carbonates of the Veporic Foederata cover unit, which was flattened by basal "rabotage" and dissolution during thrusting.

The 2B-type, ophiolite-bearing breccias, are the least known, though probably most significant tectonites occuring at the Western Carpathian superficial nappe soles. Ophiolitic fragments were obviously derived from the footwall units in time when the Silicic nappes moved over an oceanic suture. They were involved within the mobile basal breccias and then transported above distant paleogeographic domains. Nonetheless, this does not necessarily mean that the allochthonous sheet (the Silica and Stratená nappes in the discussed example) had to be palinspastically located on the other side of the suture (i.e. south of the Meliatic suture in our case, cf. HÓK et al., 1995). It might have followed a curved translation path and ophiolitic clasts might have come not directly from the narrow suture, but from an ophiolitic or mélange nappe in a high structural position, which was later destroyed by erosion. However, paleogeographic considerations are beyond the scope of this paper.

In conclusion, we emphasize that study of clasts included in basal thrust breccia tectonites may provide important information concerning their origin, and about emplacement mechanisms and translation paths of the overlying allochthonous sheets. From our observations we can infer differences in thrusting mechanisms between frontal and rear parts of the Fatric and especially Hronic nappes, being induced most probably by the subaqueous vs. subaerial position of the substratum during thrusting, respectively. The extensive incorporation of substratum units into thrusting processes of the Silicic nappe system suggests these to be typical relief nappes differing from the previous ones not only by the mechanism, but possibly also the time of their final emplacement (PLAŠIENKA, 1996).

*Acknowledgements*

The paper conributes to the research project "Geodynamic evolution of the Western Carpathians" and to the Academic grant project No. 1 3052 96. The Geological Survey of the Slovak Republic and the Scientific Grant Agency are thanked for the financial support.

## References


AMIEUX P. & JEANBOURQUIN P., 1989: Cathodoluminiscence et origine diagénétique tardive des cargneules du massif des Aiguilles Rouges (Valais, Suisse). Bull. Soc. Géol. France, 160, 123–132.

BURKHARD M. & KERRICH R., 1988: Fluid regimes in the deformation of the Helvetic nappes, Switzerland, as inferred from stable isotope data. Contrib. Mineral. Petrol., 99, 416–429.

CARTER K.E., DWORKIN S.I., CARMIGNANI L., MECCHERI M. & FANTOZZI P., 1994: Dating thrust events using 87Sr/86Sr: an example from the Northern Apennines, Italy. Jour. Geol., 102, 297–305.

CORNELIUS H. P., 1927: Über tektonische Breccien, tektonische Rauhwacken und verwandte Erscheinungen. Cbl. Mineral. Geol. Paläont., Abt. B, 120–130.

CROS P., ARBEY F. & BLANC P., 1996: Cathodoluminiscence des minéraux carbonatés et sulfatés (Trias ardéchois, bassin du Sud-Est, France): intérets stratigraphiques et tectoniques. Bull. Soc. Géol. France, 167, 39–52.

HÓK J., KOVÁČ P. & RAKÚS M., 1995: Structural investigations of the Inner Carpathians - results and interpretation (in Slovak, English summary). Miner. slov., 27, 231–235.

JACKO S. & SASVÁRI T., 1990: Some remarks to an emplacement mechanism of the West Carpathian paleo-Alpine nappes. Geol. Zbor. Geol. carpath., 41, 179–197.

JAROSZEWSKI W., 1982: Hydrotectonic phenomena at the base of the Krížna nappe, Tatra Mts. In M. Maheľ (ed.): Alpine structural elements: Carpathian-Balkan-Caucasus-Pamir orogene zone. Veda, Bratislava, 137–148.

JAROŠ J., KRATOCHVÍL M. & ZLOCHA J., 1981: Mesoscopic structural analysis of serpentinite bodies in the Spišsko-gemerské rudohorie Mts. (Eastern Slovakia; in Slovak, English summary). Miner. slov., 13, 527–548.

JEANBOURQUIN P., 1988: Nouvelles observations sur les cornieules en Suisse occidentale. Eclogae Geol. Helv., 81, 511–538.

KOZUR H., 1991: The evolution of the Meliata-Hallstatt ocean and its significance for the early evolution of the Eastern Alps and Western Carpathians. Palaeogeogr. Palaeoclimatol. Palaeoecol., 83, 109–135.

LEINE L., 1971: Rauhwacken und ihre Entstehung. Geol. Rundschau, 60, 488–524.

MAHEĽ M. & BIELY A., 1956: Die genetische Verknüpflung von Rauhwacken und Gips im nordgemerischen Werfen (in Slovak, German summary). Geol. Práce, Spr., 6, 53–55.

MASI U. & TUCCI P., 1993: Geochemical features of the "calcare cavernoso" from the Monte Argentario area (southern Tuscany) and genetic implications. Geol. Romana, 29, 155–161.

MASSON H., 1972: Sur l' origine de la cornieule par fracturation hydraulique. Eclogae Geol. Helv., 65, 27–41.

MILOVSKÝ R., 1996: Distribution of deformation and structural relationships in the profile between the Veporic crystalline basement and the sole of the Muráň nappe (in Slovak). Unpublished thesis, Comenius Univ., Bratislava, 92 p.

MIŠÍK M., 1972: Lithologische und fazielle Analyse der mittleren Trias der Kerngebirge der Westkarpaten. Acta Geogr. Geol. Univ. Com., Geologica, 22, 5–154.

MÜLLER W. H., 1982: Zur Entstehung der Rauhwacke. Eclogae Geol. Helv., 75, 481–494.

PLAŠIENKA D., 1981: Tectonic position of some metamorphosed Mesozoic series of the Veporicum (in Slovak). Unpublished thesis, Geol. Inst. Slov. Acad. Sci., Bratislava, 153 p.

PLAŠIENKA D., 1995: Cleavages and folds in changing tectonic regimes: the Veľký Bok Mesozoic cover unit of the Veporicum (Nízke Tatry Mts., Central Western Carpathians). Slovak Geol. Mag., 2/95, 97–113.

PLAŠIENKA D., 1996: Mid-Cretaceous (120-80 Ma) orogenic processes in the Central Western Carpathians: brief review and interpretation of data. Slovak Geol. Mag., this volume.

RYE D. M. & BRADBURY H. J.: Fluid flow in the crust: an example from a Pyrenean thrust ramp. Am. Jour. Sci., 288, 197–235.

SCHMID S., 1982: Microfabric studies as indicators of deformation mechanisms and flow laws operative in mountain building. In K. J. Hsü (ed.): Mountain building processes. Academic Press, London etc., 95–110.

SLAVKAY M. & ROHÁLOVÁ M., 1993: Carbonate breccias near Poniky, their lithologic and tectonic importance (in Slovak, English summary). Západ. Karpaty, Geol., 17, 39–50.

WARRAK M., 1974: The petrography and origin of dedolomitized, veined or brecciated carbonate rocks, the "cornieules", in the Fréjus region, French Alps. Jour. Geol. Soc. London, 130, 229–247.

SLOVAK GEOLOGICAL MAGAZINE

# Gader Limestones - a new lithostratigraphic unit of the Hronicum in the Veľká Fatra Mts. and its extension in the Western Carpathians.

MILAN POLÁK, MILAN HAVRILA, IVAN FILO & JOZEF PEVNÝ

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

*Abstract.* In the western part of the Veľká Fatra Mts., in the area of the Tlstá Fold, in the Hronicum tectonic unit we distinguished a new lithostratigraphic unit, the Gader Limestones. These limestones are sediments of the carbonate platform. The age of the formation was established as Pelsonian. The article is dealing with extension of this formation in the Western Carpathians and paleogeographic interpretation of the sedimentation area.

*Key words:* Western Carpathians, Hronicum, Triassic, Gader Limestones.

## Introduction

In the course of geological mapping of the Veľká Fatra Mts., in its western part we recorded already in the 80-ies an occurrence of strata in the Hronicum, which are most extensively found in the area of the Tlstá Fold. In the last years, we mapped them in detail in the Veľká Fatra Mts.(Fig. 2) and investigated lithofacially at several profiles. At the same time M. Havrila studied these strata in other parts of the Hronicum of the Western Carpathians (Žiar, Strážovské vrchy Mts. and northern part of the Veľká Fatra Mts.), and was dealing with their stratigraphy, correlation and paleogeographic interpretation. We define them as a new lithostratigraphic unit - the Gader Limestones.

## History

ILAVSKÝ & ČERVEŇOVÁ (1952) were dealing for the first time with carbonate strata in the Tlstá massif, however, without their nearer subdivision. They ranged all strata to the Middle Triassic. Later on, BYSTRICKÝ (1956) for the compilation of general maps 1:200 000 presented a fundamental characterisation of the Triassic limestones, ranging the limestones under study to the Middle-Upper Triassic. These limestones were characterised in greater detail for the first time by PERŽEL (1967, 1969), who assigned them to the Strážov Nappe and on the basis of fossil remnants of foraminifers and dasycladaeans he estimated their age as Middle Anisian-Ladinian. From the study of the documentation material of M. Peržel and literature it is evident that the Gader Limestones in question, underlying limestones with physoporels and overlying the Wetterstein Limestones, were described together.

In the Žiar Mts. the limestones under study were generally ranged to the Gutenstein Limestones (BIELY, 1956; NEMČOK, 1985; MELLO, 1994). In the Strážovské vrchy Mts. they were once ranged to the Rhaetian (MAHEĽ, 1946, 1961,1967, 1969; ANDRUSOV, 1951), another time to the Anisian - to the Gutenstein Limestones (MAHEĽ, 1946), or together with other types of Triassic limestones to the Pelsonian - Illyrian of the Strážov nappe (HANÁČEK, 1974).

## Designation

According to the Gaderská dolina Valley in the western part of the Veľká Fatra Mts., east of the village Blatnica where many profiles of these strata are uncovered.

## Type profile (holostratotype)

Vápenná dolina Valley (Fig. 1, 2), 900 m SE of the Blatnica castle ruin. Profile on the left side of the valley, formed by layered limestones dipping 50° WNW.

## Reference profiles (parastratotypes)

They are situated in the higher part of Konský dol, at Malá Hlboká - 1 km SW of Tlstá (1370,0 m), at Klepec

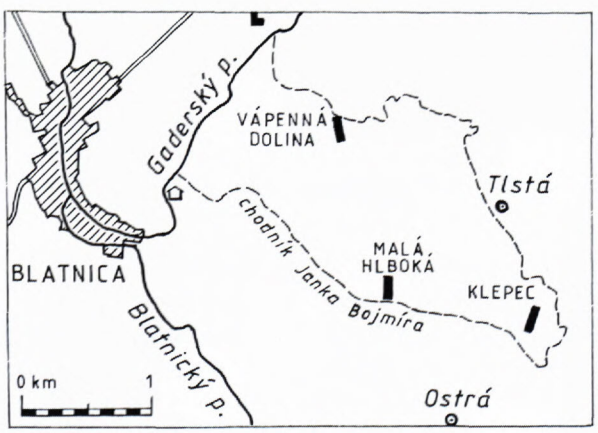



*Fig. 1 Localization of stratotype profiles of the Gader Limestones*

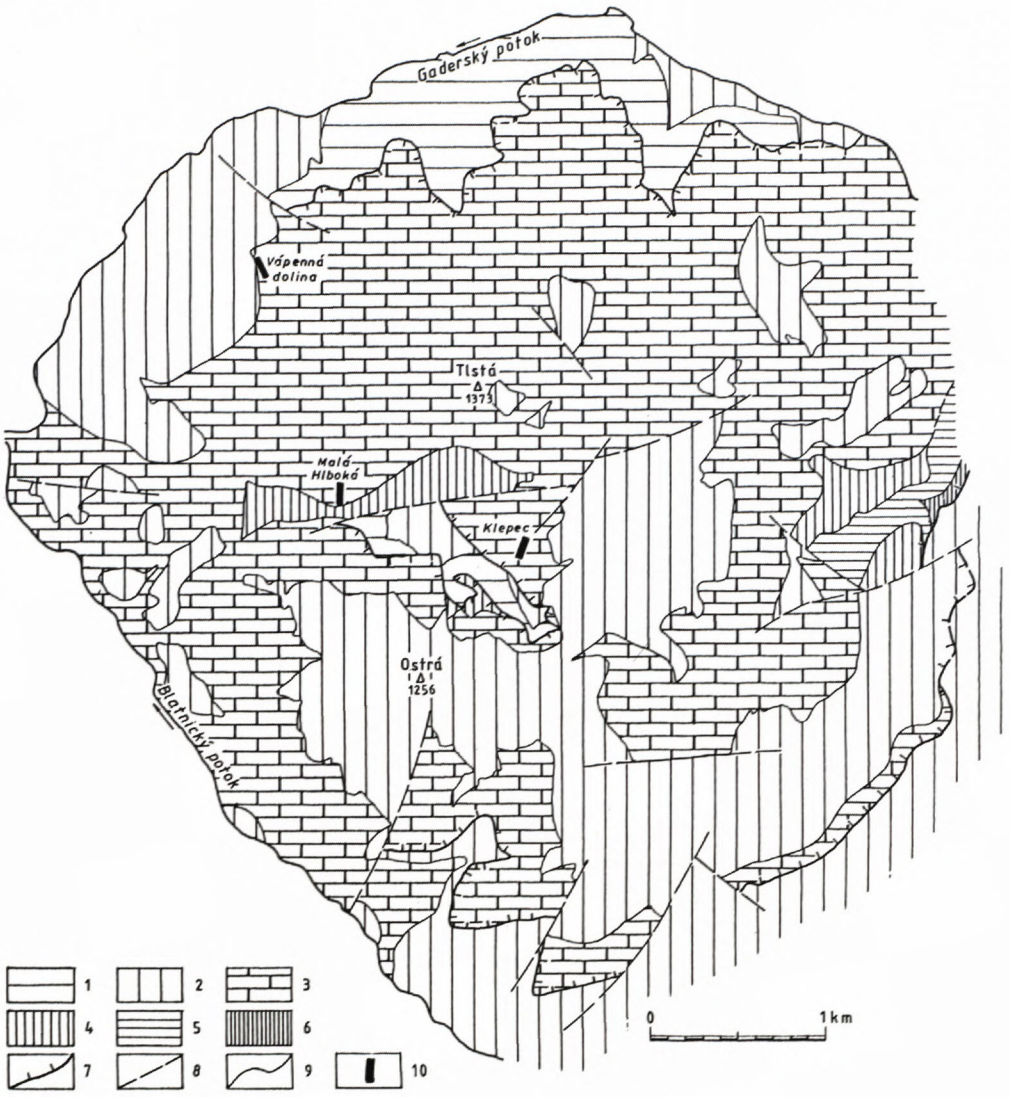



*Fig. 2 Schematic geological map of the area of Tlstá*
*1.Wetterstein Limestones, 2. light-coloured dolomites (with algae), 3. Gader Limestones, 4. dark brecciated dolomites, 5. Gutenstein Limestones, 6. Gutenstein Dolomites, 7. overthrust lines, 8. faults, 9. lithological boundaries, 10. stratotype profiles of the Gader Limestones*

1 km SSE of Tlstá (Fig. 2), near Ráztočno in the Žiar Mts. and at Ostrá Malenica in the Strážovské vrchy Mts.

## Position, underlying, overlying strata, boundaries, morphology

The Gader Limestones in the Veľká Fatra Mts. are a part of a bed sequence, which begins with a wedging-out layer of the Gutenstein Dolomites, continues with the Gutenstein Limestones and dark-grey Ramsau Dolomites. In most cases they are directly underlain by dolomites, only in places there is tectonic contact with the Gutenstein Limestones. In other areas of the Western Carpathians the substratum is not known. The Gader Limestones are overlain by light-grey to white algal, in the southern part also crinoidal dolomites. The bed sequence terminates with the Wetterstein Limestones (Fig. 3, 4). The lower and upper boundary of the Gader Limestones are distinct both lithologically and in morphology. The limestones form rock galleries, several tens of metres high, with vertical walls, frequent overhangs, half-caves to caves (Mažarná Cave).

## Lithology

In the Tlstá area the Gader Limestones are layered to thick-layered (20 - 200 cm), of grey to dark-grey colour with a characteristic brown shade. In the lower part more

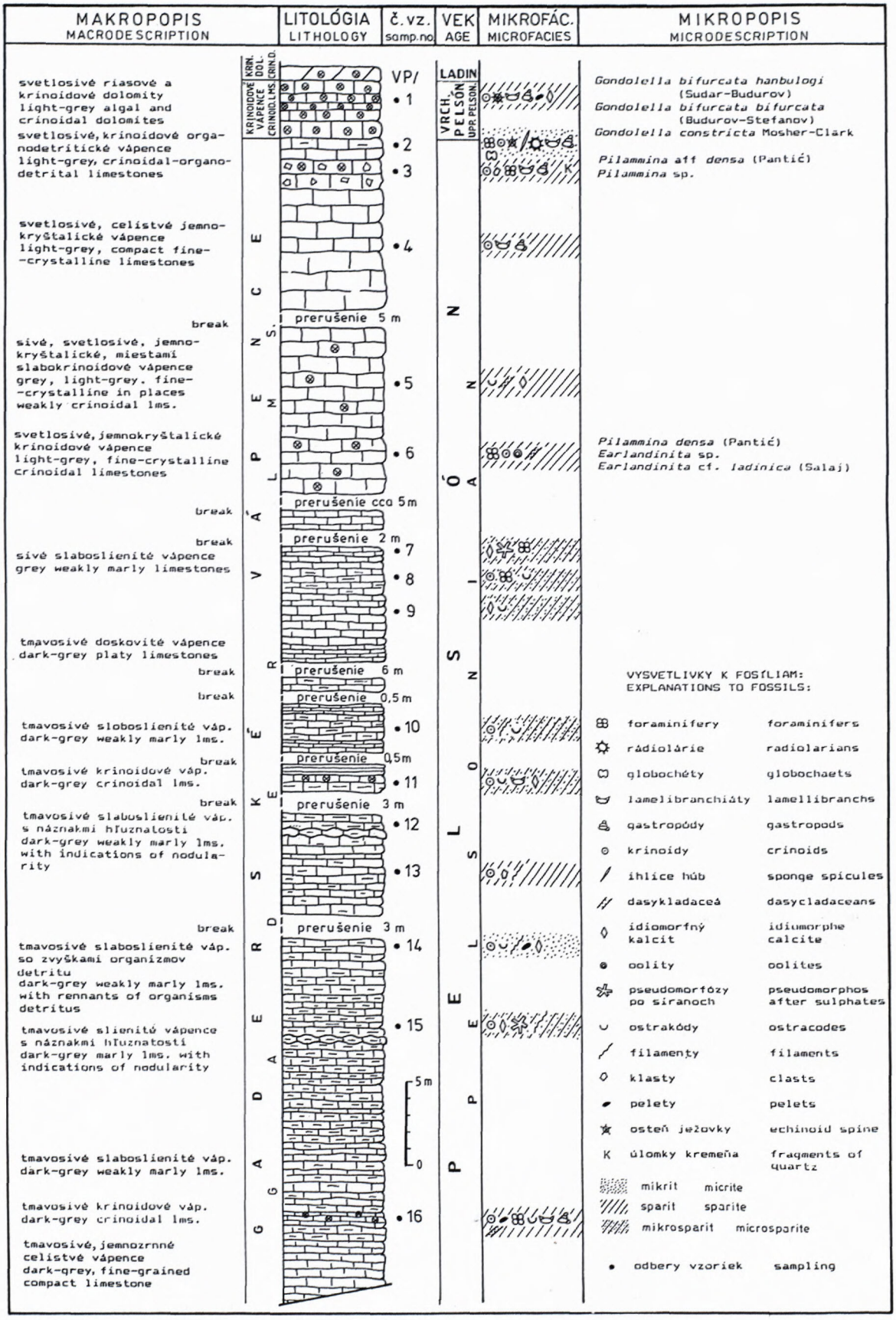



*Fig. 3 Lithostratigraphic profile of the Gader Limestones*

| STUPEŇ STAGE | | PODSTUPEŇ SUBSTAGE | LITOSTRATIGRAFICKÉ JEDNOTKY LITHOSTRATIGRAPHICAL UNITS | HRÚB. [m] THICK. | FOSÍLIE FOSSILS |
|---|---|---|---|---|---|
| STREDNÝ TRIAS MIDDLE TRIASSIC | LADINIAN | LONGOBARD LONGOBARDIAN | WETTERSTEINSKÉ VÁPENCE WETTERSTEIN LIMESTONES | 100 ≀ | Diplopora annulata (Schafh.) Schafh., var. **annulata**, Diplopora annulata (Schafh.) Schafh., var. **dolomitica** Pia, Teutloporella herculea (Stopp.) **Pia** |
| | | FASAN FASSANIAN | SVETLOSIVÉ RIASOVÉ A KRINOIDOVÉ DOLOMITY LIGHT GREY DASYCLADACEAN AND CRINOIDAL DOLOMITES | 300 ≀ | Diplopora annulata (Schafh.) Teutloporella herculea (Stopp.) Pia |
| | ANISSIAN | ILÝR ILLYRIAN | KRINOIDOVÉ VÁPENCE CRINOIDAL LIMESTONES | max. 10 | Gondolella bifurcata hanbulogi (Sudar-Budurov), Gondolella bifurcata bifurcata (Budurov-Stefanov), Gondolella constricta Mosher-Clark |
| | | PELSÓN PELSONIAN | GADERSKÉ VÁPENCE GADER LMS. RAMSAUSKÉ DOLOMITY RAMSAU DOLOMITES 0-100 m | do 100 | Pilammina aff. densa Pantić, Pilammina densa Pantić, Erlandinita sp., Erlandinita cf. ladinica (Salaj), Oligoporella pilosa Pia, var. pilosa, Physoporella dissita (Gümb.) Pia, P. pauciforata (Gümb.) Steinm. var. undulata Pia, P. cf. praealpina Pia, Diplopora hexaster (Pia) Pia |
| | | BITYN BITHYNIAN | GUTENSTEINSKÉ VÁPENCE GUTENSTEIN LIMESTONES | do 80 | |
| | | EGEJ AEGEAN | GUTENSTEINSKÉ DOLOMITY GUTENSTEIN DOLOMITES | 0-10 | |

*Fig. 4 Lithostratigraphic table of the Tlstá nappe*

marly types of limestones are predominant (macroscopically they often resemble the Reifling Limestones, however, without cherts, typical nodularity and layers of shales). In the upper part there are prevailingly compact and fine-grained limestones.

In the uppermost part of the profile there are found several layers of light-grey crinoidal limestones.

The true thickness of the Gader Limestones Formation does not exceed 100 m. The false thickness of the limestone complex in the Tlstá area attains up to 300 m, due to their distinct refolding and slicing.

In other mountain ranges of the Western Carpathians or outside the area of the type profile the Gader Limestones attain a relatively great thickness (up to 110 m). They have even bedding planes, are of grey to greyish-brown colour, rather lighter shades are common. Thick bedding (5-100 cm) is characteristic. Layers around 40 cm thick reach the highest frequency, in the uppermost part they are distinctly thinner, about 20 cm. From structural marks, parallel, and less oblique lamination is distinct, mainly found in the lower part. The sediments may be characterised as microsparites to sparites, rarely pelsparites and biosparites, with low frequency of allochems, from which crinoid stems, pellets, oolites, foraminifers and fish teeth are present. Because of dolomitization and recrystallization they are often preserved as phantoms only. Organic detritus (prevailingly detritus of crinoid stems) is rare in the lower part, in the upper part it becomes common, it is of sandy fraction, with a tendency to upward grain coarsening. In the uppermost part of the strata there is conspicuous bioturbation. A rather rare, but characteristic constituent of the Gader Limestones are imperfectly sorted, detrital carbonates of coarse sandy fraction with graded bedding, with imperfectly rounded organoclasts and bioclasts of fine gravel fraction.

## Type profile - Vápenná dolina Valley

Overlying the dark-grey Ramsau dolomites, the lower part of the profile (3 layers) is formed by dark-grey compact fine-grained to fine-crystalline limestones. Above them there occur dark-grey, grey weakly marly and marly layered to thick-layered (20 - 200 cm) limestones with characteristic brownish tint. They pass then into thinner-layered (20 - 80 cm), in places even platy (5 - 10 cm) dark-grey to grey weakly marly limestones, sporadically with indications of nodularity and with undulated bedding planes. In this complex two layers with remnants of organic detritus are found. This part of the profile attains a thickness of about 45-46 m.

The profile continues with light-grey thick-layered (120-250 cm), fine crystalline and slightly crinoidal limestones, attaining a thickness of about 20-25 m.

The following is a layer (about 2-3 m), formed by distinctly detrital, highly crinoidal light-coloured limestones. This subsequently passes into thick-layered (100 - 150 cm), compact fine-crystalline weakly crinoidal limestones.

They are overlain by light-grey algal and crinoidal dolomites.

## Microfacial characterisation

From microfacial point of view the limestones are prevailingly of microsparite or sparite texture, with relatively low frequency of organic remnants.

In the lower part of the profile there are mainly fragments of crinoidal stems, lamellibranchs, ostracods, foraminifers are sporadically present as well. Additionally there are pellets, pseudomorphs after evaporite minerals are present sporadically. In the following part the assemblage becomes more monotonous, filaments,

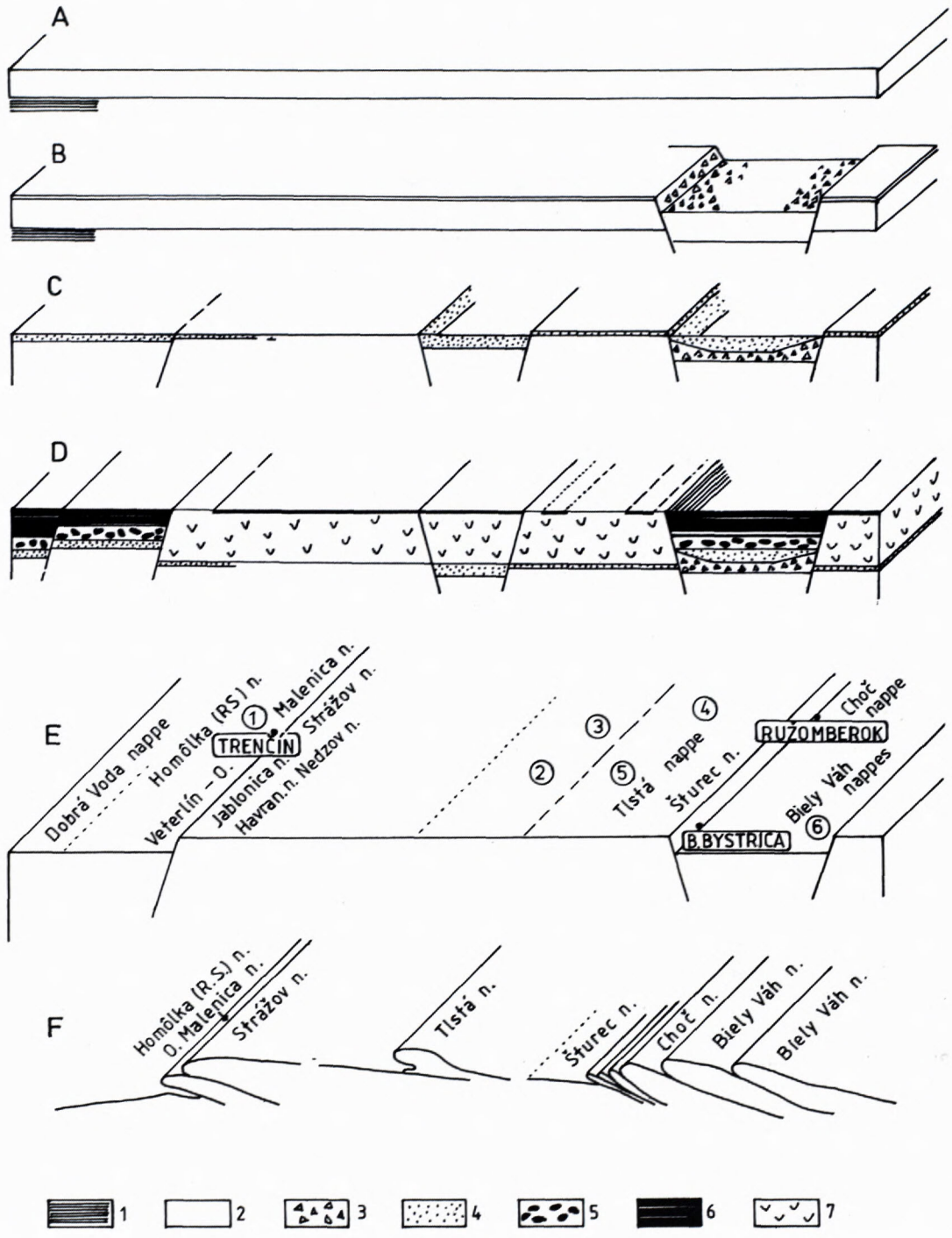



*Fig. 5 Reconstruction of geological development: A. Scythian -Pelsonian; B. Pelsonian; C. Upper Pelsonian -Lower Illyrian; D. Upper Illyrian - Tuvalian; E. distribution of sedimentation areas of future nappes in the Triassic; F. nappe structure formed in the period after the Middle Turonian and before the Paleogene*

*Lithology: 1. Benkov and Šuňava Formations; 2. Gutenstein Dolomites, Gutenstein Limestones, Ramsau Dolomites, Annaberg Limestones, Steinalm Limestones, Gader Limestones; 3. Farkašovo Breccia; 4. Crinoidal limestones, Schreyeralm Limestones, Zámostie Formation; 5. Reifling Limestones, Partnach Formation, Raming Limestones, Göstling Limestones; 6. Lunz Member; 7. Wetterstein Limestones, Wetterstein Dolomites*

*Localites: 1 Ostrá Malenica, 2 Ráztočno, 3 Kláštor pod Znievom, 4 Krpeľany, 5 Tlstá, 6 Zámostie. Compiled by: M. HAVRILA, 1996.*

ostracods, sporadically crinoid stems and foraminifers are prevalent. The groundmass is fining upward, becomes micritic or microsparitic, corresponding to deepening of the sedimentation area. In this part there is an essentially lower share of organodetrital material.

In the upper part of the Gader Limestones organic detritus is distinctly increasing in amount, fragments of crinoid stems, foraminifers are frequent, oolites are sporadic.

In the uppermost part of the profiles (Vápenná dolina Valley, Konský dol, Malá Hlboká and others) there is distinct accumulation of organic detritus, mainly crinoid fragments, brachiopods, lamellibranchs, gastropods, foraminifers and echinoid spines. Micrograded bedding may be often observed in them. We may characterise the limestones as crinoidal. On the basis of lithology and age, these crinoidal limestones may be correlated with the Zámostie Formation.

## Fossils and age

On the profile in the Vápenná dolina Valley J. Salaj determined from the Gader Limestones the following foraminifers: *Pilammina* aff. *densa* (PANTIČ), *Pilammina* sp., *Earlandinita* sp., *Earlandinita* cf. *ladinica* (SALAJ). From the profile in Konský dol he determined: *Duostommina* sp., *Meandrospira insolita* (Ho), *Meandrospira cheni* (Ho). Besides that, PERŽEL (1969) mentioned from the area of Tlstá foraminifers determined by E. Kristan-Tollmann: *Meandrospira dinarica* KOCHANSKI DEVIDÉ-PANTIĆ, *Earlandinita oberhauseri* SALAJ, *Neoendothyra kuepperi* (OBERHAUSER), *Neoendothyra reicheli* REITLINGER. Cores of ostracods and gastropods, crinoid stems and coprolites are present as well.

M. Havrila and J. Pevný determined the following conodonts from crinoidal limestones (from profiles in the Vápenná dolina Valley and Konský dol): *Gondolella bifurcata hanbulogi* (SUDAR et BUDUROV), *Gondolella bifurcata bifurcata* (BUDUROV et STEFANOV), *Gondolella constricta* MOSHER et CLARK, *Gondolella* aff. *bulgarica* (BUDUROV et STEFANOV), *Gondolella bulgarica* (BUDUROV et STEFANOV) f. juv., form transitional between *Gondolella bulgarica* (BUDUROV et STEFANOV) and *Gondolella bifurcata hanbulogi* (SUDAR et BUDUROV), *Ozarkodina tortilis* TATGE, *Prioniodina* (*Cypridodella*) *muelleri* (TATGE), *Hindeodella* (*Metaprioniodus*) *spengleri* (HUCKRIEDE), *Hindeodella* (*Metaprioniodus*) *suevica* (TATGE), *Diplododella magnidentata* (TATGE), *Enantiognathus ziegleri* (DIEBEL). Further, from organic remnants there were teeth and scales of fish, crinoid stems, gastropod cores, spines and interambulacral plates of echinoids and from macrofauna brachiopods "*Rhynchonella*" sp., *Spiriferina* sp., determined by J. Pevný.

From the locality Krpeľany, from crinoidal and nodular limestones (Zámostie Formation), from lateral equivalents of crinoidal limestones of the Tlstá Fold they determined: *Gondolella bifurcata bifurcata* (BUDUROV et STEFANOV), *Gondolella constricta* MOSHER et CLARK, *Gondolella comuta* (BUDUROV et STEFANOV), *Gondolella bulgarica* (BUDUROV et STEFANOV), *Gondolella bifurcata hanbulogi* (SUDAR et BUDUROV), *Ozarkodina tortillis* TATGE, *Enantiognathus ziegleri* (DIEBEL), *Hindeodella* (*Metaprioniodus*) *spengleri* (HUCKRIEDE), *Calclamna trettoensis* MOSTLER, *Theelia* sp., *Tetravirga* sp. Besides that fragments of crinoids, fish teeth and scales, small gastopods, spines and interambulacral plates of echinoids were found too.

From nodular limestones at the locality near Kláštor pod Znievom they determined: *Gondolella bifurcata bifurcata* (BUDUROV et STEFANOV), *Gondolella constricta* MOSHER et CLARK, *Gondolella* cf. *comuta* (BUDUROV ET STEFANOV), *Neohindeodella triasssica triassica* (MÜLLER), *Hindeodella (Metaprioniodus) suevica* (TATGE), *Diplododella* cf. *lautissima* (HUCKRIEDE), *Prioniodina (Cypridodella) muelleri* (TATGE), *Chirodella dinodoides* (TATGE), *Calclamnella anisica* MOSTLER, *Calclamnella* n. sp., *Calclamna trettoensis* MOSTLER, *Priscopedatus quadratus* MOSTLER, *Tetravirga* sp., *Achistrum* sp., *Theelia* sp. Besides that there are found crinoid stems, fish teeth and scales, spines and pedicellaria of echinoids, elements of ophiuria, sponge spicules.

From the locality Ráztočno in the Žiar Mts. from the material of M. Havrila, J. Pevný determined the following Pelsonian - Illyrian fauna of brachiopods in a mass occurrence found diachronously in the whole thickness of the Zámostie Limestones formation: *Coenothyris vulgaris* (SCHLOTH.), *"Rhynchonella"* sp., *Tetractinella trigonella* (SCHLOTH.), *Punctospirella fragilis* (SCHLOTH.), *Volirhynchia vivida* (BITTNER), *Schwagerispira schwageri* (BITTNER), *Anisactinella* cf. *quadriplecta* (MÜNSTER), *Spiriferina* sp. Besides that the limestones contain remnants of crinoids, gastropods, fish (teeth).

Probably from the Gader Limestones in the area of Mojtín PUŠKÁROVÁ (1980) mentioned *Neospathodus kockeli* (TATGE), which would confirm their Pelsonian age.

Foraminifers of the species *Glomospira densa* PANTIĆ from a mass occurrence mentioned by HANÁČEK (1974) come from the Zámostie Limestones of Ostrá Malenica and Tupá Malenica and from the Schreyeralm Limestones in the area of Mojtín (Suchý vrch). Equally, the brachiopods *Spiriferina fragilis* (SCHLOTH.), *S. (Mentzelia) mentzeli* (DUNK.), *S. (M.)* cfr. *Kőves-kaliensis* (SUESS) BÖCKH, published by KULCSÁR (1915), very probably come from the Schreyeralm Limestones of Suchý vrch. From this lithostratigraphic unit there is derived also the microfauna of conodonts and holothurians, published by PEVNÝ (1984). Unpublished fauna of brachipods: *Piarorhynchella trinodosi* (BITTNER), *Volirhynchia vivida* (BITTNER), *Schwagerispira schwageri* (BITTNER) and *Mentzelia mentzeli mentzeli* (DUNKER) from the material of M. Havrila, determined by J. Pevný, has been

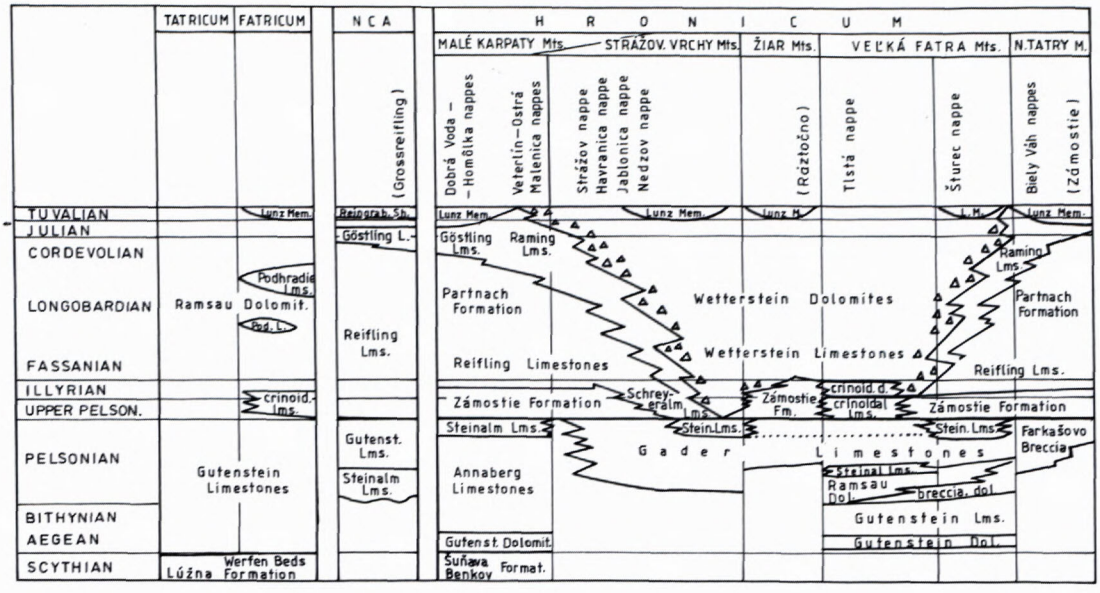



*Fig. 6 Comparative lithostratigraphical table.*
*In the parentheses are the names of localites. RS - Rohatá skala. NCA - Norhern Calcareous Alps. Compiled by: M. HAVRILA, 1996.*

mentioned by HAVRILA & PEVNÝ (1991) from the locality Ostrá Malenica from the Zámostie Limestones On the basis of the obtained fossils and superposition, the age of the Gader Limestones in the Tlstá Fold was established as Pelsonian, and the age of crinoidal limestones of the Tlstá Fold and of nodular and crinoidal limestones from the localities Krpeľany and Kláštor pod Znievom as Upper Pelsonian.

## Correlation

Due to the fact that the Gader Limestones are often found at the base of tectonic bodies of the Hronicum and thus the strata stratigraphically underlying them are not known, and the Gader Limestones at the first glance are similar to the Gutenstein or Annaberg Limestones, and further, since fossils are rare in both facies types, we meet with difficulties in their definition and correlation.

Moreover, also the Gutenstein and Annaberg Limestones are not clearly understood. These in places take up a position between the Steinalm and Reifling Limestones, for example at the locality Grossreifling (SUMMESBERGER and WAGNER, 1972), elsewhere they are found between Lower Triassic strata and the Ramsau Dolomites, for example in the Tatricum and Fatricum of the Western Carpathians, in other places, for example in the Tlstá Fold nappe they are overlying the Ramsau Dolomites (POLÁK et al., 1996) and at last we also designate so limestones overlying Lower Triassic strata and underlying limestones with physoporells of little thickness, i. e. the Steinalm Limestones in the Hronicum of the Malé Karpaty Mts. It results from the above mentioned that as Gutenstein or Annaberg Limestones we regard limestones with various position and with various stratigraphic range. The relationships of facies at the stratigraphic level of the Gader Limestones (Pelsonian) have so far been insufficiently clarified and the use of the names of lithostratgraphic units is therefore uncertain.

As a suitable index horizon, making possible to carry out correlation, there are proposed strata overlying the above mentioned strata. They are, in the environment of the carbonate platform, crinoidal limestones of the Tlstá Fold with their lateral equivalents, occurring in the environment of forming basins - the Schreyeralm Limestones and Zámostie Formation. Lateral relationships of carbonate platform facies with facies of basins and lateral mutual relationships of basinal facies may be observed well in the Strážovské vrchy Mts. in the area of Ostrá Malenica - Mojtín. These facies maintain their position also across facial areas, i. e. in the whole Hronicum region and at the same time their stratigraphic range was sufficiently precisely and accurately delimited (Upper Pelsonian or Upper Pelsonian - Lower Illyrian).

The Gader Limestones and their equivalents (Steinalm Limestones, limestones with physoporells, Annaberg and Gutenstein Limestones) formed under quite balanced conditions on a "uniform" carbonate platform (ramp ?).Their overlying bed sequence is variegated, distinctly reflecting the bathymetric situation connected with the disintegration of the carbonate platform during the Upper Pelsonian and the formation of facial areas (Biely Váh and Čierny Váh) of the Hronicum.

## Genesis

The character of facies and mainly the distribution of organic remnants in the profile permit us, to a certain

degree, to contemplate the conditions, under which the Gader Limestones were deposited. The conditions of sedimentation apparently changed in that time. The lower parts contain a relatively low amount of organic detritus, the character of which points to a genesis in the enviroment of carbonate platform. The middle part is characterised by fining upward of material and increasing proportion of organisms signalizing short-termed deepening.

In the upper part of the profile in crinoidal limestones the proportion of organic detritus, mainly of crinoids, lamellibranchs, gastropods and brachiopods, is increasing. The uppermost bed is characterised as distinctly organodetritic with prevalence of coarse crinoidal and other organic detritus. These limestones represent a sediment partly formed by currents.

## Discussion and conclusion

The Gader Limestones are located in the western part of the Veľká Fatra Mts., mainly in the Tlstá massif. To a small extent they occur also in the southern part of the Žarnovická dolina Valley and Malý Šturec, further in the area of Veľký Šturec and in the north-western part of the mountains, NE of Krpeľany. Further on, they were also found in the Žiar Mts. (Ráztočno and Kláštor pod Znievom) and in the Strážovské vrchy Mts. (Ostrá Malenica and Mojtín).

In the type area the Gader Limestones are found in two partial tectonic units (duplexes) of the Tlstá Nappe ranged to the Hronicum complex. The same situation is in the northern part of the Veľká Fatra Mts. near Krpeľany

The conclusions are the following:

- distinguishing of the Gader Limestones as a new formal lithostratigraphic unit of the Hronicum
- establishing of the age as Pelsonian, making possible their correlation with other lithostratigraphic units of the Hronicum
- obtaining a more precise time level of the disintegration of a "uniform" carbonate platform - the Upper Pelsonian
- achieving more detailed knowledge of paleogeography of the part of the Hronicum between the Strážovské vrchy Mts. and Veľká Fatra Mts.
- further evidence was presented in favour of paleogeographical reconstruction of the Hronicum by HAVRILA (1992, 1993).

## References


ANDRUSOV, D., 1951: Podrobná geologická mapa Československej republiky. List Považská Bystrica 4361/3. Bratislava.

BIELY, A. in MAHEĽ, M., 1956: Záverečná správa o základnom geologickom výskume mezozoika na liste generálnej mapy . Zprávy o mapovaní mezozoika na južných svahoch Žiaru. Manuskript-archív GÚDŠ, Bratislava (In Slovak).

BUČEK S., JENDREJÁKOVÁ, O., PAPŠOVÁ, J. a PUŠKÁROVÁ, K., 1991: Príspevok k biostratigrafii veterlínskej a havranickej jednotky Bielych hôr (Malé Karpaty, Západné Karpaty). Geol. Práce, Spr. (Bratislava), 92, 29-51 (In Slovak, Engl. res.).

BYSTRICKÝ, J., 1956: Príspevok ku geológii Veľkej a Malej Fatry. Niekoľko poznámok o obalových sériách. Geol. Práce, Spr. (Bratislava), 6, 80-83 (In Slovak).

BYSTRICKÝ, J., 1973: Triassic of the West Carpathians Mts. (Malý Šturec). Guide to excursion D. X. Congr. Carpathian-Balkan Geol. Assoc. Vyd. Geol. Úst. D. Štúra, Bratislava, 1-137, apendix 1-21.

BYSTRICKÝ, J., 1983: Stratigrafická tabuľka triasu. In Stratigrafický slovník Západných Karpát, 1 (A-K). Geol. Úst. D. Štúra, Bratislava, Tab. 8 (In Slovak).

BYSTRICKÝ, J., 1986: Stratigraphic Ranging and Zonation of Dasycladal Algae in the West Carpathians Mts., Triassic. Miner. slov. (Bratislava), 18, 4, 289-321.

BUDUROV, K. and STEFANOV, S., 1972: Platform-Conodonten und ihre Zonen in der Mittleren Trias Bulgariens. Mitt. Gesell.- u. Bergb., 21, Wien, 829-852.

BUDUROV, K. and STEFANOV, S., 1975: Neue Daten über die Conodonten-Chronologie der Balkaniden der Mittleren Trias. C.R. Acad. bulg. Sci., 28, 6, Sofia, 791-794.

HANÁČEK, J., 1974: Litologicko-stratigrafické a tektonické poznatky z triasových karbonátových komplexov v sv. časti Strážovskej hornatiny na liste Pružina a Fačkov. Manuscript. Archív Geol. Úst. D. Štúra (In Slovak).

HANÁČEK, J., 1976: Nové poznatky o triase strážovského a chočského príkrovu v Strážovskej hornatine. Záp. Karpaty, sér. geológia 1, Geol. Úst. D. Štúra, Bratislava, 125-149 (In Slovak).

HAVRILA, M., 1993: Výskum panvových a svahových sedimentov bielovážskej sukcesie a paleogeografia hronika. Manuscript. Archív Geol. Úst. D. Štúra (In Slovak).

HAVRILA, M. a BUČEK, S.,1992: Svahové detritické sedimenty hronika. Manuskript. Archív Geol. Úst. D. Štúra (In Slovak).

HAVRILA, M. a PEVNÝ, J.,1991: Profil Ostrá Malenica. Manuscript. Archív Geol. Úst. D. Štúra (In Slovak).

ILAVSKÝ, J. a ČERVEŇOVÁ, Ž., 1952: Geologické štúdiá na západnom svahu Veľkej Fatry. Geol. Práce, Soš. (Bratislava), 30, 5-61, 18 tab. (In Slovak).

KOCHANOVÁ, M. a MICHALÍK, J., 1986: Stratigraphy and macrofauna of the Zámostie limestones (Upper Pelsonian - Lower Illyrian) of the Choč nappe at the Southern Slopes of the Nízke Tatry Mts. (West Carpathians). Geol. Zbor. Geol. Carpatica 37, 4, Bratislava, 501-531.

KOVÁCS, S. and KOZUR, H., 1980: Stratigraphische Reichweite der wichtigsten Conodonten (ohne Zahnreihenconodonten) der Mittel - und Obertrias. Geol. Paläont. Mitt. Innsbruck, 10, 2, Innsbruck, 47-78.

KULCSÁR,K, 1915: Geologische Verhältnisse der Umgebung von Csavajó, Villabanya, Csicsmány und Zsolt. Ung. Geol. Reichsanst. Budapest, 124-148

MAHEĽ, M., 1946a: Zpráva o geologickom mapovaní v Strážovskej hornatine. Práce Štátneho geologického ústavu, 16, Bratislava (In Slovak).

MAHEĽ, M., 1946b: Geológia strednej časti Strážovskej hornatiny. Práce Štátneho geologického ústavu, 14, Bratislava. (In Slovak).

MAHEĽ, M., 1961: Nové poznatky z niektorých "kľúčových území" v Strážovskej hornatine. Geol. Práce, Správy, Bratislava (In Slovak).

MAHEĽ, M., 1967: Regionální geológie ČSSR II. Západní Karpaty. Svazek 1, ÚÚG ČSAV, Praha (In Czech, Engl. res.).

MAHEĽ, M., 1969: Zlomy a ich úloha počas mezozoika vo vnútorných Karpatoch. Geol. Práce, Správy, 47, Bratislava, 7-29. (In Slovak, Engl. res.)

MELLO, J. in ŠIMON, L., ELEČKO, M., GROSS, P., KOHÚT, M., MIKO, O., LEXA, J., MELLO, J., HÓK, J., MACINSKÁ, M., KÖHLER, E. a JÁNOVÁ, V., 1994: Vysvetlivky ku geologickým mapám 36-133 (Handlová), 35-244 (Prievidza - 4), 36-131 (časť Ráztočno). Manuskript. Archív Geol. Úst. D. Štúra (In Slovak).

MOSTLER, H. 1980: Ein Beitrag zur mitteltriasischen Mikrofauna von Recoaro und Tretto (Vicentin, Italien). Geol. Paläont. Mitt. Innsbruck, 9, 9, Innsbruck, 321-351.

NEMČOK, M., 1985: Geologické pomery mezozoika na juhu pohoria Žiar. Manuscript (Diplomová práca). Archív Kat. Geol. a Paleont. PrF UK, Bratislava (In Slovak).

PERŽEL, M., 1967: Litologický výskum mezozoika a geochemicko-surovinové zhodnotenie karbonátových hornín pre mapu prognóz v JZ časti Veľkej Fatry. Dielčia záverečná správa. Manuskript. Archív Geol. Úst. D. Štúra. (In Slovak).

PERŽEL, M., 1969: Strážovský príkrov vo Veľkej Fatre. Geol. Práce, Spr. (Bratislava), 48, 119-122 (In Slovak).

PERŽEL, M. a ANDRUSOVOVÁ, V., 1967: Geologický výskum mezozoika JZ časti Veľkej Fatry. Manuskript. Archív Geol. Úst. D. Štúra, 1-52, Tab. I-XXVIII.

PEVNÝ, J., 1984: Conodonts and holothurian sclerites of the Strážov nappe north of Mojtín. Západné Karpaty, sér. Paleontológia, 9, Bratislava, 165-92.

POLÁK, M., FILO, I., PRÍSTAŠ, J., KOVÁČ, P., SIRÁŇOVÁ, Z., HAVRILA, M. a PEVNÝ, J., 1996: Čiastková záverečná správa. Vysvetlivky ku geologickej mape 1:25 000, listy 36-114 Turčianske Teplice, 36-112 Valča, 36-132 Horná Štubňa. Manuscript. Archív Geol. Služby Slov. Rep., Bratislava (In Slovak).

PUŠKÁROVÁ, K., 1980: Nové stratigrafické poznatky o triase Strážovských vrchov. Rigorózna práca, Geofond, Bratislava.

SUDAR, M. and BUDUROV, K., 1979: New Conodonts from the Triassic in Yugoslavia and Bulgaria. Geol. na .Balkanite, 9, 3, Sofia, 47-52.

SUMMESBERGER, H. and WAGNER, L., 1972: Der Stratotyp des (Trias). Ann. Naturhistor. Museum Wien 76, Wien, 515-538.

## Explanations to the Plate I-VIII

Plate I

1 - 3, 6, 7. *Gondolella bifurcata hanbulogi* (SUDAR et BUDUROV)
vrása Tlstej, Veľká Fatra
1. SCAN 1486/1996 (110x), 2-3. SCAN 1489, 1490/1996 (100x), 6. SCAN 1500/1996 (110x), 7.SCAN 1499/1996 (120x)

4, 5, 8. *Gondolella* aff. *bulgarica* (BUDUROV et STEFANOV)
vrása Tlstej, Veľká Fatra
4-5. SCAN 1492, 1493/1996 (100x), 8. SCAN 1488/1996 (120x)

9 - 10. *Gondolella bifurcata bifurcata* (BUDUROV et STEFANOV)
vrása Tlstej, Veľká Fatra
9-10. SCAN 1497, 1498/1996 (100x)

Plate II

1 - 5. *Gondolella constricta* MOSHER et CLARK
vrása Tlstej, Veľká Fatra
1-2. SCAN 1495, 1496/1996 (100x), 3. SCAN 1507/1996 (270x), 4-5. SCAN 1508, 1509/1996 (4. 160x, 5. 170x)

6, 7.*Gondolella bulgarica* (BUDUROV et STEFANOV) f.juv.
vrása Tlstej, Veľká Fatra
6-7. SCAN 1501, 1502/1996 (270x)

8 *Gondolella bulgarica* (BUDUROV et STEFANOV)
vrása Tlstej, Veľká Fatra
SCAN 1487/1996 (100x),

9 *Gondolella* cf. *cornuta* (BUDUROV et STEFANOV)
Krpeľany, Veľká Fatra
SCAN 1529/1996 (140x),

Plate III

1. *Diplododella magnidentata* (TATGE)
vrása Tlstej, Veľká Fatra
SCAN 1503/1996 (200x)

2. *Hindeodella (Metaprioniodus) spengleri* (HUCKRIEDE)
vrása Tlstej, Veľká Fatra
SCAN 1504/1996 (270x)

3. *Enantiognathus ziegleri* (DIEBEL)
vrása Tlstej, Veľká Fatra
SCAN 1505/1996 (190x)

4. *Hindeodella (Metaprioniodus) suevica* (TATGE)
vrása Tlstej, Veľká Fatra
SCAN 1506/1996 (180x)

5 - 6. *Calclamna trettoensis* MOSTLER
Krpeľany
5. SCAN 1510/1996 (160x), 6. SCAN 1511/1996 (200x)

7. *Theelia* sp.
Krpeľany
SCAN 1512/1996 (250x)

Plate IV

1, 2. *Calclamnella anisica* MOSTLER
Kláštor pod Znievom
1 SCAN 1518/1996 (270x), 2. SCAN 1519/1996 (300x)

3. *Calclamnella* n. sp.
Kláštor pod Znievom
SCAN 1520/1996 (370x)

4. *Ophiuridae*.
Kláštor pod Znievom
SCAN 1522/1996 (110x)

5. *Priscopedatus quadratus* MOSTLER
Kláštor pod Znievom
SCAN 1517/1996 (300)

6. *Tetravirga* sp.
Kláštor pod Znievom
SCAN 1521/1996 (140x)

7. *Calclamna trettoensis* MOSTLER
Kláštor pod Znievom
SCAN 1516/1996 (180x)

Foto: K. Horák, GS SR

Plate V.

1. Organodetrical texture of crinoidal limestones with cross sections of gastropods, crinoids and foraminifers.
VD-1 - Vápenná dolina Valley (x 36)

2. *Glomospirella articulosa* (PLUMMER)
KD-4 - Konský Dol (x 36)

3. *Pilammina densa* PANTIČ, *Dentalina hoi* TRIFONOVA
VD-2 - Vápenná dolina Valley(x 36)

4. *Pilammina densa* PANTIČ, radiolarians, filaments, ostracodes from the lower part of the Gader Limestones.
VD-2 - Vápenná dolina Valley(x 36)

Plate VI.

1. *Pilamminella* sp. (cf. *Semiplana*) KOCHANSKI-DEVIDÉ & PANTIČ)
VD-1 - Vápenná dolina Valley (x 36)

2. *Endothyranella pentacamerata* SALAJ
VD-6 - Vápenná dolina Valley (x 36)

3. cf. *Trochamina* sp. Marginal vertical section
KD-4 - Konský Dol (x 36)

4. *Trochamina* sp. (cf. *Jannennis* BRÖNNIMAN &PAGE)
VD-2 - Vápenná dolina Valley (x 36)

5 *Pilamminella densa* PANTIČ
VD-6- Vápenná dolina Valley (x 36)

6 Graded bedding of detrital limestones with organoclasts (crinoids, lamellibranchs) and lithoclasts
Krpeľany. Natural size

Plate VII.

1. *Diplopora hexaster* (PIA) PIA, *Physoporella dissita* (GÜMB.) PIA
Tmavá dolina Valley, Physoporell Limestones
Material of M. Peržel (x 12)

2. *Diplopora hexaster* (PIA) PIA, *Oligoporella* sp.
Tmavá dolina Valley, Physoporell Limestones
Material of M. Peržel (x 12)

3. *Diplopora annulata* (SCHAFH.) SCHAFH. var. *annulata*, *Diplopora annulata* (SCHAFH.) SCHAFH. var. *dolomitica* (PIA) PIA
elev. P. Červené, Wetterstein Limestones
Material of M. Peržel (x 12)

4. Oosparitic texture. Oolites, the centres are formed by algal clusters, cyanophyceans, foraminifers, echinoid spines
Dubiny, Wetterstein Limestones
Material of M. Peržel (x 12)

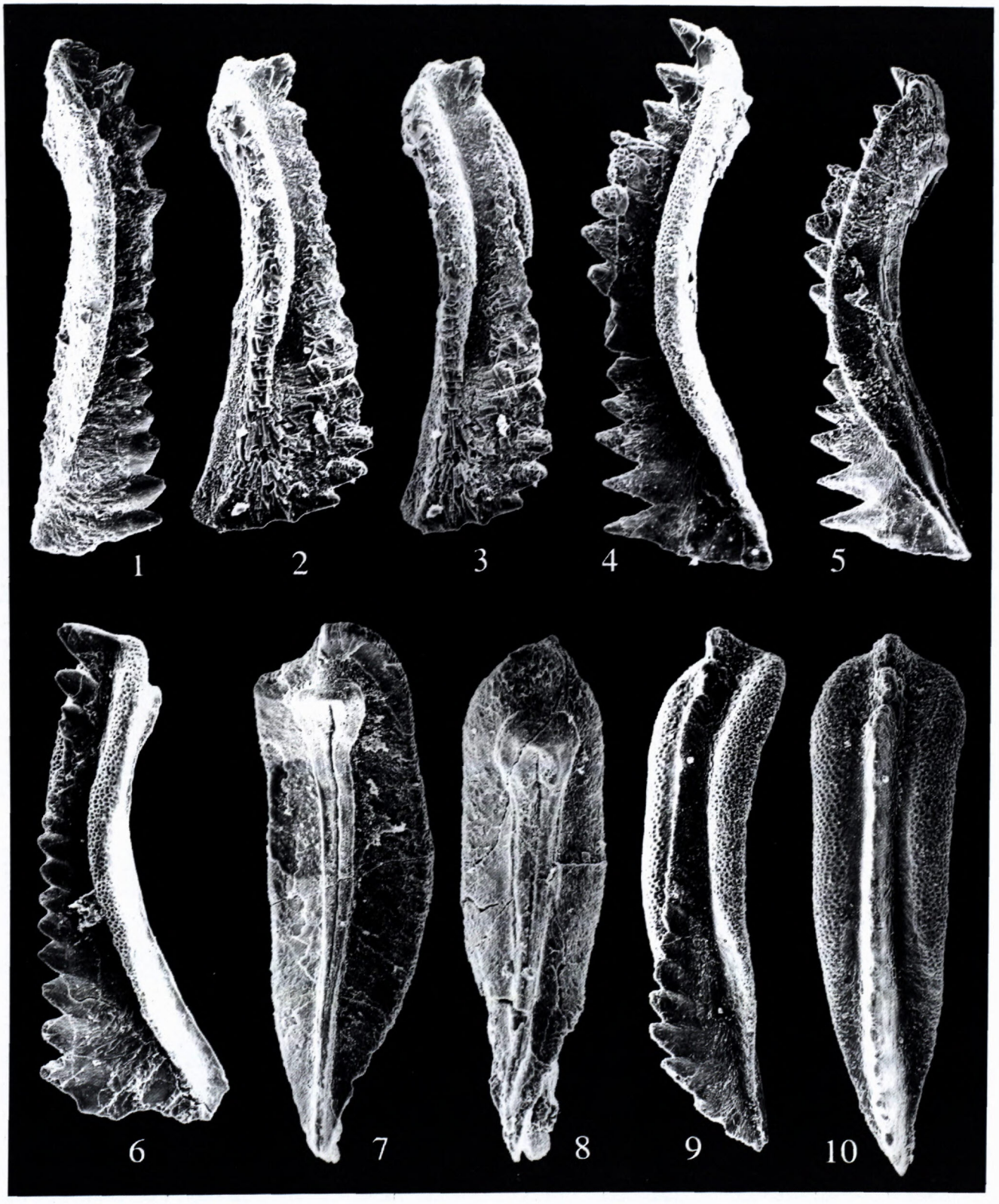
Plate VIII.

1. *Physoporella dissita* (GÜMB.) PIA, *Diplopora* cf. *hexaster* PIA
Selenec Valley, Physoporell Limestones
Material of M. Peržel (x 12)

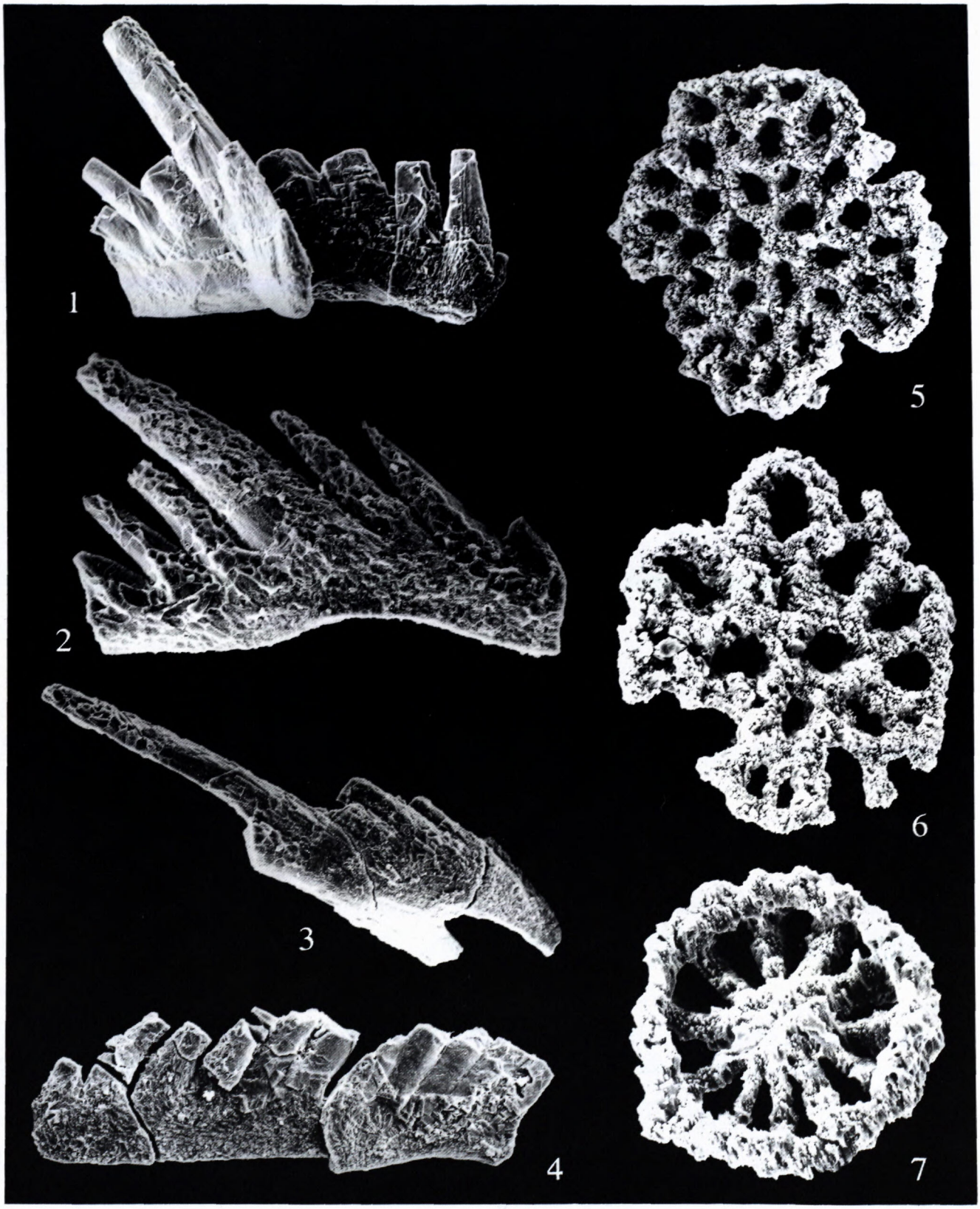
2. *Physoporella dissita* (GÜMB.) PIA
Selenec Valley, Physoporell Limestones
Material of M. Peržel (x 12)

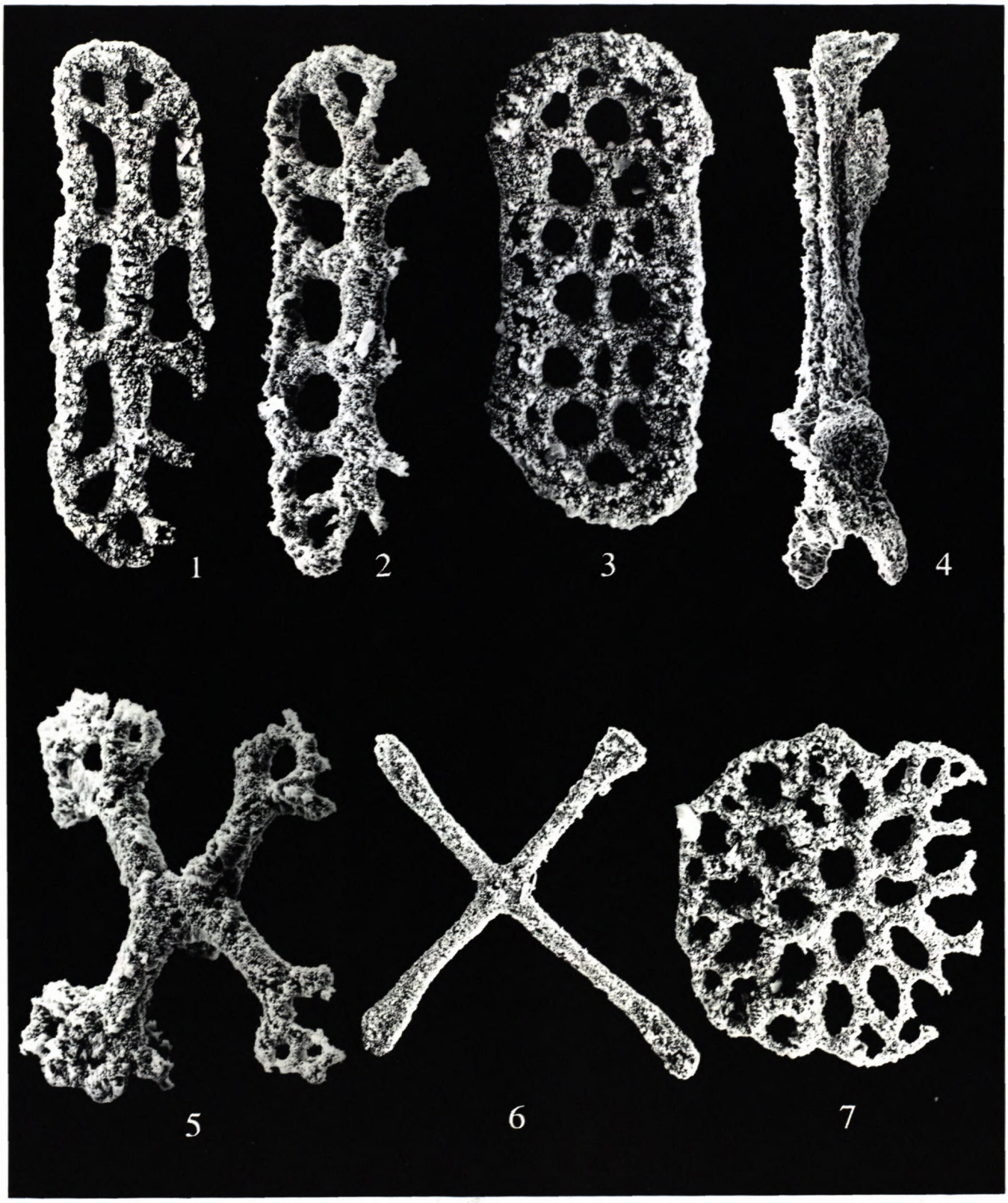
3. *Physoporella dissita* (GÜMB.) PIA - top part
Selenec Valley, Physoporell Limestones
Material of M. Peržel (x 12)

4. *Physoporella dissita* (GÜMB.) PIA
Selenec Valley, Physoporell Limestones
Material of M. Peržel (x 12)


1
2
3
4
5
6
7
8
9
10

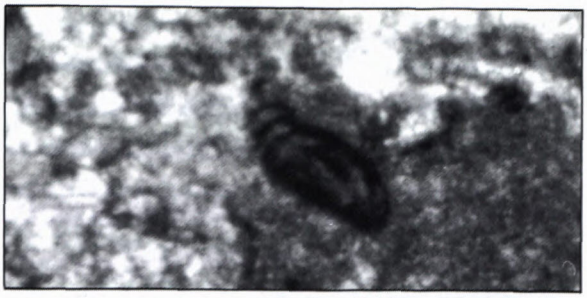

1
2
3
4
5
6
7
8
9


1
2
3
4
5
6
7

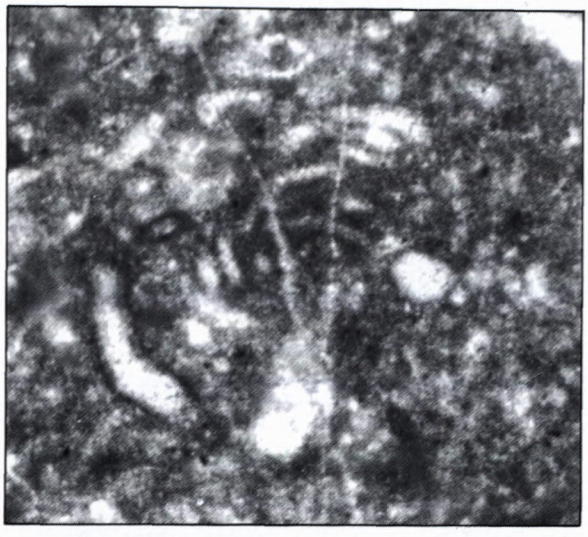

1
2
3
4
5
6
7



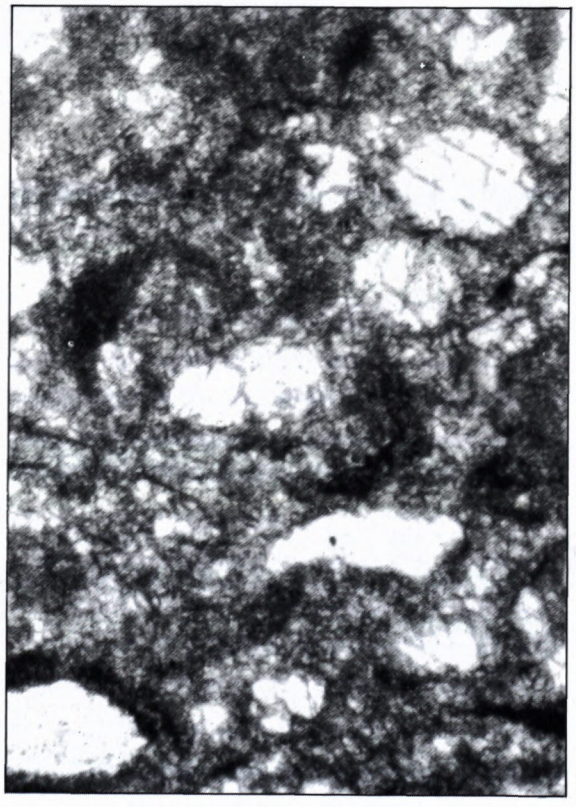
1



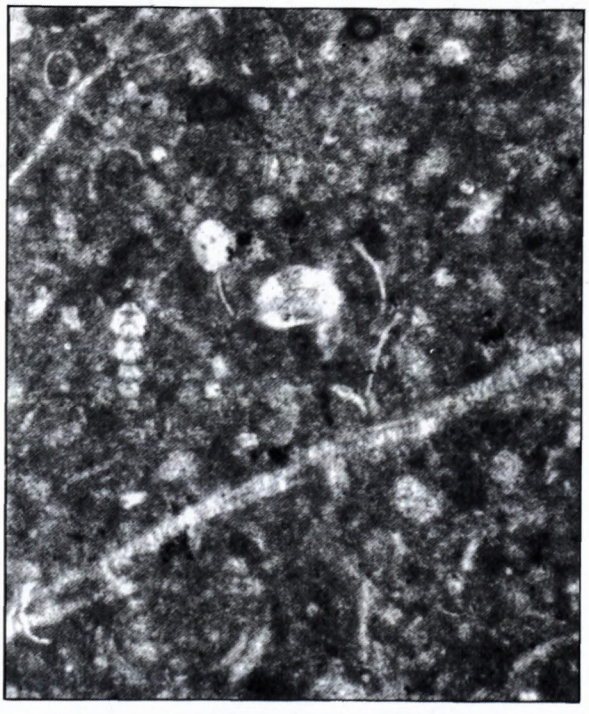
2



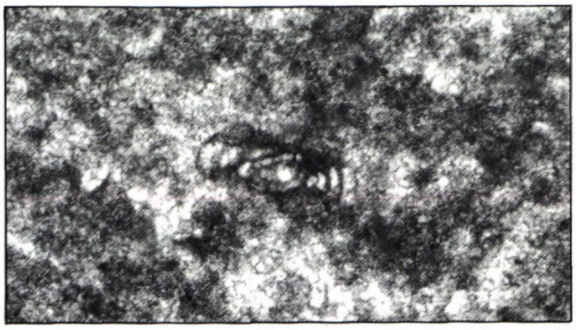
3



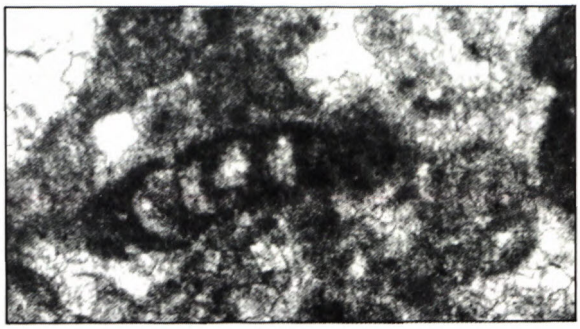
4



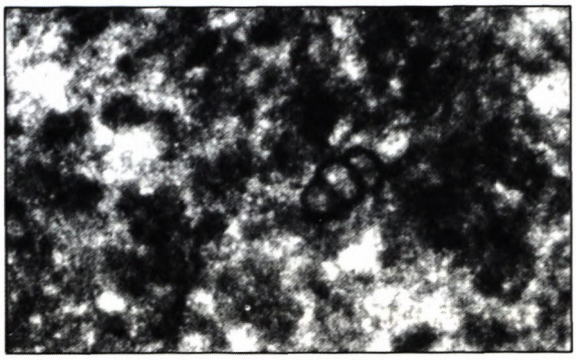
5



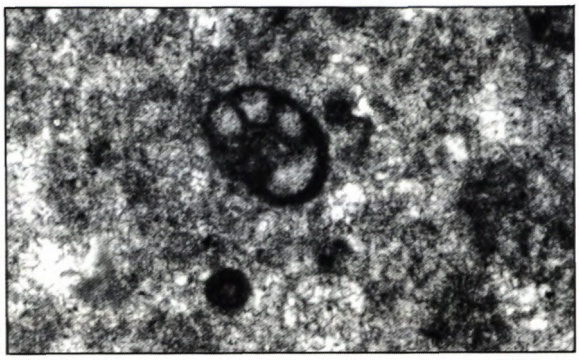
1



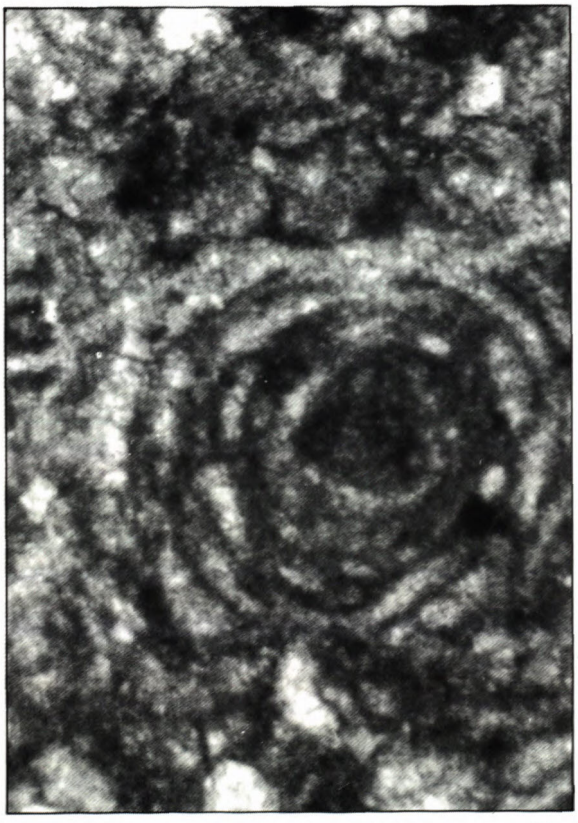
2



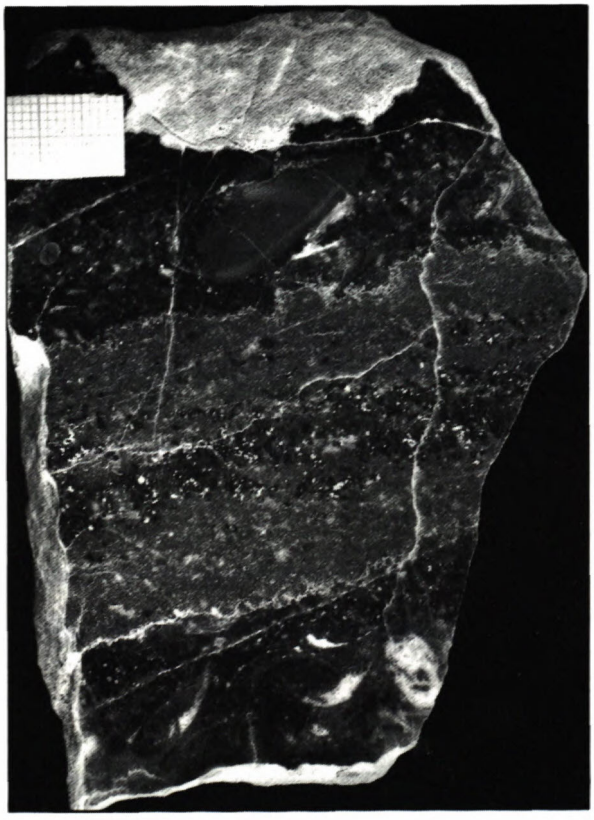
3



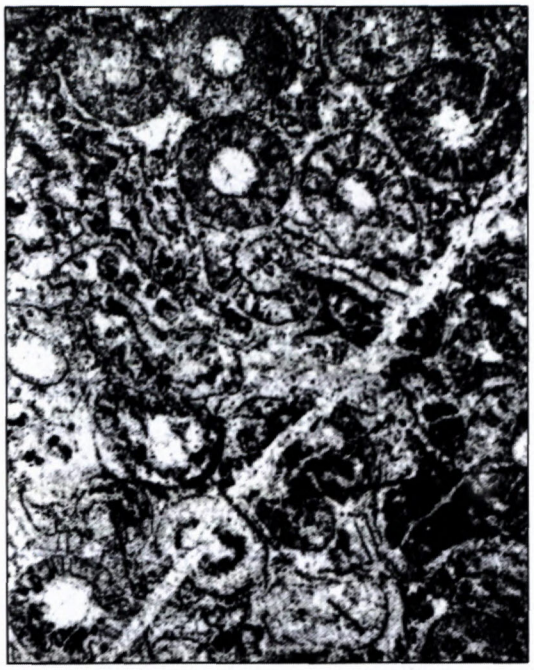
4



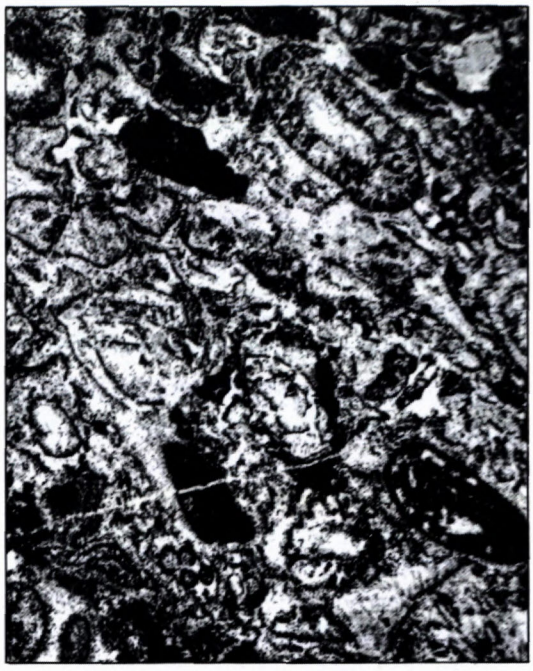
5



6



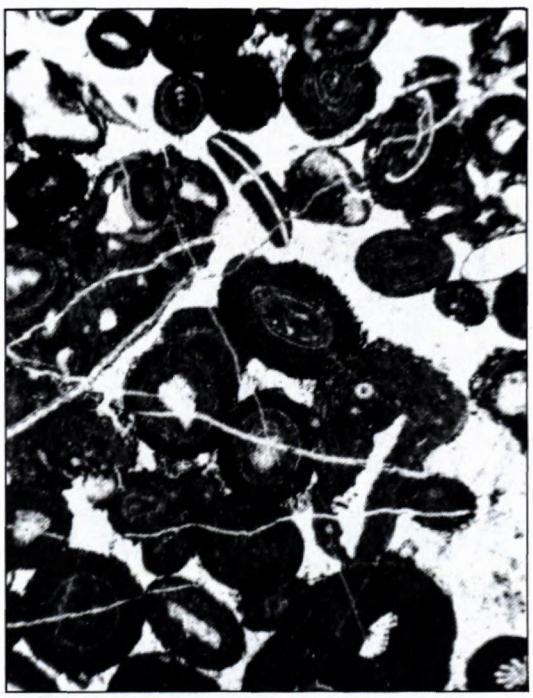
1



2



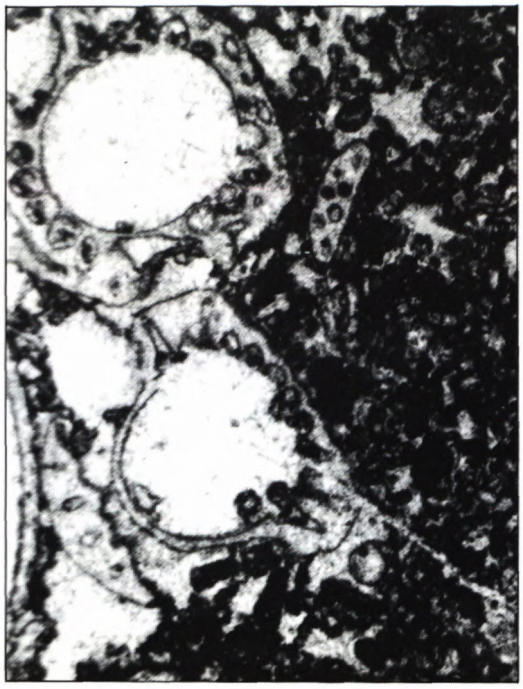
3



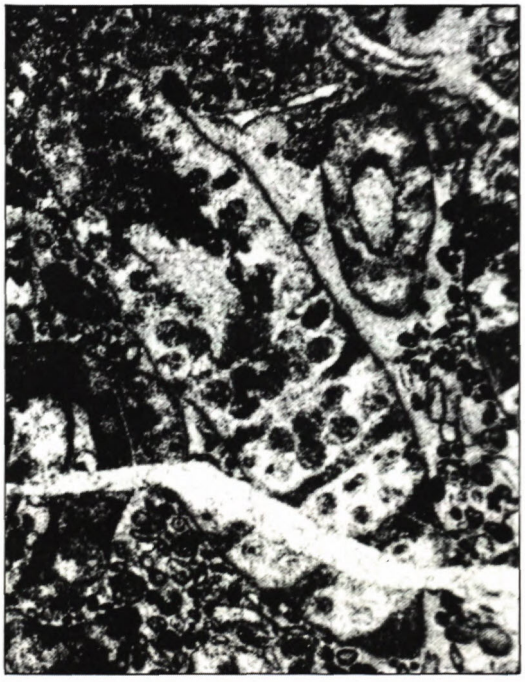
4



1



2



3



4

SLOVAK GEOLOGICAL MAGAZINE

# Jurassic of the innermost Western Carpathian zones - its importance and influence on the geodynamic evolution of the area

MILOŠ RAKÚS

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

*Abstract:* In comparison with other tectonic units, the Jurassic of the innermost Western Carpathian zones has been preserved only rudimentarily. The character of Jurassic sediments, however, indicates that they must have been much more extensive and their present absence has been caused by later erosion. The importance of Jurassic sediments for the reconstruction of the geodynamic evolution of the area is extraordinary, as they record the tectono-sedimentary events of the Jurassic period.

The most important phenomenon of this zone was the Meliatic oceanic domain, the closure of which led to Upper Jurassic structuring of the innermost Western Carpathian zones. A new sedimentary cycle started only after a great hiatus - in the Senonian and it ended definitely the Mesozoic evolution stage.

*Key words:* Western Carpathians, Jurassic, tectono-sedimentary evolution

## General framework

The Western Carpathians are, similarly as the Alps, a multi-stage mountain system, consisting of several regional tectonic units, generated during repeated Upper Jurassic, Cretaceous and Tertiary convergence. Mutual interrelations of such created units are not always clear, leading in some cases to controversial opinions on their palinspastic arrangement.

The long-term (over 130 Ma) convergent trend of the Western Carpathian section of the Alpids led to the formation of a belt mountain range, where usually only parts of the original sedimentary basins and their basement have been preserved. These remnants were further many times reduced, laterally dislocated and even rotated due to repeated oblique collisions. The shortening of the space achieved such a degree that superficial nappes are wholly detached from their basement (flysch nappes of the Outer Carpathians, nappes of Hronicum and Silicicum).

Considering the above facts we necessarily arrive to the conclusion that the elaboration of paleogeographic reconstructions, or of a geodynamic model, is in this case not a simple and, above all, not an unambiguous task. The risk to start in a wrong direction is great, which is confirmed by the present "overproduction" of geodynamic models. Experience shows that problems start to appear already in the moment where general, globally used models are attempted to be applied to a mountain range, where geology has been studied for over a hundred years. The authors of the model are in such a case exposed to a special problem: how to harmonise the existing, many times extraordinary quantity of regional-geological information. To be honest, we must admit that to date the authors only rarely succeeded in this, especially as far as the Carpathian system is concerned. In spite of certain scepticism I must say that the elaboration of paleogeography or geodynamic modelling is in a certain way a very exciting journey, full of discoveries, but also a "marche arriére". With certain exaggeration we could say that it is in a way an "intellectual challenge" presented by Nature to us, geologists, which is worth of being accepted.

In view of my personal experience with such "modelling journeys" the presented contribution is not aimed at solving the whole extent of problems related to the geodynamic evolution of the Inner Western Carpathians. Its aim is rather to provide information on the possible geodynamic evolution of the innermost Western Carpathian zones, on the example of the Jurassic of Meliaticum and Silicicum, where, most probably, we are confronted with first manifestations of Mesozoic convergent tectonics in the Western Carpathians.

In comparison with other tectonic units, the Jurassic of the innermost Western Carpathian zones has been preserved only rudimentarily. The character of Jurassic sediments however shows that they must have been much more extensive and their present absence is most probably the result of later erosion.

Although Jurassic sediments are in comparison with Triassic ones represented only to a limited extent, their importance for the reconstruction of the geodynamic evolution of the back part of the Western Carpathians is extraordinary. This special importance lies in the fact that they are the last known, or preserved,

sediments of the Triassic-Jurassic cycle, which contain records of tectono-sedimentary events.

Another sedimentary cycle followed only after the Paleo-Alpine structuring associated with uplift, caused by the closure of the Meliatic domain. The new sedimentary cycle started after a considerable hiatus - in the Senonian and it ended definitively the Mesozoic stage in this area.

## Main paleogeographic domains of the Inner Western Carpathians

In the Inner Western Carpathian area there are generally distinguished three paleotectonic units: Gemericum, Silicicum and Meliaticum. This order shows also their palinspastic arrangement, which has been accepted by several geologists (KOZUR & MOCK, 1973, ANDRUSOV, 1975, GRECULA 1983, MELLO et al. 1992, KOVÁCS et al. 1989, KOVÁCS 1992, KOZUR 1992, KOZUR-MOSTLER 1992, HAAS et al. 1995). An unavoidable result of this arrangement was the south-vergent thrust of the Silica Nappe onto Meliaticum, which was opposite to the vergency of other units of the Western Carpathians. A recently carried out structural investigation has shown that tectonic structure of the Inner Western Carpathians on Slovak territory formed due to north-vergent thrusting (HÓK et al., 1995), which confirmed the in the 80-ties expressed, but never published idea (RICOU 1986). This information as well as the present mutual position of the above mentioned units allow to suggest the following palinspastic arrangement (in present orientation, from north to south) Gemericum- Meliaticum - Silicicum. Practically the same arrangement has been presented recently by DALLMEYER et al (1996).

However, as indicated by several paleomagnetic studies from the Western Carpathian area (MÁRTON et al.,1988 and 1991, KRUCHYK et a., 1991 and KRS et al. 1993), Western Carpathian tectonic units are rotated in anti-clockwise direction, in the range from 110° (for the Permian) to 30° (Upper Cretaceous). Although this information is at present largely not reflected in paleogeographic reconstructions, it is evident that eventually it will influence the view on the original orientation of the paleogeographic zones. This paleomagnetic information, however, will not influence the sense - vergency - of tectonic polarity, which, even after rotation, remains from inside to outside.

**Gemericum**: within the Inner Western Carpathians, it represents the outermost (lowermost) tectonic unit, where the Paleozoic is dominant. We must however note that Mesozoic history of this paleogeographic domain is still a great unknown entity. With any certainty, only Lower Triassic sediments may be confirmed here (IVANOV 1953). In the Nižná Slaná depression, we could include here a part of the Štítnik Formation (VOZÁROVÁ & REICHWALDER 1983, MELLO 1992). The presence of the Middle Triassic is probable, based on lithology (MELLO 1992). Stratigraphically higher Mesozoic, or maybe Jurassic members have never been proved! The chronic absence of the Mesozoic, especially the Jurassic, led to considerations that this space could be the home area of the Silica Nappe, which slipped due to gravitation to the south.

**Meliaticum**: Although Meliaticum, as a regional tectonic unit, was introduced into Carpathian literature more than twenty years ago (KOZUR & MOCK 1973), we must note that it is still the subject of lively discussions. In the Western Carpathians there is scarcely such a unit, which would have to undergo so many changes in its stratigraphy and sedimentology.

The originally Middle-Upper Triassic succession was gradually complemented by the Jurassic (KOZUR & MOCK 1985), while, at the same time, a continuous bed succession was being considered. From paleogeographic viewpoint, it was considered an oceanic domain opened already in the Middle Triassic (Pelsonian- Illyrian) and surviving into the Jurassic, and its width was estimated at 800-1000 km (KOZUR 1979 and 1991).

The evidence of Upper Triassic age of a part of limestones included into Meliaticum (KOZUR & MOCK 1973) caused a "small earthquake" and, at the same time, it started, so to say, a "Meliatic age".

At the end of the 80-ties and beginning of 90-ties, "meliatomania" was the fashion of the day and from several localities in northern Hungary (e.g. Tornakápolna, Szarvaskö) there were described successions identified as Meliatic (KOVÁCS 1984 and 1992, RÉTI 1985). Occurrences of Meliaticum were described even in the Austrian Alps (MANDL - ONDREJIČKOVÁ 1991, KOZUR 1991 and KOZUR & MOSTLER 1992). This new situation caused a wave of speculations and authors introduced the idea of the "Meliatic-Hallstatt Ocean" (KOZUR 1991).

Similarly, in the Western Carpathians, where the term "Meliaticum" originated, there were described several new occurrences of Meliaticum: Jaklovce (MOCK et al. 1993), Folkmár (KOZUR & MOCK 1995), Čoltovo (MELLO & GAAL 1984), the borehole Brusník (VOZÁROVÁ & VOZÁR 1992), borehole Držkovce (MELLO et al.1995) and, recently, Ondrejisko in Stratenská hornatina Mts. (HAVRILA & OŽVOLDOVÁ 1996 in press). It must be noted that the last mentioned occurrence is especially important for the analysis of the mutual relationship of Meliaticum and Silicicum. In view of the fact that it is situated below the Stratenský Nappe, as well as the north-vergency of the Silicicum itself (HÓK et al.1995), we can hardly doubt the ultra-Meliatic origin of the Silica Nappe! This fact, as well as our new investigations at the localities Jaklovce and Folkmár allow to disrespect the recently presented hypothesis on the "Folkmár suture zone", sensu KOZUR & MOCK (1995). The existing regional geologic information excludes the existence of two sutures in Meliaticum.

Intensive investigation of Meliaticum within the project "Geodynamic evolution of the Western Carpathians" in recent years brought new, surprising information forcing us to change radically the opinion on the stratigraphy and sedimentology of Meliaticum. It has been proved (MOCK et al. 1992, 1993 and our own studies) that the continual Triassic-Jurassic bed succession at the classical locality is a Jurassic olistostrome! It has been discovered that the "bed successions" of Middle and Upper Triassic occurring there are more or less disintegrated blocks in a formation of dark, non-calcareous shales with intercalations of radiolarites of Bathonian-Callovian age. Similar conclusion has been reached at other localities as well (boreholes Brusník and Držkovce, Čoltovo).

Based on the present knowledge on the Jurassic of Meliaticum s.s. (RAKÚS et al. in press), we include here only a formation of dark to black non-calcareous shales with occasional passages of gradational sandstones of flyschoid character, spotted claystones and black or green, sometimes also red radiolarites of Bathonian-Callovian age (ONDREJIČKOVÁ 1990, OŽVOLDOVÁ in MOCK et al. 1993) and irregular olistostromatic accumulations. The size and composition of the olistostrome material varies from several $cm^3$ to several $m^3$. The material are above all various Triassic limestone types: crystalline limestones - marbles, quartzose and sandy limestones, cherty limestones, radiolarites, basic volcanites and serpentinites (MOCK et al. 1992, VOZÁROVÁ & VOZÁR 1992).

From the paleogeographic viewpoint, we understand Meliata as an "oceanic" domain, connected by a system of transformational faults with the Vardar, and not Kimmerian ocean, sensu KOZUR (1991). In view of the fact that in the Slovak part of the Inner Western Carpathians there are not known more important occurrences of basic volcanics, comparable e.g. with those in the Apusenians, we assume that Meliata had on the Slovak territory a more or less limited extent (rhomboschasma sensu DERCOURT et al. 1990).

Recently, STÄMPFLI (1996) published a paper, in which he considered Meliata to be a "back arc basin" . The result of a petrologic study of basic rocks of Meliaticum (IVAN & KRONOME 1996) appears to be consistent with this idea. Stämpfli (.l.c.) put the origin of Meliata already into the late Permian! In view of geological information available in the Western Carpathians we can hardly consider oceanic character of Meliata from the Permian!

As far as the beginning of sedimentation in so defined Meliata is concerned, we note that the oldest biostratigraphically proved sediments of Meliaticum are ? Rhaetian - Lower Jurassic in age (HLÔŠKOVÁ in MELLO et al. 1994). As it has been already mentioned, Doggerian-Bathonian-Callovian age has been repeatedly proved from radiolarites, intercalated in shales (KOZUR & MOCK 1985, ONDREJIČKOVÁ 1990, OŽVOLDOVÁ in MOCK et al. 1993). In this time, Meliata achieved the maximum of its extension, which resulted in oceanic character of the sedimentation and the formation of a new oceanic crust (HOVORKA & SPIŠIAK 1993).

The origin of the olistostromatic material is still a problem. In view of the fact that the material was transported into the Meliatic basin already lithified, as well as the fact that its age, including basic rocks, is Triassic-? Jurassic, we could assume that its origin was in the obducted parts of Kimmerides sensu STÄMPFLI (1995).

In the Upper Jurassic, Meliata was gradually but rapidly closed. Parts of the sedimentary prisms of Meliaticum could be subducted below the thrust Silicicum domain, while they were exposed to HTP conditions, as it is documented in the Bôrka Nappe (MAZZOLI et al 1992, MALOUSKI et al. 1993 and DALLMEYER et al. 1996). We assume that the duration of Meliata did not exceed approximately 50 Ma.

**Silicicum:** we consider it as the innermost situated paleotectonic unit of the Inner Western Carpathians, composed of several superficial nappes. Its basement is unknown. Characteristic features of Silicicum are the absence of a Paleozoic-Hercynian fundament and, for the Carpathians, a thick development of Triassic sediments, showing an affinity to the Austro-Alpine facial area (Apulian microplate).

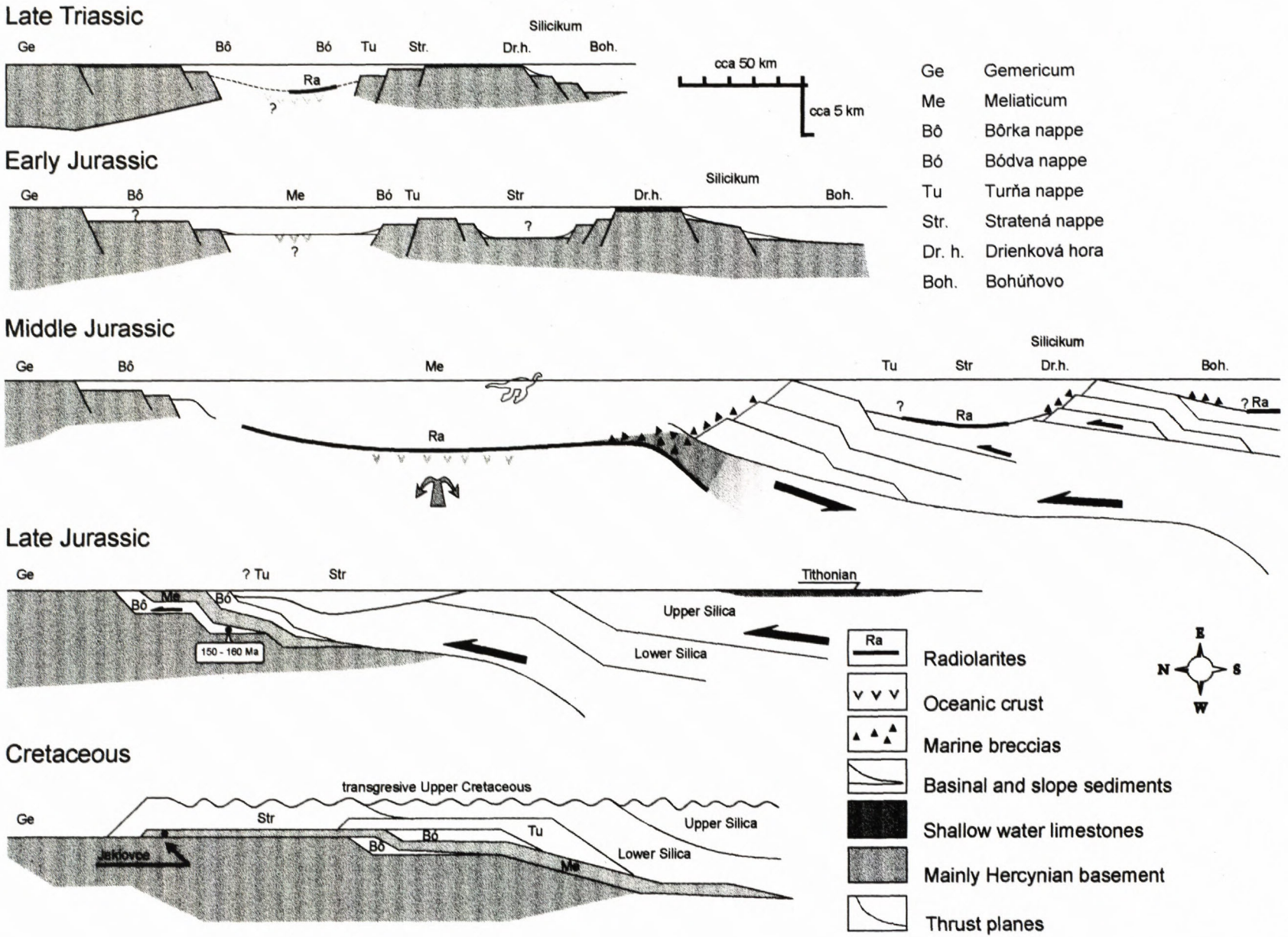
In the Jurassic, the area of Silicicum was near to Meliata (? rim basin), which is indicated by the similar sedimentary-tectonic regime in the Doggerian. The closure of Meliata led to an intensive structuring of Silicicum leading to a nappe structure and its subsequent uplift (? Kimmeridgian). The last occurring Jurassic sediments are shallow-water algal limestones, which we however know only from secondary occurrences (MIŠÍK & SÝKORA 1980).

## Tectono-sedimentary development of the area (Fig. 1)

When reconstructing the tectono-sedimentary development of the Inner Western Carpathians in the Jurassic, we base our considerations above all on information provided by the rock record of Meliaticum and Silicicum. For well-known reasons, Gemericum can be used for this purposes only to a very limited extent. We attempted to harmonise the numerous regional data with the general geodynamic development in this section of the Alpids. The selection of time levels was made bearing in mind the possible stratigraphic control and an important tectono-sedimentary event.

### Late Triassic (215-205 Ma)

In the time of the Late Triassic, the area of the Inner Western Carpathians, above all Silicicum, was in extensional regime, which resulted in the division of the origi-


Late Triassic
Ge
Bô
Bó
Tu
Str.
Dr.h.
Boh.
Silicikum
Ra
?
cca 50 km
cca 5 km
Early Jurassic
Ge
Bô
Me
Bó
Tu
Str
Dr.h.
Boh.
Silicikum
Middle Jurassic
Ge
Bô
Me
Tu
Str
Dr.h.
Boh.
Silicikum
Ra
? Ra
Late Jurassic
Ge
? Tu
Str
Tithonian
Bô
Me
Bó
150 - 160 Ma
Upper Silica
Lower Silica
Cretaceous
transgresive Upper Cretaceous
Ge
Str
Bó
Tu
Bô
Me
Jaklovce
Upper Silica
Lower Silica
Ge Gemericum
Me Meliaticum
Bô Bôrka nappe
Bó Bódva nappe
Tu Turňa nappe
Str. Stratená nappe
Dr. h. Drienková hora
Boh. Bohúňovo
Ra Radiolarites
Oceanic crust
Marine breccias
Basinal and slope sediments
Shallow water limestones
Mainly Hercynian basement
Thrust planes
E
N
S
W

nal, in the Middle Triassic formed carbonate platform, into a system of intra-platform basins with deep-water sedimentation (radiolarites in the Bódva Nape, Hallstatt limestones and Zlambach Beds in the Silica Nappe). At the same time, shallow-water carbonate platforms with reef-lagoon facies occur here as well (of Dachstein reef limestone type), separated from basin areas by normal synsedimentary faults (?Drienkova hora Fault). The same fault system appears to have controlled also the extent of Rhaetian sediments, which has been proved with certainty only in intra-platform basins. Its presence in horst elevations is problematic.

In Meliata itself, the presence of the Late Triassic is questionable. The reason may be found in the different view on the definition of Meliata and, especially, on the beginning of its formation as a domain. With certain limitations, we could include into the Uppermost Triassic the formation of black shales with small lithoclasts of carbonates, known from the borehole Držkovce (MELLO et al. 1994). Based on sporomorphs and microplankton, they are classified as Rhaetian? to lower Liassic (HLÔŠKOVÁ 1994).

In the Bôrka Nappe, we include into the Upper Triassic to ?Liassic also the formation of black shales and sandstones (MELLO 1992).

## Early Jurassic (205 - 180 Ma)

The extensional regime started in the Late Triassic, continued in the Liassic and controlled the distribution of facies. In elevated parts (Muráňska plošina Plateau, Geravy, Drienková hora), the Lower Liassic (probably Sinemurian, RAKÚS et al. in press) is transgressive in relation to Norian limestones. The continuing extensional regime caused the formation of open fissures, the depth of which could reach several tens of meters (Geravy). These neptunic dikes are filled with red biomicritic limestones of Toarcian age (canyon of the Muráň River below the Meliata village). In basal Liassic limestone, there are often present breccias (Bleskový prameň) indicating synsedimentary activity of the faults (fault escarpment).

In intra-platform basins, spotted marls of Allgäu Beds type sedimented, with layers of sandy-crinoid limestones (calciturbidites) and calcareous sandstones (Bohúňovo). In these beds, the occurrence of blue amphiboles has been recorded in the heavy fraction (personal communication of Dr. Aubrecht), which would indicated erosion of obducted ophiolitic complexes.

In the Stratenský Nappe, a formation of black shales and biomicritic limestones with spongoliths sedimented in this time. Small penetrations of basic volcanites occur here rarely.

In Meliata, the Liassic is represented by the sedimentation of dark to black shales, with thin layers of gradationally bedded sandstones and spotted claystones, while in some places (the cutting of the Muráň River) the formation is of flyschoid character.

## Middle Jurassic (180 - 155 Ma)

The time of the Middle Jurassic could be described as "revolutionary" in the geotectonic development of the Inner Western Carpathians. The extension reached its maximum, due to subsidence and the activity of extensional listric faults, resulting in the oceanisation of existing basins. This regime resulted above all in the formation of a new oceanic crust (basaltic pillow lavas in Szarvaskö (CZÁSZAR et al. 1990). In the Bathonian-Callovian (approx. 169 -159 Ma), first subductional movements occurred in Meliata, resulting in the formation of low-angle disjunctive-nappe surfaces and the movement of nappes in Silicicum. This is indicated by the olistostromatic beds in radiolarites of Bleskový prameň (MELLO 19973, SÝKORA & OŽVOLDOVÁ 1995, RAKÚS et al. in press), or in Aggteleg karst (LESS & SZENPÉTRY 1988). Similarly, in Meliata itself, the majority of olistolithic accumulations falls into this time.

## Late Jurassic (150 - 145 Ma)

In this time, the continuing subduction led to complete closure of Meliata as an oceanic domain. The structuring of Silicicum continued especially in its back parts, where a system of nappes formed. The subsequent uplift resulted in the interruption of sedimentation. Sedimentation continued only in frontal parts of the Silica Nappe system, as a "carried basin" (Stratenský Nappe), with pelagic limestone facies. In this time (probably after the Oxfordian), Meliata, including the Bôrka Nappe, was already buried below Silicicum and exposed to HTP conditions (MALOUSKI et al. 1993, DALLMEYER 1994, DALLMEYER et al. 1996).

The uplifted back parts of Silicicum became again a sedimentation area, which was however, contrary to the deep-water sedimentation in the Doggerian, markedly shallow-water (algal limestones with Clypeina). Although Tithonian limestones are found at a secondary occurrence (MIŠÍK & SÝKORA 1980), there are no serious doubts as to their belonging to the Silica Nappe System. The great facial contrast between the Doggerian and Tithonian appears to support well the idea of an uplift due to Upper Jurassic tectonogenesis.

In view of the above mentioned tectono-sedimentary development and the fact that in the whole Inner Western Carpathian area there is a chronic absence of Lower Cretaceous sediments, we assume that in this time the area was without sedimentation. A new sedimentation cycle started only in the Sennonian, with a lagoon-marine cycle.

## Conclusion

The above outlined "scenario" of the geodynamic development in the Inner Western Carpathians appears to correspond well with the present level of information on the geology of this region. As follows from the above mentioned facts, Jurassic sediments proved to by a suitable key for the deciphering of the tectonic-sedimentary development. Testing should follow, which would show to which extent the proposed model is rational. Regardless of the result of the test I would like to direct the attention to three moments resulting from the paper:

- as the first one I would like to mention that the Western Carpathians, similarly as the Alps, are a multistage mountain range, where a time sequence of great tectonic events may be observed. The tectonosedimentary development of the Jurassic in the Inner Western Carpathians would appear to support this idea.
- indisputable progress in the knowledge of stratigraphy and sedimentology of Meliaticum, and, subsequently, of the tectonic structure, was achieved only due to extensive and consistent use of biostratigraphic methods. Again, the importance of biostratigraphic methods for synthetic studies has been proved.
- two decades ago, the problems of Meliaticum did not exist, and even not so long ago, it appeared to be a purely Western Carpathian problem. Within a few years, and it must be said that thanks to a great investigative effort, it became the problem of Alpine geology, the effects of which may be estimated only with great difficulty. In view of certain historical and cultural facts, the Alps will most probably remain a model terrain, on which the attention of the geological community will be focused, as it has been recently written, very charmingly, by Professor TRÜMPY (1996). With certain satisfaction we may state, on the example of Meliata, that even an incomparably smaller territory, with a less rich history of investigations, such as the Western Carpathians, may become a source of inspiration for a thoroughly studied mountain range.

## References


ANDRUSOV, D., 1975: Apercu bref du bati des Carpathes occidentales.- Xth Conr. Carp. Balk. Geol. Ass., Gen. Proc. Bratislava, p. 95-108

BALLA, Z., 1984: The North Hungarian Mafics and Ultramafics. - Acta Geol. Hung. 27(3-4), Budapest, p. 341-357.

CSÁSZÁR, G., GALÁCZ, A. HAAS, J., KÁZMÉR, M., KOVÁCS, S. NAGZMAROSY, A., SZENTGYORGY, K., & VOROS, A., 1990: Paleogeography of the Pannonian basin. in: IGCP project 198 "Evolution of the northern margin of tethys", joint publ. ESRI-GUDŠ and SGF, N. S., 154, III, pt. 1, p. 63-89.

CSONTOS, L. & PELIKAN P., 1991: Radiolarians from the Bukk Mts. A M. Áll. Foldt. Int. Évijelentese az 1989. Érvoll(1991), Budapest, p. 357-381

CSONTOS, & L. VOROS. A., 1992: Mesozoic Plate-tectonic Reconstruction of the Alpine-Carpathian-Pannonian Region, Part1: Definition and Correlation of the Main Tectonic Units. - Terra abstracts, Abstr. suppl.No 2 to Terra nova, 4, p. 13-14, (ALCAPA meeting, Graz), Blackwell Sc. Publ. Oxford, London, etc.

DALLMEYER, R. D., NEUBAUER, F., FRITZ, H. & PUTIŠ, M., 1994: Variscan vs. Alpine tectonothermal evolution within the Eastern Alps and Western Carpathians, Austria-Slovakia. J.Tectonics Reg. Geol. 75, Suppl. 1, p. 12-13, Amsterdam

DALLMEYER, R. D., NEUBAUER, F., HADLER, R., FRITZ, H., MULLER, W., PANA, D. & PUTIŠ, M., 1996: Tectonothermal evolution of the internal Alps and Carpathians: Evidence from $^{40}Ar/^{39}Ar$ mineral and whole-rock data. Eclogae geol. Helv. 89/1, p. 203-227

DERCOURTE, J., RICOU,L. E., ADAMIJA, S., CSÁSZAR, G., FUNK, P., LEFELD, J., RAKÚS, M., SANDULESCU, M & TOLLMANN, A., 1990: Anisian to Oligocene Paleogeography of the European Margin of Tethys (Geneva to Baku). in: IGCP project 198 "Evolution of the northern margin of Tethys", joint publ. ESRI - GÚDŠ and SGF, N.S., 154, part III, p. 158-190

GRECULA, P., 1983: Gemericum - segment riftogenného bazénu Paleotétydy. Mineralia Slovaca - Monogr., Bratislava, Alfa: 263p. (In Slovak)

GRILL, J., 1988: A Rudabányai - hegység jura formációi. Magy. Áll. Fold. Int. Évi. az 1986, erv.(1988), Budapest ,p.69-103

HAAS, J., KOVÁCS, S., KRYSTYN, L. & LEIN, R., 1995: Significance of Late Permian-Triassic facies zones in terrane reconstruction in the Alpine-North Pannonian domain. Tectonophysics 242 (1995), p. 19-40

HAVRILA, M. & OŽVOLDOVÁ, L., 1996: Meliaticum of the Stratenská hornatina Hills. Slovak Geol. Mag. 3-4/96

HLÔŠKOVÁ, Z., 1994: Palynologické vyhodnotenie vrtu Držkovce-1. Archív GÚDŠ Bratislava

HÓK, J., KOVÁČ, P. & RAKÚS, M., 1995: Výsledky štruktúrneho výskumu Vnútorných Karpát a ich interpretácia. Mineralia Slovaca 23 (1995), p. 231-235

HOVORKA, D. & SPIŠIAK, J., 1993: Mesozoic Volcanic Activity of the Wetern Carpathians Segment of the Tethyan Belt: Diversities in Space and Time. Jb. Geol. B.-A., 136/4, p. 769-782.

IVAN, P. & KRONOME, B., 1996: Predmetamorfný charakter a geodynamické prostredie vzniku vysokotlakovo metamorfovaných bazitov meliatskej jednotky na lokalitách Radzim, Bôrka, Hačava a Rudník. Mineralia Slovaca 28(1996), 1, p. 26-337 (In Slovak)

IVANOV, M., 1953 : Geologicko - petrografické a rudné pomery v severnej severnej časti Spišsko - gemerského rudohoria medzi Kluknavou Žakarovcami. Geol. Zbor., IV, 3/4, p. 705 - 750.

KOVÁCS, S., 1984: North Hungarian Triasssic Facies Type - a review. Acta geol. Hung., 27, 3-4, p. 251-264

KOVÁCS, S. 1992: Tethys "western ends" during the Late Paleozoic and Triassic and their possible genetic relationships. Acta geol. Hung., 35/4, p. 329-369

KOVÁCS, S., 1992: Presence of a Cimmerian Ocean in the Alps-Carpathians - a reality or absurdity? Terra nova

Abstracts suppl. 2, 1992, ALCAPA meeting in Graz, Austria, p. 38

KOVÁCS, S., CSÁSZÁR, G., HAAS, J., NAGY, E. & VÖRÖS, A., 1989: The Tisza Superunit was originally Part of the North Tethyan(European) Margin. in IGCP project 198"Evolution of the Northern Margin of the Tethys", joint publ. of ESRI - GÚDŠ and SGF, N. S.,154, II, p. 81-100

KOZUR, H., 1979: Einige Probleme der geologischen Entwinklung im südlichen Teil der Inneren Westkarpaten. Geol. paläont. Mitt., 9/4, p. 155-170

KOZUR, H., 1991: The geological evolution at the western end of the Cimmerian ocean in the Western Carpathians and Eastern Alps. Zbl. Geol. Paläont. 1/1,p. 99-121

KOZUR, H. & MOCK, R., 1973: Zum Alter und zur tektonische Stellung der Meliata Serie des Slovakischen Karstes. Geol. zbor. SAV, 24/2, p. 365-374

KOZUR, H. & MOCK, R., 1985: Erster Nachweis von Jura in der Meliata Einheit der Sudlichen Westkarpaten. Geol. Pal. Mitt. 13/10, p. 223-238

KOZUR, H. & MOSTLER, H., 1992: Erster Paläontologischer Nachweis von Meliatikum und Sud-Rudabanyaikum in den Nordlichen Kalkalpen, Österreich) und ihre Beziehungen zu den Abfolgen in den Westkarpaten. Geol. Pal. Mitt., 18, p. 87-129.

KOZUR, H. & MOCK, R., 1995: First evidence of Jurassic in the Folkmar suture zone of the Meliaticum in Slovakia and its tectonic implication. Geol. Soc. Greece, Spec. Publ. No.4, 1995, p. 53-58

KRS, M., PRUNER, P. & KRSOVÁ, M., 1993: Paleomagnetické výskumy v roku 1992 pre úlohu: Hlbinná stavba a geodynamický model Západných Karpát. GÚ ČAV, Paleomag. lab. Pruhonice, Archív GÚDŠ Bratislava

KRUCZYK, J., KADZIALKO-HOFMOKL, M., LEFELD, J., PAGÁČ P. & TÚNYI, I., 1992: Paleomagnetism of Jurassic sediments as evidence for oroclinal bending of the Inner West Carpathians. Tectonophysics, 206, p. 315-327

LESS,GY. & SZENTPÉTERY, I., 1988: Geological map of Aggtelek.

MALOUSKI, H., REILICH, P. & MATTE, P., 1993: Ar-Ar dating of the Inner Carpathians Variscan basement and Alpine mylonitic overprinting. Tectonophysics, 223, p. 313-337

MANDL, G. & ONDREJIČKOVÁ, A., 1991: Ueber eine triadische Tiefwasserfacies (Radiolarite, Tonschiefer) in den Nördlichen Kalkalpen - ein Vorsicht. Jb. Geol. B.-A., 134/2, p. 309-318.

MÁRTON, P., ROZLOŽNÍK, L. & SASVÁRI, T., 1981: Implications of a paleomagnetic study of Silica nappe, Slovakia. Geophysic Int. Jour., 107, p. 67-75

MÁRTON, E., MÁRTON, P., LESS, G., 1988: Paleomagnetic evidence of tectonic rotation in the southern margin of the Inner West Carpathians. Physic of the Earth and Planetary Int., 52, p. 256-266

MAZZOLI, C., SASSI, R., VOZÁROVÁ, A., 1992: The pressure character of Alpine metamorphism in the Central and Inner Western Carpathians. in: Spec. vol. IGCP-276, Geol. Úst. D. Štúra, p. 109-117

MELLO, J. & GAAL, Ľ., 1984: Meliatská skupina v čoltovskej rokli. Geol.Práce, Správy 81, p. 51-62 (In Slovak)

MELLO, J., ELEČKO, M., GAÁL,Ľ., HÓK, J., HANZEL, V., KOVÁČ, P., PRISTAŠ, J., REICHWALDER, P., SNOPKO, L., STEINER, A., SLAVKAY, M., VASS, D. & VOZÁROVÁ, A., 1992: Vysvetlivky ku geologickej mape Slovenského krasu 1:50.000. Manuscript, Archív GÚDŠ, Bratislava

MELLO, J., VOZÁROVÁ, A., VOZÁR, J., GARGULÁK, M., HANZEL, V., KÁČER, Š., KÁROLI, S., MOLÁK, B., ŠUCHA, V. & ŠIRÁŇOVÁ, V.,1994: Vyhodnotenie štruktúrneho vrtu Držkovce -1. Archív GÚDŠ, Bratislava (In Slovak)

MIŠÍK, M. & SÝKORA, M., 1980: Jura der Silica Einheit, rekonstruirt aus gerollen und oberkretazische Suesswasser Kalke des Gemerikums. Geol zbor. SAV, 31/3: 239-261.

MOCK, R. (edit.), 1992: Problematika meliatika v oblasti Spišsko-gemerského rudohoria a v Slovenskom krase - etapová správa za rok 1992., manuscript, Archív GÚDŠ, Bratislava, p. 1-33, (In Slovak)

MOCK R. (edit.)., 1993: Problematika meliatika v oblasti Spišsko-gemerského rudohoria a v Slovenskom krase. Archív GÚDŠ, p. 1-22, pl.1-16

ONDREJIČKOVÁ, A., 1990: Radiolárie triasu a jury Slovenského krasu., manuscript, Archív GÚDŠ, Bratislava, p. 1-54, 151 pl. (In Slovak)

RAKÚS, M., 1992: A possible palinspastic arrangement during the Jurassic in the West Carpathians territory. Int. Geol. Congr. Kyoto 1992, Abstracts I-3-24 (6989)

RAKÚS, M., 1993: Úskalia a problémy paleogeografických rekonštrukcií mezozoika Západných Karpát in: RAKÚS and Vozár edit.: Geodyn.model a hlbinná stavba Západných Karpát, GÚDŠ, Bratislava:, p. 103-107 (In Slovak)

RAKÚS, M., SÝKORA, M. & OŽVOLDOVÁ, L., 1996: Jurassic of silicikum and meliaticum. Slovak Geol. Mag. (in prep.)

RÉTI, Zs., 1985: Triassic ophiolite fragments in an evaporitic melange, Northern Hungary. Ofioliti, 10 (2/3), Bologna, p. 411-422.

STAMPFLI, G.M., 1996: The Intra-Alpine terrain: A Paleotethyan remnant in the Alpine Variscides. Eclogae geol. Helv. 89/1, p. 13-42, Basel

TRÜMPY, R., 1996: Alpine geology: whence, whither? Eclogae geol. Helv., 89/, p. 7-12, Basel

VOZÁROVÁ, A. & REICHWALDER, P., 1983: Gočaltovská skupina in: BAJANÍK & VOZÁROVÁ et al.: Vysvetlivky ku geologickej mape Slovenského rudohoria - východná časť. GÚDŠ Bratislava, p. 122-130 (In Slovak)

VOZÁROVÁ, A. & VOZÁR, J., 1992: Tornaikum and meliatikum in borehole Brusník BRU-1, Southern Slovakia. Acta Geol. Hung., 35/2, Budapest, p. 97-116

SLOVAK GEOLOGICAL MAGAZINE

# Mid-Cretaceous (120-80 Ma) orogenic processes in the Central Western Carpathians: brief review and interpretation of data

DUŠAN PLAŠIENKA

Geological Institute of the Slovak Academy of Sciences, Dúbravská cesta 9, 842 26 Bratislava, Slovakia

*Abstract.* The scenario of the mid-Cretaceous (120-80 Ma, i.e. Aptian to Campanian) tectonic processes in the Central West Carpathian area includes collapse of the thermally softened supra-Veporic thrust stack and exhumation of the Veporic metamorphic core complex by orogen-parallel extensional unroofing, triggered by underthrusting of the Fatric (Krížna) crust accompanied by detachment of the sedimentary filling of the Fatric basinal area to form the Krížna cover nappe. This was later gravitationally emplaced northward above the Tatric cover and followed by gliding of Hronic (Choč) and Silicic cover nappes. In the early Late Cretaceous, contraction affected the outer, northern Tatric margin of the CWC facing the Penninic-Vahic oceanic realm. All these processes exhibit an outward (generally northward) polarity.

*Key words:* Central Western Carpathians, paleo-Alpine orogenesis, crustal stacking, nappe emplacement

## Introduction

The Cretaceous stage, mid-Cretaceous times in particular, was the main period of tectogenesis of units in the Central Western Carpathians (CWC). The CWC are defined here as an early Alpidic orogenic belt located between two principal, more or less latitudinally trending oceanic sutures: the Penninic-Vahic (opened in the Middle Jurassic, closed in the latest Cretaceous to Early Tertiary) in the north and the Meliata-Hallstatt (opened in the Middle Triassic or earlier, closed in the Late Jurassic) in the south. However, the exact position of especially the latter suture is a matter of controversy and several branches of both oceanic domains may be present in the Carpathian edifice (e.g. KOZUR & MOCK, 1995). The CWC, as a lateral analogue of the Austroalpine system, are composed of Tatric, Veporic and Gemeric thick-skinned basement sheets, and Fatric, Hronic and Silicic cover nappe groups. Paleogeographically only the Fatric (Krížna) nappes were clearly positioned within the CWC basement area – between the Tatric and Veporic domains. The homeland of the Hronic (Choč) nappes remains disputable, though most probably located still northwards of the Meliata-Hallstatt oceanic channel. The Silicic units with obvious "southern" affinities, which are often underlain by Meliatic slices, might be derived from the southern margin of this ocean (HÓK et al., 1995). Nevertheless, after being emplaced during the Late Cretaceous, the Silicic nappes became integral constituents of the CWC.

The aim of this paper is to register the most important, sufficiently precisely (directly or undirectly) age-constrained paleotectonic data and to interpret them tentatively in order to reconstruct the temporal and spatial interplay among different tectonic processes operative during the main phase of nappe thrusting in the CWC.

## Mid-Cretaceous events

In the following paragraphs, the principal data coming from the stratigraphic, sedimentologic, magmatic, metamorphic, geochronologic and structural rock record are listed and their tentative interpretations are presented. Due to the limited extent of the present paper, only the most important general articles and some newest results are quoted. Processes, which probably have left the records discussed, are synoptically depicted in Fig. 1. The timescale by GRADSTEIN et al. (1994) is adopted.

**Period 120-110 Ma** (Aptian to early Albian). Almost no direct data exist from the Meliatic, Silicic, Hronic, Gemeric and south Veporic units, except some radiometric datings: one solitary formation plateau age of amphibole from the Veporic basement (115 Ma, KOVÁČIK and MALUSKI, 1994) and the age of Alpidic remobilization of U, Mo and Cu vein mineralization in the northern Gemeric domain (130±2O Ma, U-Pb isotopic dating of higher-grade veins and 115±10 Ma, Pb model age of low-grade veins - ROJKOVIČ et al., 1993). At the north Veporic – south Fatric interface (Veľký Bok unit), pelagic sedimentation terminated and no younger rocks are known. Huge olistostromatic bodies derived from the south were formed in the Fatric Zliechov basin (JABLONSKÝ & MARSCHALKO, 1992). Ephemeral "Urgonian"

carbonate platforms gradually ceased in the north Fatric - south Tatric domains, rimmed by allodapic clastic fans (MIŠÍK, 1990; MICHALÍK & SOTÁK, 1990; MICHALÍK, 1994), and generally pelagic deposition continued in the Fatric-Tatric-Vahic area. Some siliciclastic turbidites of local sources were deposited in the northern Tatricum (Solírov fm., JABLONSKÝ et al., 1993). Areally extensive, though volumetrically negligible submarine hyalobasanitic volcanism in the Fatric and Tatric region (HOVORKA and SPIŠIAK, 1993) is a very important paleotectonic signature.

The above facts may be interpreted as records of a gradual thermal equilibration and slow uplift of the southern "supra-Veporic" collisional zones ("Andrusov mountain range" in Fig. 1) and a northward progradation of contraction to the Veporic-Fatric margin (Veľký Bok domain). Its imbrication produced the topographic gradient controlling the mass slope resedimentation in the Fatric Zliechov basin. Contemporaneously, an extensional impulse occured in the Fatric-Tatric foreland which caused rejuvenization of normal faulting and block tilting accompanied by small portions of mantle-derived lavas piercing the strongly thinned crust. The carbonate buildups grew on elevated edges of tilted blocks, probably assisted by foreland bulge upbending and the sea-level drop.

**Period 110-90 Ma** (middle Albian to late Turonian). Only scarce, sufficiently age-constrained data are available in the Meliatic-Gemeric-Veporic-Silicic-Hronic areas (except some thermochronological in the Veporic basement, summarized by KOVÁČ et al., 1994). The Alpidic metamorphic peak in the Veporicum has been recently estimated to maximum 550-600 °C and 8-10 kbar in the deepest basement unit (Janák, unpublished) and to at least 400 °C and 6-8 kbar in the Permian cover (JANÁK & PUTIŠ, unpublished data), the low-grade metamorphic imprint in the overlying Gemericum is documented by the 105 Ma plateau age from the Permian sediments (DALLMEYER et al., 1994). The thrusting-related structural record in the rear parts of the Fatric Krížna cover nappe and in the Veľký Bok units (their décollement and stacking) is generally well known (PLAŠIENKA 1983, 1995a and references therein) and partly dated (101 Ma, K-Ar on white micas - NEMČOK & KANTOR, 1989). After the rapid submersion of Urgonian carbonate platforms, only pelagic and synorogenic coarsening-upward flysch sedimentation (Poruba fm.) is present in the Fatric (up to the early Cenomanian) and Tatric (up to the early Turonian) zones. The flysch conglomerates contain, except common CWC lithofacies, also a lot of "exotic" pebbles of disputable provenance (see reviews by MIŠÍK et al., 1981; MIŠÍK & MARSCHALKO, 1988). However, only pelagites are present in the Vahic Belice unit (PLAŠIENKA et al.,1994). Shortening within the Tatric basement began already to the end of this stage, as some contractional structures at the South Tatric ridge - Šiprúň basin interface (Nízke and Vysoké Tatry Mts.) are partly saled by the superimposed Krížna nappe (Fig. 1).

Interpretation: the thermal equilibration and peak of Barrowian metamorphism was probably reached in the deeply buried (more than 20 km!) Veporicum some 110-100 Ma b.p., thermal softening enabled its later unroofing. However, during the mid-Cretaceous stage, a rapid underplating of the Fatric basement below the Veporic one forced compressional upheaval of the Veporic-Gemeric-Meliatic ("exotic") pile, the top of which became exposed to intense erosion and fed the neighbouring Klape-Poruba flysch basin by coarse, mostly "exotic" clastics (the Klape unit is considered here as a Fatric element, adopting the view of PLAŠIENKA, 1995b). This acceleratively developing situation is schematically outlined in Fig. 1. Tatric Urgonian platforms were submerged due to flexural downbending of the lower orogenic plate, which contributed also to the development of forearc or trench-type flysch basins. Contemporaneously, the sedimentary succession of the Fatric basin was detached from its underthrust substratum along the horizon of Upper Scythian shales and evaporites and formed up an imbricated fold-and-thrust wedge accreted to the upper Veporic plate (cf. PLAŠIENKA & PROKEŠOVÁ, 1996). Inversion started in the inner Tatric zones.

**Period around 90 Ma** (late Turonian). Extensive surface overthrusting event in the CWC: emplacement of the Fatric (Krížna) and Hronic (Choč) décollement cover nappe systems, narrowly constrained by the youngest Tatric cover sediments below the Krížna overthrust plane (lower Turonian) and the oldest basinal post-nappe Gosau deposits atop the Hronic nappes (upper Coniacian in the western part of the CWC). Structural features at soles of superficial nappes include overpressured carbonate tectonic breccias, sometimes entirely dissolved ("macrostylolite" of JAROSZEWSKI, 1982), without a considerable deformation effect on the footwall rocks (PLAŠIENKA & SOTÁK, 1996). The emplacement of the Krížna nappe is recorded by extensional structures superimposed on older contractional ones in its rear and dorsal parts (PROKEŠOVÁ, 1994).

Interpretation: structural associations and relationships in the cover nappes point to the final gravity gliding emplacement mechanism, though push from the rear and gravity spreading might contributed as well, especially in the first phases of thrusting. The necessary topographic gradient was produced by overstepping the frontal Tatric ramp in the case of the Krížna nappe (cf. PLAŠIENKA and PROKEŠOVÁ, 1996). The detachment and driving mechanisms of Hronic nappes, especially of those floored by thick Upper Paleozoic sedimentary and volcanic sole (Ipoltica group), is more difficult to interpret. Probably Hronic nappes were derived from southern, rapidly uplifting zones juxtaposed to the "Andrusov Mountain Range" in the SW (?) which escaped considerable Early Cretaceous stacking. The

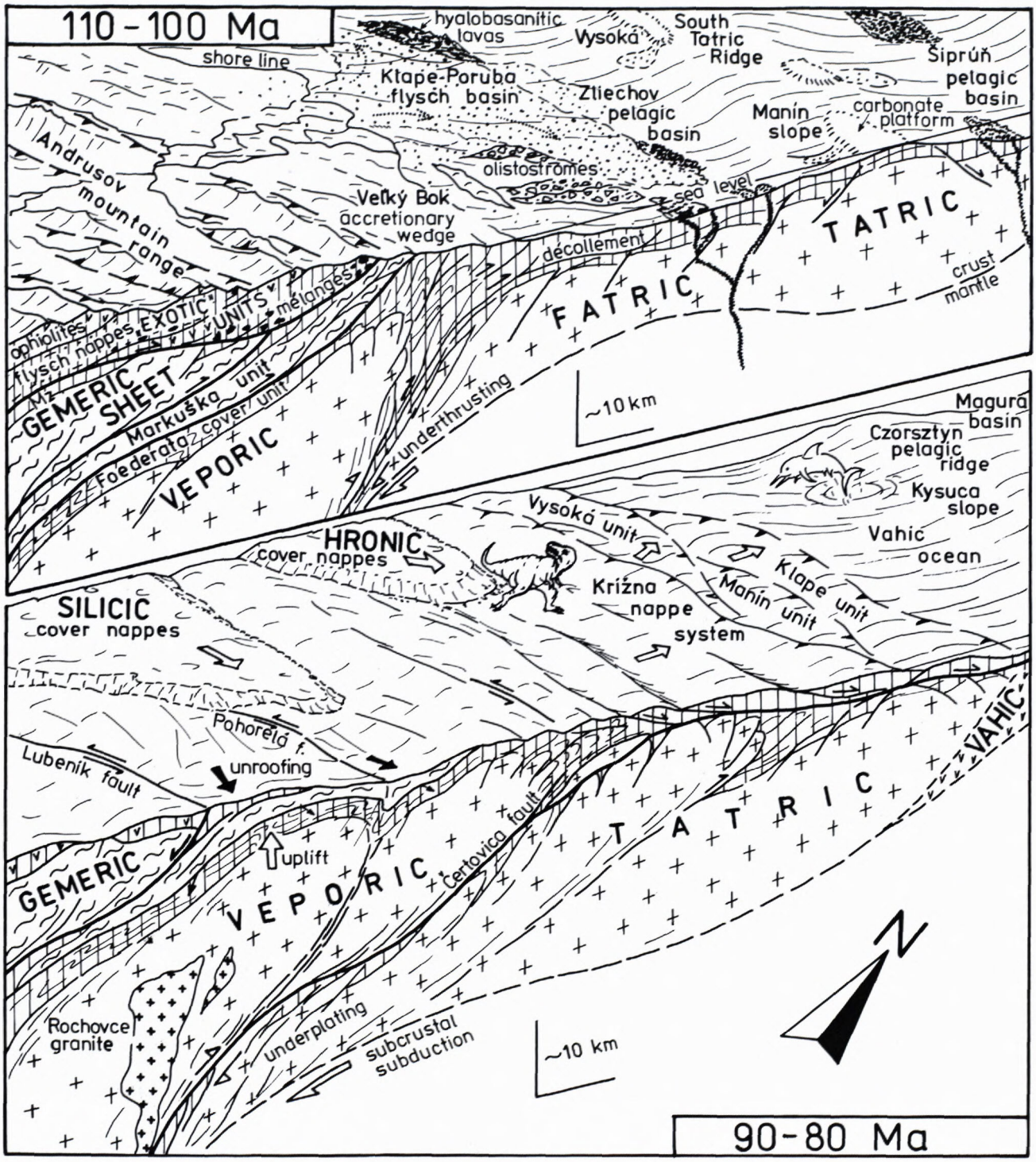



*Fig. 1. Schematic cartoon synoptically depicting the major mid-Cretaceous tectonic events in the Central West Carpathian area.*

Silicic units might be originally related to the Hronic ones, their final emplacement event seems to be younger, however.

**Period 90-80 Ma** (latest Turonian to early Campanian). Most of the cooling isotopic ages from the Veporic metamorphic core complex fall within this time interval (see review by KOVÁČ et al., 1994, and references therein). Cooling accompanied ductile extensional unroofing of the Veporic core with top-to-the east kinematics in its eastern part (HÓK et al., 1993; PLAŠIENKA,

1993). Orogen-parallel extension occured under a general N-S contractional regime with sinistral transpression along SW-NE trending wrench zones (e.g. the Pohorelá fault zone - HÓK & HRAŠKO, 1990; PUTIŠ, 1991; MADARÁS et al., 1994). Extension culminated by intrusion of the Rochovce granite in the southern Veporicum (81 Ma zircon age - HRAŠKO et al., 1995). The Rochovce granitic body is an alkaline intrusion generated by anatexis of crustal rocks and emplaced in an extensional regime in higher crustal levels (RADVANEC, 1995) with a contact aureole superimposed on regional mineral assemblages. Unmetamorphic Silicic nappes in the Veporic and Gemeric area overrode a deeply denuded substratum, therefore a pronounced metamorphic and structural gap exists at their bases, representing some 15-20 km of missing rock column in-between. Sporadically preserved Lower Senonian sediments in the CWC (except their northern rim) consist of probably Santonian continental conglomerates and fresh-water limestones and lower Campanian open-marine variegated marls. The Vahic Belice succession exhibits the change from eupelagic to coarsening-upward flysch sedimentation at the Turonian/Coniacian boundary (PLAŠIENKA et al., 1994). Lower Senonian sediments along the outer Tatric edge in the Periklippen zone show variable compositions and sedimentary enviroments, from transgressive and then deepening succession of the Gosau group up to continuos (?) mid- to Upper Cretaceous pelagic and flysch sequences (e.g. SALAJ, 1994a, b, 1995).

Interpretation of these data considers extensive gravitational collapse of the southern CWC zones triggered by contractional uplift of the Veporic core, probably due to underplating of a buoyant Fatric crust and enhaced by strain softening after thermal relaxation of the Lower Cretaceous thrust stack. The rapidly exhumed Veporic cover and basement units were in turn immediately overthrust by unmetamorphic cover nappes of the Silicic system. The Veporic cover and upper parts of the basement were highly mobile during low-angle extension which superposed sheet-like units with discontinuously decreasing metamorphic overprint and "condensed" isograds. The area was sinking at least until the middle Campanian, when it was covered by an epicontinental sea (partly also as a consequence of the sea level rise). No record of this stage has been ascertained in the northern (Tatric) area of the CWC, which was most probably a dry land exposed to karstification of especially the Triassic carbonate complexes of the highermost Hronic nappes (MICHALÍK and ČINČURA, 1992; ČINČURA & KÖHLER, 1995), but zones along the northern CWC margin underwent the main compressional phase after the conversion of the Tatric/Vahic passive margin into the active one (PLAŠIENKA, 1995b, c). The frontal Fatric-Hronic nappe elements partly glided into a position above the Vahic in front of the Tatric edge, where they became incorporated into fold-and-thrust complexes accreted to the toe of the upper (Tatric) plate. Sedimentary cover of the oceanic Vahic basement was partly detached to form a subcretionary complex underneath the Tatric toe (PLAŠIENKA, 1995d). It follows that the converging zone was composed of sectors where the Tatric/Vahic contact was buried below the Central Carpathian nappe units topped by compressional piggyback forearc-type basins and sectors where this contact was exposed at the surface and trench-type wildflysch sedimentation occured atop the lower Vahic plate (Belice unit, PLAŠIENKA, 1995d, Fig. 8).

## Conclusion

The above scenario clearly illustrates the northward propagation of mid-Cretaceous orogenic processes in the CWC area. In the time interval considered (120-80 Ma), the southern Veporic, Gemeric and Inner Western Carpathian zones were the site of post-collisional (after suturing of the Meliata-Hallstatt ocean) thermal relaxation and gradually accelerating uplift triggering the extensional collapse of the Veporic metamorphic core complex. Simultaneously, the shortening axis migrated northwards to attack the north Veporic - south Fatric and later the Tatric zones. The emplacement of Fatric and Hronic nappe systems appears to be a very time-limited surface event, being driven by gravitational spreading and gliding towards the foreland, generally not related to the main compressive phases in the respective paleogeographic domains. The passive to active margin inversion of the Tatric/Vahic interface during the early Senonian fits well the overall shortening polarity within the CWC. Consequently, the mid-Cretaceous contraction in the CWC realm had to be driven by geodynamic processes other than subduction of the Penninic-Vahic slab along their outer edge.

*Acknowledgements*

The paper conributes to the research project "Geodynamic evolution of the Western Carpathians" and to the Academic grant project No. 1081. The Geological Survey of the Slovak Republic and the Scientific Grant Agency are thanked for the financial support.

## References

ČINČURA J. & KÖHLER E., 1995: Paleoalpine karstification – the longest paleokarst period in the Western Carpathians (Slovakia). Geol. carpath., 46, 343–347.

DALLMEYER R. D., NEUBAUER F., FRITZ H. & PUTIŠ M., 1994: Variscan vs. Alpine tectonothermal evolution within the Eastern Alps and Western Carpathians, Austria – Slovakia. Rom. J. Tect. Reg. Geol., 75, Suppl 1 – ALCAPA II Abstr Vol.

GRADSTEIN F. M., AGTERBERG F. P., OGG J. G., HARDENBOL J., VAN VEEN P., THIERRY J. and HUANG Z., 1994: A Mesozoic time scale. J. Geophys. Res., 99, 24051–24074.

HÓK J. & HRAŠKO L., 1990: Deformation analysis of the western part of the Pohorelá line (in Slovak, English summary). Miner. slov., 22, 69–80.

HÓK J., KOVÁČ P. & MADARÁS J., 1993: Extensional tectonic of the western part of the contact area between Veporicum and Gemericum (Western Carpathians). Miner. slov., 25, 172–176.

HÓK J., KOVÁČ P. & RAKÚS M., 1995: Structural investigations of the Inner Carpathians - results and interpretation (in Slovak, English summary). Miner. slov., 27, 231–235.

HOVORKA D. & SPIŠIAK J., 1993: Mesozoic volcanic activity of the Western Carpathian segment of the Tethyan belt: Diversities in space and time. Jb. Geol. B.-A., 136, 769–782.

HRAŠKO Ľ., MICHALKO J., HATÁR J., HÓK J., VAASJOKI M. & KOTOV A. B., 1995: Upper Cretaceous granite in Western Carpathian region. Terra Abstr., 7, 1, 271.

JABLONSKÝ J. & MARSCHALKO R., 1992: Pre-flysch olistostromes in Central Western Carpathians (Barremian – Aptian of Krížna nappe, Slovakia). Geol. carpath., 43, 15–20.

JABLONSKÝ J., MICHALÍK J., PLAŠIENKA D. & SOTÁK J., 1993: Sedimentary enviroments of the Solírov Formation and correlation with Lower Cretaceous turbidites in central West Carpathians, Slovakia. Cretaceous Res.,14, 613–621.

JAROSZEWSKI W., 1982: Hydrotectonic phenomena at the base of the Krížna nappe, Tatra Mts. In M. MAHEĽ ed.: Alpine structural elements: Carpathian-Balkan-Caucasus-Pamir orogene zone. Veda, Bratislava, 137–148.

KOZUR H. & MOCK R., 1995: First evidence of Jurassic in the Folkmar Suture Zone of the Meliaticum in Slovakia and its tectonic implications. Miner. slov., 27, 301–307.

KOVÁČ M., KRÁĽ J., MÁRTON E., PLAŠIENKA D. & UHER P., 1994: Alpine uplift history of the Central Western Carpathians: geochronological, paleomagnetic, sedimentary and structural data. Geol. carpath., 45., 83–96.

KOVÁČIK M. & MALUSKI H., 1994: Alpine reactivation of eastern Veporic basement (Western Carpathians). Terra Abstr., 7, 1, 45.

MADARÁS J., PUTIŠ M. & DUBÍK B., 1994: Structural characteristic of the middle part of the Pohorelá tectonic zone; Veporicum, Western Carpathians. Miner. slov., 26, 177–191.

MICHALÍK J., 1994: Lower Cretaceous carbonate platform facies, Western Carpathians. Palaeogeogr., Palaeoclimat., Palaeoecol., 111, 263–277.

MICHALÍK J. & ČINČURA J., 1992: Cretaceous shallow marine clastics and continental/freshwater deposits in the Western Carpathians, Czechoslovakia. Cretaceous Res., 13, 157–166.

MICHALÍK J. & SOTÁK J., 1990: Lower Cretaceous shallow marine buildups in the Western Carpathians and their relationship to pelagic facies. Cretaceous Res., 11, 211–227.

MIŠÍK M., 1990: Urgonian facies in the West Carpathians. Knih. Zem. Plyn. Naft., 9a, 25–54.

MIŠÍK M., JABLONSKÝ J., MOCK R. & SÝKORA M., 1981: Konglomerate mit exotischem Material in dem Alb der Zentralen West Karpaten – Paläogeographische und tektonische Interpretation. – Acta Geol. Geogr. Univ. Comen., Geologica, 37, 5–55.

MIŠÍK M. & MARSCHALKO R., 1988: Exotic conglomerates in flysch sequences: examples from the West Carpathians. In RAKÚS M., DERCOURT J. & NAIRN A. E. M. (eds.): Evolution of the northern margin of Tethys, I.- Mém. Soc. Geol. France, n.s. 154., 95–113.

NEMČOK M. & KANTOR J., 1989: Study of movement in selected part of Veľký Bok unit. Reg. Geol. Záp. Karp., Správy o výsk. GÚDŠ Bratislava, 25, 75–82.

PLAŠIENKA D., 1983: Kinematic assessment of some structures of the Northern Veporic in relation to the generation of the Krížna nappe (in Slovak, English summary). Miner. slov., 15, 217–231.

PLAŠIENKA D., 1993: Structural pattern and partitioning of deformation in the Veporic Foederata cover unit (Central Western Carpathians). In M. RAKÚS and J. VOZÁR (eds): Geodynamic model and deep structure of the Western Carpathians. Konferencie, Sympóziá, Semináre, Geol. Úst. D. Štúra, Bratislava, 269–277.

PLAŠIENKA D., 1995a: Cleavages and folds in changing tectonic regimes: the Veľký Bok Mesozoic cover unit of the Veporicum (Nízke Tatry Mts., Central Western Carpathians). Slov. Geol. Mag., 2/95, 97–113.

PLAŠIENKA D., 1995b: Mesozoic evolution of Tatric units in the Malé Karpaty and Považský Inovec Mts.: Implications for the position of the Klape and related units in western Slovakia. Geol. Carpath., 46, 101–112.

PLAŠIENKA D., 1995c: Passive and active margin history of the northern Tatricum (Western Carpathians, Slovakia). Geol. Rundschau, 84, 748–760.

PLAŠIENKA D., 1995d: Origin and structural position of the Upper Cretaceous sediments in the northern part of the Považský Inovec Mts. Part 2: Structural geology and paleotectonic reconstruction (in Slovak, English summary). Miner. slov., 27, 179–192.

PLAŠIENKA D., MARSCHALKO R., SOTÁK J., PETERČÁKOVÁ M. & UHER P., 1994: Origin and structural position of Upper Cretaceous sediments in the northern part of the Považský Inovec Mts. Part 1: Lithostratigraphy and sedimentology (in Slovak, English summary). Miner. slov., 26, 311–334.

PLAŠIENKA D. & PROKEŠOVÁ R., 1996: Towards an evolutionary tectonic model of the Krížna cover nappe (Western Carpathians, Slovakia). This volume.

PLAŠIENKA D. & SOTÁK J., 1996: Rauhwackized carbonate tectonic breccias in the West Carpathian nappe edifice: introductory remarks and preliminary results. This volume.

PROKEŠOVÁ R., 1994: Structural analysis of the Krížna nappe in its near-root and superficial position (in Slovak, English summary). Miner. slov., 26, 347–254.

PUTIŠ M., 1991: Geology and petrotectonics of some shear zones in the West Carpathian crystalline complexes. Miner. slov., 23, 459–473.

RADVANEC M., 1994: Crystallization sequence under partial crust melting in extensive regime on the example of granite generation in Ochtiná and Rochovce area (Western Carpathians - in Slovak, English summary). Miner. slov., 26, 373–386.

ROJKOVIČ I., NOVOTNÝ L. & HÁBER M., 1993: Stratiform and vein U, Mo and Cu minerallization in the Novoveská Huta area, CSFR. Mineralium Deposita, 28, 58–65.

SALAJ J., 1994a: Geology of Middle Váh valley. Klippen and Periklippen belt, Súľov Paleogene and Mesozoics of northern part of Strážovské vrchy hills – part 1 (in Slovak, English summary). Zem. Plyn Nafta, 39, 195–291.

SALAJ J., 1994b: Geology of Middle Váh valley. Klippen and Periklippen belt, Súľov Paleogene and Mesozoics of northern part of Strážovské vrchy hills – part 2 (in Slovak, English summary). Zem. Plyn Nafta, 39, 297–395.

SALAJ J., 1995: Geology of Middle Váh valley. Klippen and Periklippen belt, Súľov Paleogene and Mesozoics of northern part of Strážovské vrchy hills – part 3 (in Slovak, English summary). Zem. Plyn Nafta, 40, 3–51.

SLOVAK GEOLOGICAL MAGAZINE

# Geodynamic setting of fluxoturbidites in West Carpathian Upper Jurassic and Lower Cretaceous sedimentary basins

JOZEF MICHALÍK[1] DANIELA REHÁKOVÁ[1] & JOZEF JABLONSKÝ[2]

[1]Geological Institute of Slovakian Academy of Sciences, Dúbravská cesta 9, 842 26 Bratislava;
[2]Geology and Paleontology Dept., Comenius University, Mlynská dolina G1, 842 15 Bratislava

*Abstract.* Eustatic and hydrodynamic regime on Tethyan shelves and microcontinents changed during Late Jurassic and Early Cretaceous. These changes are well recognizable by study of the allodapic fluxoturbidite intercalations in pelagic basinal infillings.

Tithonian (lithohoriyon Ti.6) Barmstein fluxoturbidites with platform carbonate clasts are restricted to S of the Alpine - Carpathian lithosphaeric block. No biohermal rims supplying allodapic beds have been developed around contemporaneous Jasenina Basin of northernmore Fatric Zone. Nozdrovica Breccia (litohorizon Be-7) accumulated along active faults: its composition changed from place to place.

Valanginian (Oravice, Va-4) siliciturbidites inserted in hemipelagites (equivalent to East Alpine Rossfeld Beds) originated during eustatic sea level drop by river transport bringing terrigeneous clastic material from SE. Chromian spinel grains were derived from eroded ultrabasic rocks of elevated segments of fundament.

The maximum development of fluxoturbidites has been attained during Hauterivian (Ha-3). The Strážovce Turbidite consists of bioherm rim debris, transported by channel system cutting fault slope.

Barremian (Ba-2) and Aptian (Ap-2) fluxoturbidites were associated with prograding Urgonian carbonate platforms in southern Tatric area. Other allodapes were derived from eroded elevated substrate.

Albian siliciturbidites accumulated in turbidite fan rim arising during extensive paleogeographic re-building of Central Western Carpathians. The quartzose admixture was derived from erode fundament and, partially, it was also produced by syngenetic volcanism.

*Key words:* calciturbidites, siliciturbidites, pelagic carbonate basins, Upper Jurassic, Lower Cretaceous, Western Carpathians.

The intercalation of allodapic sediments in pelagic Upper Jurassic and Lower Cretaceous sequences was associated with an eustatic drop of the sea-level and with the effects of tectonic sea bottom denivelisation. Although the Neo-Cimmerian collision zone running meridionally south of Asian Cimmerides terminates in Crimea and Dobrogea, traces (both compressive and tensional) of Neo-Cimmerian deformations are recognizable in the Carpathians (mainly in their southernmost zones: MICHALÍK 1990) and in the Eastern Alps: (TOLLMANN 1987), as well.

The deformation of outer Tethyan shelves changed the eustatic and hydrodynamic regime of the basins. During the Berriasian, global transgression (VAIL et al. 1977) and the successive change of current regime led to paleogeografic reorganisation of the broader area of the Mediterrannean Tethys (MICHALÍK et al. 1991, SOTÁK 1989). Reef growth on the Outer Carpathian border finished, the extent of carbonate platforms diminished substantionally: their products have been preserved only rarely, mostly in fragments in allodapic sediments. Microplankton remnants became an important constituent of pelagic sediments (VAŠÍČEK et al. 1994). Nannocone biomicrites sedimented in aerated eupelagic environment, while radiolarites and silicites were deposited below the CCD level. Turbidite beds and other allodapic members are inserted in Upper Jurassic and Lower Cretaceous pelagic carbonate successions of Central and Outer Western Carpathian basinal infillings. A wide range of facies types in the sections of Zliechov, Bobrovec, Vysoká, Belá, Havran and Humenné units of the Krížna Nappe, in the Butkov development of the Manín Unit (all in Central Carpathians), as well as in the Rača Unit of the Magura Basin (Outer Carpathians) allows to follow lateral transitions from distal through proximal calciturbidite deposits to deep sea fans, slope lithofacies and infillings of submarine channels.

Oxfordian to Berriasian allodapes were formed of the detritus of platform carbonates (REHÁKOVÁ 1995) transported down the slopes of elevated fundament blocks (MICHALÍK 1994). Fluxoturbidites (Barmstein Limestone) are restricted to the basin bottom in southern zones of the Alpine - Carpathian lithospheric block (MIŠÍK & SÝKORA 1982). Fluxoturbidite beds are accompanied by intercalations of contourite character.

GEOLOGICKÁ SLUŽBA SLOVENSKEJ REPUBLIKY INFORMAČNÉ STREDISKO Bratislava



*ISSN 1335-96X*

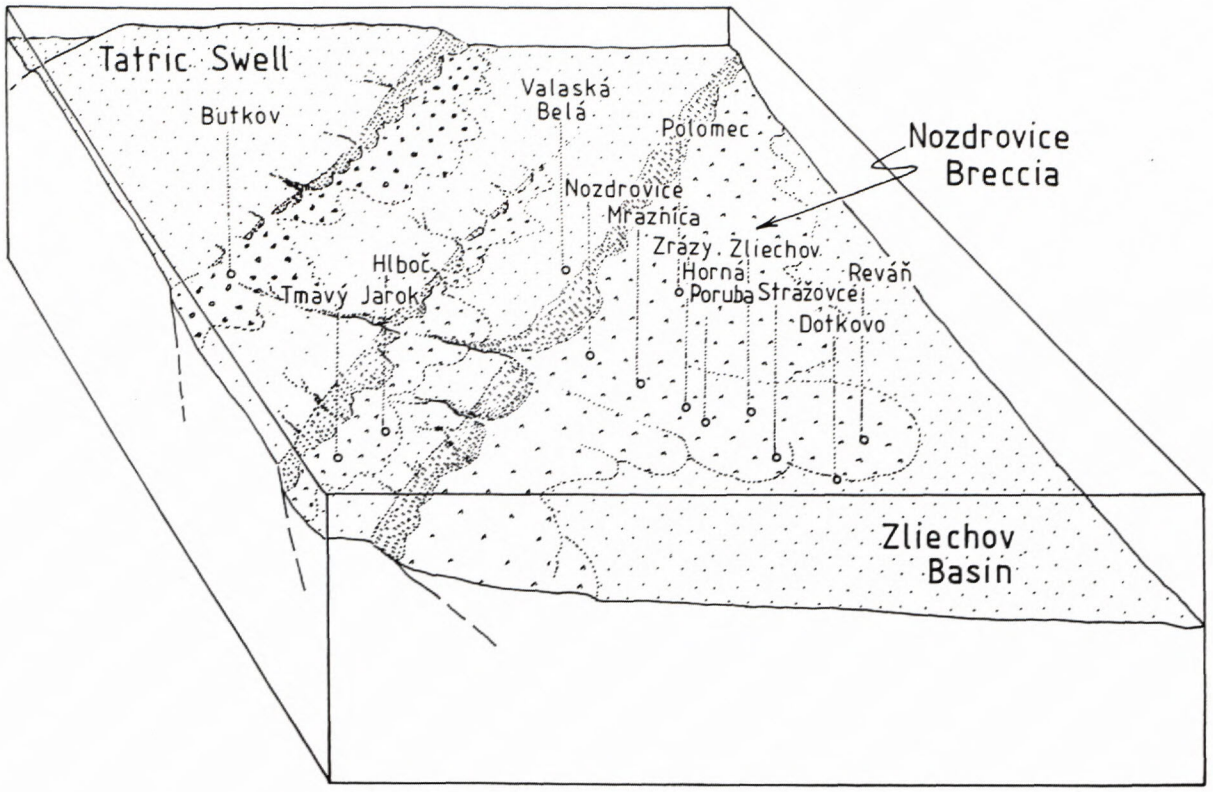



*Fig. 1. Model of origin of the Nozdrovice Breccia Beds in NW part of the Fatric Zliechov Basin during Berriasian time.*

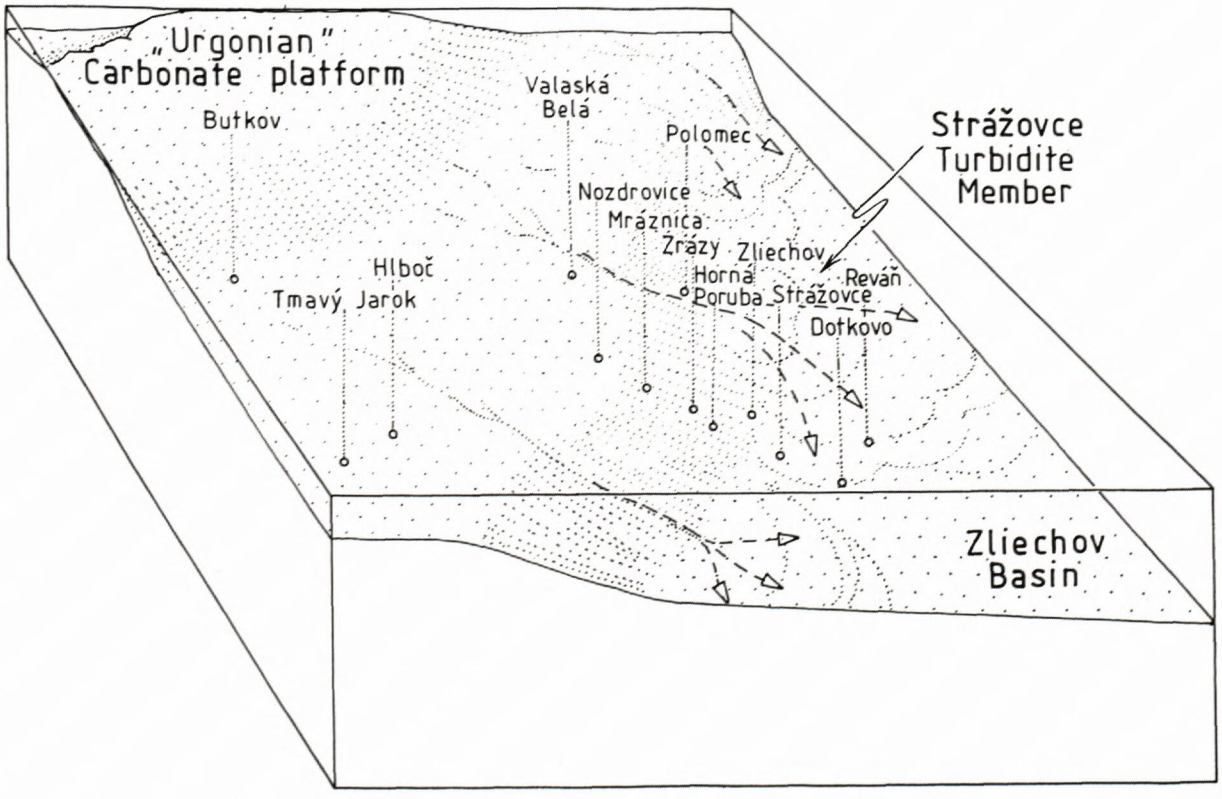



*Fig. 2. Model of origin of the Strážovce Turbidite Member in NW part of the Fatric Zliechov Basin during Hauterivian time.*

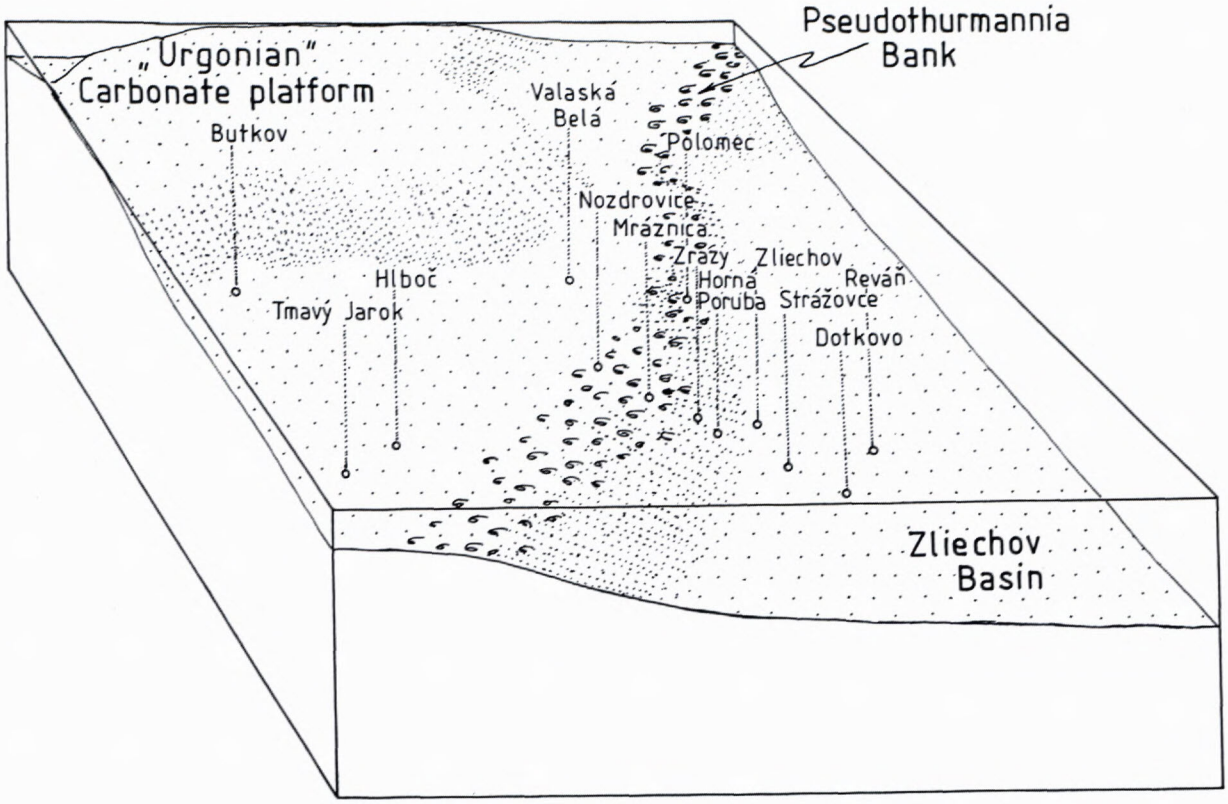



*Fig. 3. Model of origin of the Pseudothurmannia Bed in NW part of the Fatric Zliechov Basin during latest Hauterivian time.*

On the other hand, the contemporaneous filling of the Zliechov Basin (Jasenina Formation) in the Fatricum does not contain any allodapic beds. Apparently, this basin was not rimmed by bioherms at that time. Bodies of the Nozdrovica Breccia composed of basemental pelagic Upper Jurassic/ Berriasian limestone clasts accumulated along active faults (Fig.1; MICHALÍK & REHÁKOVÁ, 1995). Proximal developments (Butkov, Hlboč, Nozdrovice localities) have more variegated composition of clasts, while the breccia along the axis of the assumed submarine fan (Mráznica, Zrázy, Poruba, Zliechov, Strážovce, Reváň localities) is composed of Upper Tithonian Crassicollaria and Lower Berriasian Calpionella limestone clasts.

Upper Berriasian and Valanginian pelagic sequence contains allodapic intercalations as well. However, the maximum development of these facies was attained during Hauterivian. Calciturbidite intercalations are preserved in Magura Basin infilling in Outer Carpathians (VAŠÍČEK & REHÁKOVÁ 1994). Lower Cretaceous resediments in Pieniny Klippen Zone units occur rather exceptionally (AUBRECHT (1994).

BORZA et al.(1980) defined a Hauterivian organodetrital limestone complex inserted in the Mráznica Formation as the Strážovce Turbidite Member. It consists of limy detritus of the bioherm rim, transported into basin by a channel system cutting the fault slope along its border (Fig.2.). During the topmost Hauterivian shallowing and Tatric carbonate platform progradation, this border was the place of accumulation of fossiliferous Pseudothurmannia Beds (Fig.3).

The Strážovce Member is well exposed by the Polomec quarries near Lietavská Lúčka (BORZA et al., 1984). Probably the thickest body of allodapes (Muráň Limestone Formation) forming a big deep sea fan lens transported southwards into basinal carbonates of the Koscieliska and Muránska Lúka Formations builds the Belianske Tatry Mountains Ridge (MICHALÍK & SOTÁK 1990).

On the other hand, siliciturbidite beds contain material derived from different sources. Cimmerian deformed Inner Carpathian zones on the SE of the Alpine - Carpathian microcontinent could be regarded as a possible source area. Several siliciturbidite beds are inserted in the Valanginian hemipelagic Fatric sequence in the Juráňova Valley near Oravice (JABLONSKÝ in AUBRECHT et al., 1992). They are genetically equivalent to the clastic Rossfeld Beds in the Eastern Alps (FAUPL & TOLLMANN 1979). Their origin was connected with an eustatic drop of sea level, with the activity of rivers bringing terrigeneous clastic material into carbonate basins at that time, as well as with tectonic activity of individual segments of the

fundament. The presence of chromium spinel grains derived from eroded ultrabasic rocks is remarkable (MIŠÍK et al., 1980, MIŠÍK & SÝKORA, 1981, FAUPL & WAGREICH 1992, WAGREICH et al., 1995).

The rising proporsion of radiolarians and sponge spicules in Valanginian rocks could culminate in local concentrations of these remnants. Although some of them were caused by environmental fluctuations, others could be accumulated by distal turbidity or countour currents. Similar thin paralell bedded calcisiltites with radiolarian bands were described from the Lombardian Basin of the Southern Alps (WEISSERT, 1981; BERSEZIO, 1993).

Barremian and Aptian fluxoturbidites were frequently associated with prograding biogenic sedimentation on Urgonian carbonate platforms (MICHALÍK & SOTÁK 1990; MICHALÍK 1994) in southern Tatric area. Other allodapic deposits were derived from eroded elevated parts of the substrate (JABLONSKÝ et al. 1993).

Allodapic beds of siliciturbidite character occur more frequently in Aptian and Albian sequences. JABLONSKÝ & MARSCHALKO (1992) suggested extensive paleogeographic re-building of the area of Central Western Carpathians during the middle Albian. It was connected with basin subsidence and with the uplift of northwestern marginal zones. This process led to the accumulation of a turbidite fan rim. The quartzose admixture was derived from the eroded fundament and, partially, it was also produced by syngenetic volcanism.

## References


AUBRECHT R.,1994: Hauterivian turbidites in the Kysuca Unit (Pieniny Klippen Belt, W Carpathians).- Min.Slov. 26., 250-254.

AUBRECHT R., JABLONSKÝ J., MICHALÍK J., MIŠÍK M., REHÁKOVÁ D., SOTÁK J. & VAŠÍČEK Z. (eds.), 1992: Lower Cretaceous deposits of the Central Western Carpathians. Cretaceous and Paleogene paleogeography and geodynamics of the Alpine- Carpathian- Pannonian region. Field guide.- Bratislava, 67 p.

BERSEZIO R., 1993: Sedimentary events and rhythms in an Early Cretaceous pelagic environment: the Maiolica Formation of the Lombardy Basin (S Alps).- Giorn. Geol. 3A, 55, 1., 5-20.

BORZA K., GAŠPARÍKOVÁ V., MICHALÍK J. & VAŠÍČEK Z., 1980: Upper Jurassic/Lower Cretaceous sequence of the Krížna Nappe (Fatric) in the Strážovce section, Strážovské Vrchy Mts. (Western Carpathians). - Geol.zb.Geol.Carpathica 31, 4., 541-562.

BORZA K., MICHALÍK J., GAŠPARÍKOVÁ V., & VAŠÍČEK Z., 1984: The biostratigraphy of the Hauterivian/Barremian Boundary Beds in the Krížna Nappe, Western Carpathians (Czechoslovakia).- Cret. Research 5., 349-356.

FAUPL P. & TOLLMANN A., 1979: Die Rossfeldschichten: Ein Beispiel für Sedimentation im Bereich einer tektonisch aktiven Tiefseerinne aus der kalkalpinen Unterkreide.- Geol. Rundschau 68., 93-120.

FAUPL P. & WAGREICH M., 1992: Cretaceous flysch and pelagic sequences of the Eastern Alps: Correlations heavy minerals and paleogeographic implications.- Cret. Research 13., 387-403.

JABLONSKÝ J. & MARSCHALKO R., 1992: Pre - flysch olistrostromes in Central Western Carpathians, Barremian - Aptian of the Krížna Nappe, Slovakia.- Geologica Carpathica 43,1., 15-20.

JABLONSKÝ J., MICHALÍK J. & PLAŠIENKA D. & SOTÁK J., 1993: Sedimentary environment and correlation of the Solírov Formation with Lower Cretaceous turbidites in central Western Carpathians, Slovakia.- Cret. Research 14., 6013-621.

MICHALÍK J., 1990: Paleogeographic changes in the West Carpathian region during Kimmerian tectonic movements.- Acta geol. geogr. Univ. Comen., Geologica 45., 43-54.

MICHALÍK J., 1994: Notes to paleogeography and paleotectonics of the West Carpathians.- Mitt. Öst. Geol. Ges. 86., 101-110.

MICHALÍK J. & REHÁKOVÁ D., 1995: Sedimentary records of Early Cretaceous tectonic aktivity in the Alpine - Carpathian Region.- Slovak Geol. Magazine 2., 159-164.

MICHALÍK J., REHÁKOVÁ D., & HALÁSOVÁ E., 1990: Stratigraphy of the Jurassic/Cretaceous boundary beds in the Hlboč Valley (Vysoká Unit of the Krížna Nappe, Malé Karpaty Mts.).- Knihov. Zem. Plyn Nafta 9 (a): 183-204.

MICHALÍK J. & SOTÁK J., 1990: Lower Cretaceous shallow marine buildups in the Western Carpathians and their relationship to pelagic facies.- Cretaceous Research 11: 211-227.

MICHALÍK J., SOTÁK J., HALÁSOVÁ E., OŽVOLDOVÁ L., ONDREJÍČKOVÁ A., PETERČÁKOVÁ M., REHÁKOVÁ D. & BORZA V., 1991: Environmental-, sedimentary-, and life changes during the Jurasic/Cretaceous boundary. Min. Slov. 23, 3., 277-282.

MICHALÍK J. & VAŠÍČEK Z., 1987: Geology and stratigraphy of the environs of the Lower Cretaceous limestone deposit of Mt Butkov (Manín U., middle Váh V.).- Min. Slovaca 19, 2., 115-134.

MICHALÍK J., VAŠÍČEK Z., PETERČÁKOVÁ M. & SOTÁK J., 1990: Ku spodnokriedovej bio- a litostratigrafii tatrickej spodnokriedovej sekvencie v Zázrivskej doline (Bralo pri Párnici, Malá Fatra).- Knih. Zem. plynu a nafty 9 (a), 7-22.

MIŠÍK M. & SÝKORA M., 1981: Pieninský exotický chrbát rekonštruovaný z valúnov karbonátových hornín kriedových zlepencov bradlového pásma a manínskej jednotky. - Západné Karpaty, Geológia 7., 7-111.

MIŠÍK M. & SÝKORA M., 1982: Allodapische Barmsteinkalke im Malm des Gebirges Čachtické Karpaty.- Geol. zborn. Geol. Carpathica 33,1., 51-78.

REHÁKOVÁ D., 1995: Upper Jurassic / Lower Cretaceous carbonate microfacies and environmental models from W Carpathians and adjacent paleogeographic units.- Cret. Research 16.,283-297.

REHÁKOVÁ D. & MICHALÍK J., 1994: Abundance and distribution of Late Jurassic and Early Cretaceous microplankton in Western Carpathians. - Geobios 27,2., 135-156.

SOTÁK J., 1989: A contribution to research of Mesozoic facies in externide flysch zones, with implication on microfacies, paleogeography and paleotectonics of the Western Carpathians. In: Sedimentological problems of Western Carpathians. Dionýz Štúr's Geological Institute, Bratislava, 43-65.

TOLLMANN A., 1987: Late Jurassic/Neocomian gravitational tectonics in the N. Calcareous Alps in Austria.- In: Flügel H.W. & Faupl P. (eds.): Geodynamics of the Eastern Alps. Deuticke Verl., Vienna, 112-125.

VAIL P. R., MITCHUM R. M. JR. & THOMPSON S. III, 1977: Seismic stratigraphy and global changes of sea level, Part 3. Relative changes of sea level from coastal onlap.- In: PAYTON C. E. (ed.): Seismic Stratigraphy-Applications to Hydrocarbon Exploration. AAPG Mem., 26., 63-81.

VAŠÍČEK Z. & MICHALÍK J. & BORZA K., 1983: To the "Neocomian" biostratigraphy in the Krížna-Nappe of the Strážovské Vrchy Mts (NW Central Carpathians).- Zitteliana 10: 467-483.

VAŠÍČEK Z. & MICHALÍK J. & REHÁKOVÁ D., 1994: Early Cretaceous stratigraphy, paleogeography and life in Western Carpathians.- Beringeria 10.,1-170.

VAŠÍČEK Z. & REHÁKOVÁ D., 1994: Biostratigrafické výzkumy na lokalitě Kurovice v r. 1993 (vnější Karpaty, titon - spodní valangin).- Geol. výzk. Mor. Slezska 1994, 28.

WAGREICH M. & FAUPL P. & SCHLAGINTWEIT F., 1995: Heavy minerals from Urgonian limestone pebbles of the Northern Calcareous Alps Austria, Bavaria): Further evidence for an intra - Austroalpine suture zone. - Geol.Carpathica 46, 4., 197-204.

WEISSERT H., 1981: Depositional processes in an ancient pelagic environment: The Lower Cretaceous Maiolica of the Southern Alps.- Eclogae Geol. Helv. 74, 2., 339-352.

SLOVAK GEOLOGICAL MAGAZINE

# Protolith and geodynamic setting of the HP/LT metamorphosed basic from the northern margin of the Bôrka nappe (meliatic Unit Inner Western Carpathians)

PETER IVAN[1] & BALÁZS KRONOME[2]

[1]Comenius University, Department of Geochemistry, Mlynská dolina G, 842 15 Bratislava, Slovakia
[2]Comenius University, Department of Geology and Paleontology, Mlynská dolina G, 842 15 Bratislava, Slovakia

*Abstract:* According to protolith four types of metamorphosed basic rocks in Bôrka nappe have been found: (1) basalts (dolerites) with ophitic (doleritic) texture, (2) basalts with porphyric texture, (3) amphibolites and their phyllonites and (4) gneiss phyllonites. Basalts of type (1) formed originally a part of the slab of back-arc basin crust subducted Jurassic time (150-160 My). Porphyric basalts (with calc-alkaline signature) and other rock types might built up lower part of overriding plate in the contact with subduction zone. Recent tectonic position of the basic rocks of the Bôrka Nappe remain of tectonically reworked melange.

*Key words:* Meliatic Unit, back-arc basin, subduction, basalts

The Meliatic Unit belongs to first-order structural-tectonic units of the Inner Western Carpathians. It is thought to have been formed by the closing of the Triassic-Jurassic Meliata-Hallstatt ocean (KOZUR & MOCK, 1987; KOZUR, 1991). The Meliatic Unit is divided (according to the above mentioned authors) into three subunits: (1) Meliata Unit s.s, (2) Shale Unit of northern Bükk Mts. and probably also (3) Bôrka Nappe. All these subunits contain basic rocks. High pressure - low temperature (HP/LT) metamorphosed basic rocks from the northern margin of the Bôrka Nappe were the subject of this study .

The Bôrka Nappe rests on the subautochthon formed of the Gemeric Unit. According to REICHWALDER (1973) and LEŠKO & VARGA (1980), the Bôrka Nappe is represented by strongly imbricated slices and nappe outliers. Metamorphosed basic rocks form mainly isolated bodies varying in size, in phyllitic or carbonate host rocks.

Four important occurrences of basic rocks - (1) Vyšná Slaná - Radzim, (2) Bôrka, (3) Hačava and (4) Rudník (Fig. 1) - are located at the northern margin of the Bôrka Nappe. Based on a petrographic study, their protolith has been recognized as follows: (1) basalt (or dolerite) mostly with ophitic texture, (2) basalt (basaltic andesite) with porphyric texture, (3) amphibolites and their phyllonites and (4) gneiss phyllonites (IVAN & KRONOME, 1996). All the above rocks have been metamorphosed in HP/LT metamorphic conditions except the porphyric basalt, which displays LP/LT conditions only.

Metabasalts with relic ophitic structure occur at Vyšná Slaná - Radzim (southern slope), Hačava and Bôrka - Čremošná Valley. At the first site they were originally formed in a lava flow, with coarse-grained basalt in the central parts and fine-grained or vitrophyric partly brecciated basalts in external parts of the flow. HP/LT metamorphosed basic rocks from Hačava were originally medium- to coarse-grained basalts with ophitic texture. Basaltic protolith of the basic rocks from the Bôrka-Čremošná Valley is indicated by poorly preserved relics of ophitic texture only. These basalts were accompanied by smectite/ chlorite-rich sediments and stratiform Fe-mineralization.

Metabasalts with relic ophitic texture are composed of Na-amphibole, epidote/clinozoisite, chlorite, albite, titanite, rarely Na-pyroxene or garnet and white mica. Relics of pumpellyite and actinolite suggest progressive metamorphic evolution of these rocks. Magmatic clinopyroxenes are preserved in some coarse-grained rock types. Their composition (using the discrimination by LETERRIER et al., 1982) points to anorogenic, tholeiitic character of the parental basalt.

Metabasalt (basaltic andesite) with relic porphyric texture occurs at Vyšná Slaná - Radzim (SW slope). The original mineral composition consisting of plagioclase and pyroxene phenocrysts in trachytic matrix was replaced by a typical greenschist assemblage: chlorite + epidote + zoisite + carbonate + titanite. However, pre-existing HP/LT metamorphic stage cannot be fully excluded.

High-grade metamorphic rocks (amphibolites and gneisses) overprinted by HP/LT metamorphism were described from Rudník (approx. 15 km W of Košice) by FARYAD (1988). The amphibolites contain brown amphibole rimmed by Na-amphibole. Prevailing rock types are here HP/LT metamorphosed amphibolite and gneiss phyllonites. Bluish-grey amphibolite phyllonites are composed mainly of fine-grained inhomogeneous aggregate of albite, zoizite, epidote, Na-amphibole and titanite. An

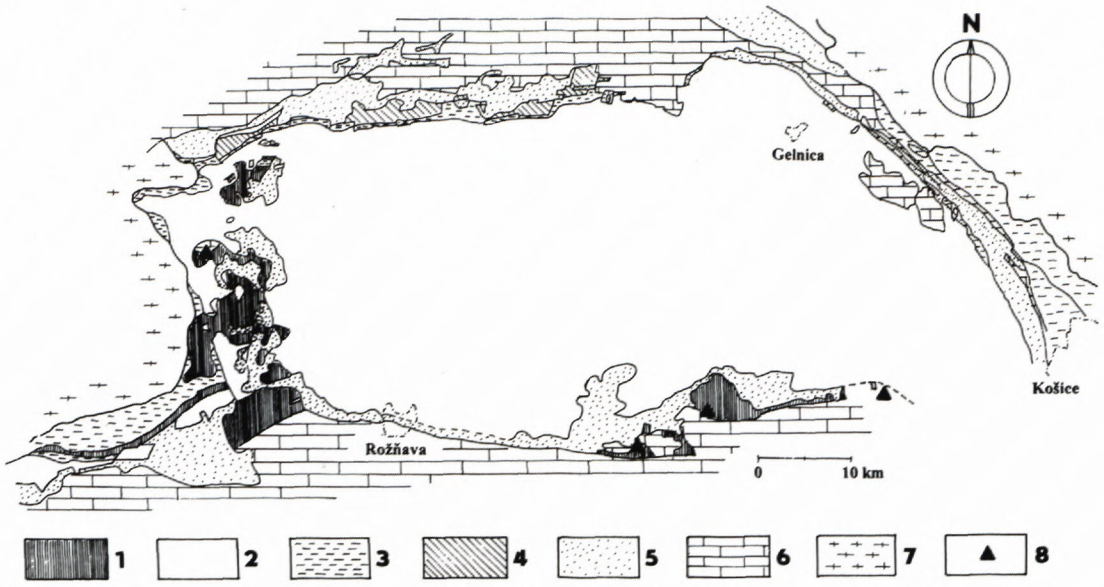



*Fig. 1: The position of the Bôrka Nappe in the geological structure of the Inner Western Carpathians (BAJANÍK et al., 1983 - adopted). 1- Bôrka Nappe, 2 - Early Paleozoic formations, 3 - clastic Carboniferous formations, 4 - Zlatník Formation (Carboniferous?) - ancient back-arc basin crust, 5 - Permian volcano-sedimentary formations (2-5 - Paleozoic of Gemeric Unit),6 - Mesozoic formations of the Gemeric and Meliatic Units, 7- Veporic Unit of the Central Western Carpathians, 8 - studied localities*

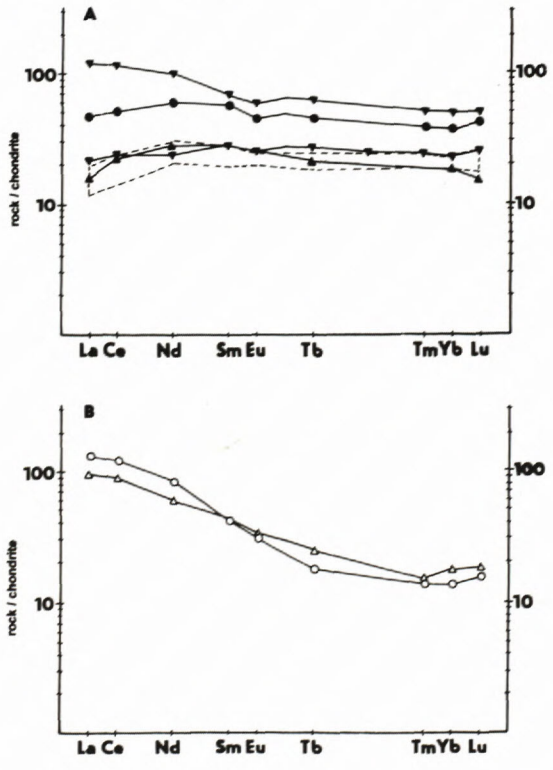



*Fig. 2: Normalised REE patterns of metamorphosed basic rocks of the northern margin of the Bôrka Nappe.*
*A- rocks with flat REE pattern. Dashed field - REE patterns of four samples LP/LT metamorphosed basalts from Jaklovce (Meliata Unit s.s.) for comparison. B- rocks with differentiated LREE/HREE enrichment.*
*Explanation of symbols - see Fig. 3. Normalisation by EVENSEN et al. (1978).*

other occurrence of blueschist with amphibolite protolith is Bôrka - Čilakovský kopec Hill. Mineral assemblages of these rocks are similar to common epidote blueschists, but in adition they usually contain Ca-amphibole (rimmed by Na-amphibole), quartz and white mica. Phantoms of a garnet have been also found. Rutile concentrically rimmed by ilmenite and titanite indicates possible origin of the amphibolite protolith by retrogression of an eclogite.

The protolith of epidote blueschists which have been found in Šugov Valley remains unknown as no relics of pre-metamorphic texture have been preserved.

The interpretation of geodynamic setting of the studied rocks is based on a trace element distribution study. Based on REE patterns (Fig. 2A,B), the basic rocks of the Bôrka Nappe can be divided into three groups: (1) metabasites with flat REE patterns, low total REE content similar to typical N-MORB, (2) metabasites with flat REE patterns and total REE content higher than in the previous group ( close to more evolved types of N-MORB) and (3) metabasites with steep slope patterns due to a differentiated LREE/HREE enrichment. The first group is represented by metabasalts with relic ophitic texture and amphibolite phyllonite from Rudník, the second group includes metabasalt from Čremošná Valley and basic rocks from Šugov Valley with unknown protolith. To the third group belong amphibolites with HP/LT metamorphic overprint from Čilakovský kopec Hill and LP/LT metamorphosed porphyric basalt from Radzim Hill. More detailed geochemical classification of these rocks has been performed using discrimination diagrams

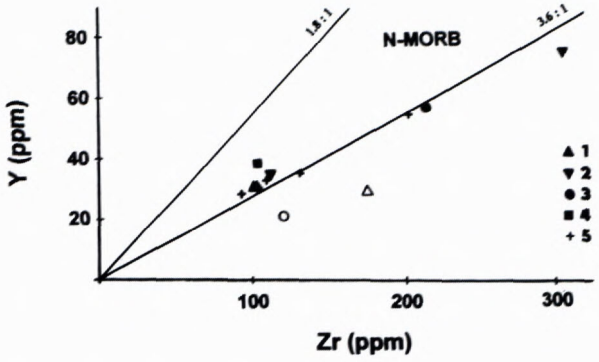



*Fig. 3: Zr vs. Y diagram (LE ROEX et al., 1983) for the metamorphosed basic rocks of the northern margin of the Bôrka Nappe. LP/LT metamorphosed basalts of Meliata Unit s.s. from Jaklovce are plotted for comparison. Explanation of symbols: 1- Vyšná Slaná - Radzim, 2- Hačava, 3 - Bôrka, 4 - Rudník, 5 - Jaklovce. Empty symbols - samples with differentiated LREE/HREE enrichment.*

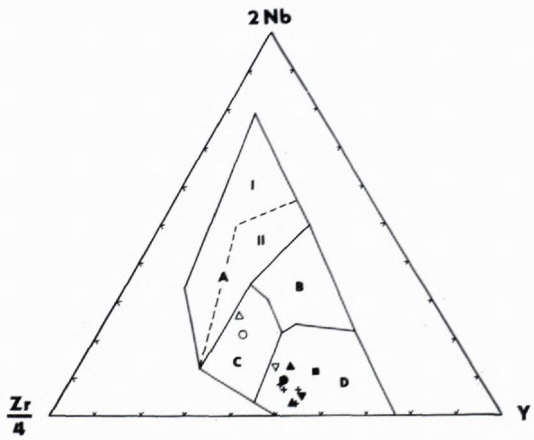



*Fig. 4: Zr/4-2Nb-Y discrimination diagram (MESCHEDE, 1986) metamorphosed basic rocks of the northern margin of the Bôrka Nappe. Explanation of symbols: see Fig. 3; AI - alkali within-plate basalts (WPB), AII- alkali and tholeiitic within-plate basalts, B - enriched mid-ocean ridge basalts (E-MORB), C - normal mid-ocean ridge basalts (N-MORB) and volcanic arc basalts (VAB), D - VAB and within-plate tholeiites (WPT).*

based mainly on HFSE distribution. Zr vs. Y and Zr/4-2Nb-Ta diagrams ( Fig. 3 and Fig. 4) classify the rocks with flat REE patterns as N-MORB, although in the first diagram they are plotted on the boundary of N-MORB field. The rocks with steep-slope REE patterns fall into the VAB/ WPT field (Fig. 4). In the Hf/3-Th-Ta diagram (WOOD, 1980; Fig. 5) they are classified as calc-alkaline volcanics and the rocks with a flat REE pattern fall mainly into the island arc tholeiite field. Although discrimination diagrams seemingly provide conflicting information in the

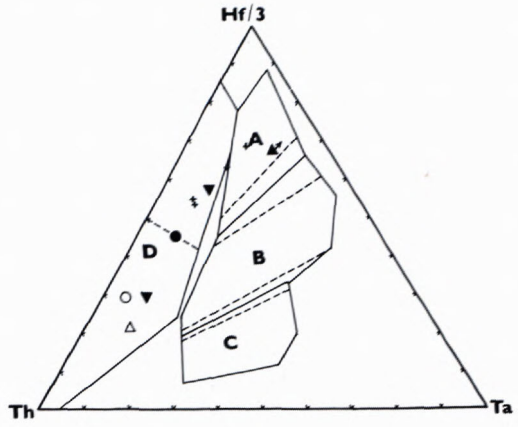



Fig. *5: H/3-Th-Ta discrimination diagram (WOOD, 1980) metamorphosed basic rocks of the northern margin of the Bôrka Nappe. Explanation of symbols: see Fig. 3; A - N-MORB, B- E-MORB, C - alkali WPB, D - destructive plate margin basalts (= VAB).*

case of rocks with flat REE patterns, this type of trace element distribution is typical for back-arc basin basalts (BABB, i.g. FLOYD et al., 1991). Summing up the results - at the studied occurrences of the Bôrka Nappe, two geochemical types of basic metavolcanics - BABB and CAB - can be distinguished.

P,T-conditions of HP/LT metamorphism were estimated as 9-12 kbar/380-460°C or 8-11 kbar/380-420°C; (FARYAD, 1995). The relatedness of such type of metamorphism to the subduction processes is generally accepted. The age of metamorphism is about 150-160 Ma (MALUSKI et al., 1993). HP/LT metamorphosed basalts with BABB signature were probably a part of a subducted slab of the Meliata-Hallstatt ocean. They are geochemically very similar to the basalts formed in recent back-arc basins. Amphibolites, gneisses, their phyllonites and amphibolitized eclogites(?) which experienced HP/LT metamorphism built primarily the hanging wall of the subduction zone, i.e. they were the lower part of the overriding continental slab. Differences in the protolith and metamorphic history of the basic rocks of the Bôrka Nappe indicate that the recent position of these rocks is in the form of blocks in a mélange. The mélange was intensively reworked especially during the pre-Gosau nappe formation, because the Gosau conglomerate in the Dobšinská Ľadová Cave contains pebbles from Bôrka Nappe rocks (HOVORKA et al., 1990).

## References

BAJANÍK, Š., HANZEL, V., IVANIČKA, J., MELLO, J., PRISTAŠ, J., REICHWALDER, P., SNOPKO, L., VOZÁR, J., VOZÁROVÁ, A., 1983:Geol. map. of Slovenské rudohorie Mts. - East. part, 1:50 000. GÚDŠ, Bratislava

FARYAD, S. W., 1988: Glaucophanized amphibolites and gneisses near Rudník (Slovenské rudohorie Mts.). Geol. Zbor. Geologica carpath., 39, p.747-763

FARYAD, S.W., 1995: Phase petrology and p,T conditions of mafic blueschists from the Meliata Unit, West Carpathians, Slovakia. J. metamorph. Geol., 13, p. 701-714

FLOYD, P.A., KELLING, G., GOKCEN S.L. & GOKCEN N., 1991: Geochemistry and tectonic environment of basaltic rocks from the Misis ophiolitic mélange, south Turkey. Chem. Geol., 89, p. 263-280

HOVORKA, D., IVAN, P., MOCK R., ROZLOŽNÍK, L. & SPIŠIAK, J., 1990: Sediments of Gossau type near Dobšiná Ice Cave: Ideas for their non-traditional interpretation. (In Slovak). Mineralia slov., 22, p. 519-525

IVAN, P. & KRONOME, B., 1996: Protolith and geodynamic setting of the HP/LT metamorphosed basic rocks at selected localities of the Meliatic Unit (Inner Western Carpathians). (In Slovak). Mineralia slov., 28, p. 26-37

KOZUR, H., 1991: The geological evolution at the Western end of Cimmerian ocean in the Western Carpathians and Eastern Alps. Zbl. Geol. Paläont. Teil I, 1, p. 99-121

KOZUR, H. & MOCK R., 1987: Deckenstrukturen im sudlichen Randbereich der Westkarpaten (Vorläufige Mitteilung). Geol.-paläont. Mitt., 14, p. 131-155

LEROEX A. P., DICK H. J. B., ERLANK A. J., REID A. M., FREY F. A., & HART S.R., 1983: Geochemistry, mineralogy and petrogenesis of lavas erupted along the southwest Indian Ridge between the Bouvet triple junction and 11 degrees east. J. Petrology, 24, p. 267-318

LEŠKO B. & VARGA I. 1980: Alpine elements in the West Carpathian structure and their significance. Mineralia slov., 12, p. 97-130

MALUSKI, H., RAJLICH P. & MATTE P., 1993: Ar-39/Ar-40 dating of the inner Carpathians Variscan basement and Alpine mylonitic overprinting. Tectonophysics, 223, p. 313-338

MESCHEDE, M., 1986: A method of dicriminating between different types of mid-ocean ridge basalts and continental tholeiites with the Nb-Zr-Y diagram. Chem. Geol., 56, p. 207-218

REICHWALDER P., 1973: Geology of the Late Paleozoic of the southwestern part of the Spišsko-gemerské rudohorie Mts. (In Slovak). Západné Karpaty, 18, p. 99-139

WOOD, D. A., 1980: The application of a Th-Hf-Ta diagram to problems of tectonomagmatic classification and to establishing the nature of crustal contamination of basaltic lavas of the Brittish Tertiary volcanic province. Earth planet. Sci. Lett., 50, p. 11-30

SLOVAK GEOLOGICAL MAGAZINE

# Meliaticum in the Stratenská hornatina Hills

MILAN HAVRILA[1], LADISLAVA OŽVOLDOVÁ[2]

[1]Geological Service of the Slovak Republic, Mlynská dolina 1, 817 04 Bratislava
[2]Department of Geology and Paleontology, Comenius University, Mlynská dolina, 817 33 Bratislava

*Abstract:* South of the Dobšiná Ice Cave in the Stratenská hornatina Hills below carbonate strata of the Silicicum of the Stratená nappe we established a formation of distal flysch character, Jurassic in age, which we have proved by radiolarians. On the basis of the age of this formation, its lithological character and presence of serpentinites occurring in equal position in close neighbourhood (Danková) we consider it as the Meliaticum.

*Key words:* Western Carpathians, Meliaticum, Jurassic, radiolarians.

## Introduction

The aim of the research project "Paleogeographic relationship of Hronicum and Silicicum" of 1995 was to contribute to the solving of the problem of the paleogeographic position of the Stratenská hornatina Mts. Mesozoic, by the analysis of its relationship to the Late Paleozoic of the Northern Gemericum, i.e. by analysing the continuity or discontinuity of the bed succession. This succession appears (see older geological maps, e.g. BAJANÍK et al., 1984) to be disrupted between the Lower and Middle Triassic. The analysis, or confirmation of the discontinuity in the bed succession was possible by a) studying the stratigraphy of the basal members of the carbonate body of the Middle-Upper Triassic, b) proving a tectonic discontinuity as the result of the determination of the occurrence of remnants of another tectonic unit on the above mentioned discontinuity plane.

## Definition of terms

To make it possible to solve the relationship of Hronicum and Silicicum, it is above all necessary to clarify the terms Hronicum and Silicicum. The reason of the special problem is that both terms represent a system of rootless nappes with unknown and unproved roots.

Such unclear position, besides Hronicum (Andrusov - BYSTRICKÝ & FUSÁN, 1973) of ultra-Veporic origin (most frequently a scar is considered between Veporicum and Gemericum, e.g. BIELY & FUSÁN, 1967; ANDRUSOV, 1968) and Silicicum, formerly of the same origin, i.e. from the Ľubeník-Margecany Line (KOZUR & MOCK, 1973), at present mostly considered as of ultra-Meliatic origin (MAHEĽ, 1986; HÓK & KOVÁČ, 1995), which is clear only in the case of the Silica Nappe of the Slovenský kras area, may be assigned to several other tectonic units, e.g. the upper sub-Tatricum (ANDRUSOV, 1968), i.e. the Strážov, Nedzov and other nappes, further the Drienok Nappe, the Muráň Nappe, the Mesozoic of the Vernár belt and the Mesozoic of the north Gemericum syncline, which are mostly classified as Silicicum (MELLO, 1979; BIELY, 1989), and less frequently, some of them, as Gemericum (the Mesozoic of the north Gemericum syncline, which appears to be the cover of Northern Gemericum).

After proving that the Upper sub-Tatricum belongs to Hronicum (HAVRILA, 1993), criteria for distinguishing (lithologically) these terms became clearer (the criteria of the occurrence of Wetterstein and Schreyeralm limestones ceased to be used, the occurrence of Lunz beds acquired greater importance). The contours of Hronicum became more precise.

If a unit belongs to Silicicum remains the most difficult to determine. The only reliable criterion based on the definition of Silicicum, or of the Silica Nappe, is the superposition in relation to Meliaticum, e.g. ultra-Meliatic origin in the sense of later studies. This is fulfilled with any certainty only by the Silica Nappe of Slovenský kras, e.g. the tectonic unit lying on Meliaticum, assuming north-vergency of the Silica Nappe (MAHEĽ, 1986; HÓK & KOVÁČ, 1995), which has been lately evidently accepted to a greater extent.

Therefore, questionable remains only the classification of the Drienok Nappe, Muráň Nappe, the Mesozoic of the Vernár belt and the Mesozoic of the Northern Gemericum syncline, i.e. units classified so far as Silicicum.

The most questionable is the position of the Mesozoic of the Northern Gemericum syncline. It is either considered to belong to Silicicum (e.g. MELLO & Mock in MELLO et al., 1975; MOCK in MIŠÍK et al., 1980), or to the cover of Gemericum. It however appears that there is a

possibility to solve its classification. The key is the occurrence of ultrabasic bodies (serpentinites) in the area of Danková, i.e. rocks which are at present included into Meliaticum and which we do not know to occur in another tectonic unit. Therefore, we focused our attention principally to this unit.

## The problem of the classification of the Northern Gemericum syncline Mesozoic

The Mesozoic of the Northern Gemericum syncline, in view of the fact that it appears to be the cover of northern Gemericum, was in the past included into Gemerides (ZOUBEK, 1957; MAHEĽ, 1955, 1961, 1967). The reason for this was the proved gradual litholigic transition (without clear interruption) from the Permian to the Lower Triassic, well observable in the Smižany - 1 borehole (MAHEĽ & VOZÁR, 1971; BAJANÍK & VOZÁROVÁ, 1979), documented by the gradual change of sedimentary structures from river to shore (VOZÁROVÁ in VOZÁROVÁ, FEJDIOVÁ & SALAJ, 1993), the occurrence of intraformational clastic Permian material in the Lower Triassic (VOZÁROVÁ in VOZÁROVÁ & VOZÁR, 1988), uranium mineralization passing from the Permian into the Lower Triassic (VOZÁR, oral communication), equal maturity of Permian and Lower Triassic sediments (VOZÁROVÁ in VOZÁROVÁ, FEJDIOVÁ & SALAJ, 1993) and the same very low grade of metamorphism in the whole succession (very low metamorphism of the Permian has been proved by Šucha, oral communication by VOZÁROVÁ).

The bed succession should continue uninterrupted into the Middle - Upper Triassic (MAHEĽ, 1955, 1967). However, the following facts contradict this statement:

1. Structural discordance between the clastic beds of the Lower Triassic and carbonates of the Middle - Upper Triassic, which is clearly suggested by older maps (KLINEC et al., 1976; BAJANÍK et al., 1984) in the whole North Gemericum Mesozoic belt, i.e. in the Stratenská hornatina Mts. and in Galmus, and even in the Muráň Nappe. In all of the above areas various members of the Middle-Upper Triassic bed succession are in contact with the Lower Triassic, which also does not everywhere have its upper carbonate part (upper Campilian). The most obvious is the discontinuity in Galmus and Murovaná skala, where carbonates of the Middle-Upper Triassic are lying immediately on the Early Paleozoic, implying very strongly that complexes of the Lower Triassic do not belong to the same tectonic unit as Middle-Upper Triassic ones.

2. The result of mapping and stratigraphic works of BYSTRICKÝ (1982), BYSTRICKÝ et al. (1982) from the area of Ľadová (Ice) Cave, which proved that dark limestones with cherts assumed by MAHEĽ (1955) to be Anisian, are Upper Triassic (Carnian), proving thus paleontologically that the basal beds of the carbonate complex lying on the paleontologically proved Lower Triassic, are Upper Triassic, and thus that it is not a continuous bed succession.

3. The discontinuity of the bed succession mentioned in the above points 1 and 2 is enhanced by the occurrence of serpentinites on this plane at Danková, i.e. in the overlier of the Lower Triassic and in the underlier of the carbonate complex of Stratenská hornatina Mts. (see the map of MAHEĽ, 1955; FEDOR, 1968). This position of serpentinites at Danková has been confirmed by KAMENICKÝ (1957), FEDOR (1968) and accepted further by HÁBER & HOVORKA (1981), JAROŠ, KRATOCHVÍL & ZLOCHA (1981) and HOVORKA (1985). Generally there is mentioned the sliced structure of the basic body at Danková and the tectonic restriction of the body (KORDIUK, 1941; KAMENICKÝ, 1951, 1957; FEDOR, 1968; JAROŠ, KRATOCHVÍL & ZLOCHA, 1981; HOVORKA, 1985). Serpentinites in the same position, with the same elongated shape and concordant with the general course of geological units, having the same sliced character and tectonic boundaries as well as contact effects, have been reported by KORDIUK (1941), KAMENICKÝ (1957), ANDRUSOV (1959), MAHEĽ (1967), JAROŠ, KRATOCHVÍL & ZLOCHA (1981), HOVORKA (1983) and MAHEĽ (1986) to occur elsewhere (Dobšiná, Jaklovce) in the North Gemericum belt. In the past, due to the fact that the ultrabasic bodies acquired the sliced structure along with the Lower Triassic beds, it was assumed that they belong to Lower Triassic complexes. Similarly, due to their alleged contact effect, Lower Triassic age was assigned to the basic volcanism. MAHEĽ (1957, 1967), due to the alleged thermal alteration of the overlying Anisian dolomites, suggested younger than Lower Triassic age. HOVORKA (1979, 1983) re-evaluated the thermal contact of the basic rocks and he mentioned that these are secondary reaction rims of rodingite type. After distinguishing the Meliata Series and the Silica Nappe (KOZUR & MOCK, 1973), the basic bodies of the southern belt became clearly a part of Meliaticum. Similar was the destiny of a part of bodies in the northern belt (Jaklovce - Margecany), where Jurassic age of the host rocks of the "Jaklovce Series" (MOCK in MIŠÍK et al., 1980) of the ultabasics was proved by findings of belemnites and radiolarians (MOCK et al., 1993, 1995).

In view of the above facts it is logical to assign the serpentinite body from Danková (Čuntava) to Meliaticum, which would confirm the correctness of the classification of the Stratenská hornatina Mts. carbonates with a different tectonic unit (Silicicum) than the silica-clastics of the Lower Triassic (Gemericum).

## Results of field investigations

The field work was carried out in 1995 between the Besník saddle and Spišská Nová Ves. It was aimed at the confirmation of the above mentioned tectonic discontinuity between the carbonates of Stratenská hornatina

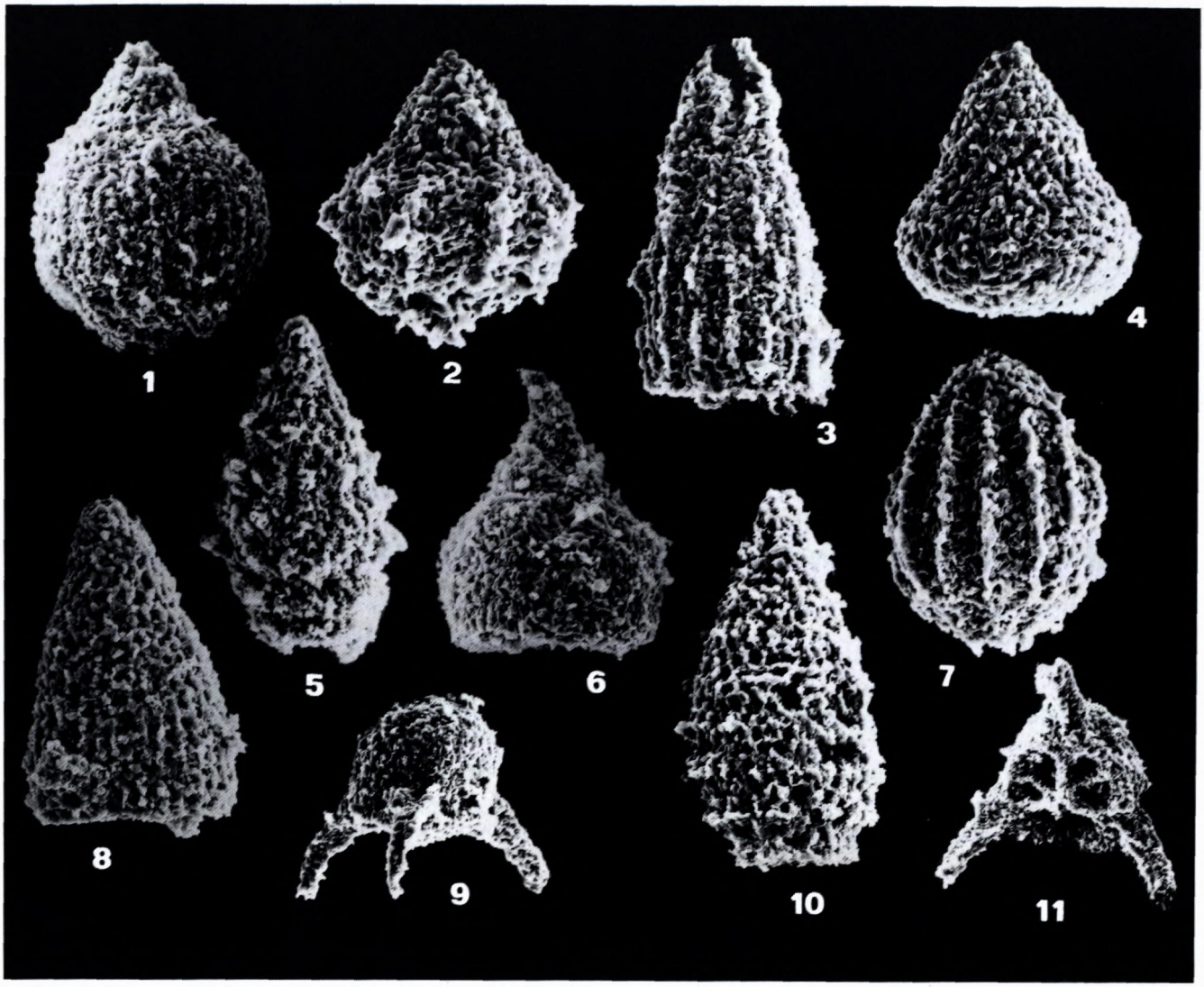



*Fig. 1 Tricolocapsa plicarum* YAO *- 0049, 300 x; 2 - Unuma latusicostatus (AITA) - 0300, 300 x; 3 - Transhsuum sp. - 0298, 300 x; 4 - Stichocapsa japonicum* YAO *- 0291, 300 x; 5 - Parvicingula dhimenaensis ssp.A sensu* BAUMGARTNER *et al. 1995 - 0058, 300 x; 6 - Eucyrtidiellum sp. - 0059, 350 x; 7 - Protonuma japonicus* MATSUOKA *et* YAO *- 0296, 300 x; 8 - Parahsuum sp. - 0295, 300 x; 9 - Saitoum sp. - 0294, 250 x; 10 - Parvicingula dhimenaensis dhimenaensis* BAUMGARTNER *- 0287, 300 x; 11 - Saitoum sp. - oral view from Fig. 9 - 0293, 240 x*

Mts. and the Lower Triassic lying below them. The effort was focused on: a) the confirmation of the stratigraphic break suggested by BYSTRICKÝ et al. (1982) and its generalisation. With this aim, samples were taken from the base of the carbonate succession, from basin and slope facies (especially dark clayey limestones with cherts and claystone beds classified by MAHEĽ (1957) as Middle Triassic - Anisian) for biostratigraphic evaluation. Upper Triassic age has not been proved yet in the whole area, however, Middle Triassic rocks have not been found too; b) finding of bodies of Meliaticum occurring on the above mentioned tectonic discontinuity plane.

The field work could not confirm the occurrence of a continuous bed succession (with the exception of the Gľac Nappe), but in spite of this, the expected bodies of Meliaticum could not be found as well, with the exception of the above mentioned serpentinites at Danková (where, however, no other members of the Meliaticum olistostrome could be found), and with the exception of a lenticular body, whose content could be assigned to Meliatcum, occurring 1.5 - 2.0 km ESE of the serpentinites of Danková, i.e. 0.5 km SE of the elev. p. Ondrejisko, or 0.5 km E of the elev. p. Strmá pirť. This body was known already to MAHEĽ (1957, 1967), who described it in the following way: "In the western part of the mountain range, layers of dark-grey and black clayey, sometimes slightly sandy shales covered by tiny mica flakes, and layers of dark grey quartzose shales to quartzites with

abundant pyrite, are found in a varied, predominantly red-violet complex". He classified the body as Lower Triassic, belonging to the North Gemericum unit.

The field work revealed that the body consists mostly of black-grey, frequently spotted, totally calc-free, strongly quartzified pelites - pelagites (shales), with fine mica, angular grey silicite clasts, further with layers of sandy pelites to fine-grained quartz sandstones, with abundant mica (i.e. of lithofacies of distal flysch character), with layers of light-grey-green, highly-clayey radiolarites. This succession is facially similar to the succession from Florianikogel in Northern Limestone Alps (Meliaticum), and to the succession from Honce. The pelites are macro- and microfacially similar to shales of the Meliaticum Jurassic on the type locality. The pelites and radiolarites contain radiolarians, which were evaluated by Dr. Ožvoldová.

The association (see Pl. 1) contained predominantly radiolarian cores (exclusively naselarians), the test walls were preserved more rarely.

Relatively abundant was the species *Tricolocapsa plicarum* YAO. *Tricolocapsa conexa* MATSUOKA, which was the most abundant species in association from Meliata, has not been preserved.

From other identifiable forms were found: *Eucyrtidiellum* sp., *Parahsuum* sp., *Parvicingula dhimenaensis dhimenaensis* BAUMGARTNER, *Parvicingula dhimenaensis* ssp. A sensu BAUMGARTNER et al., 1995, *Protunuma japonicus* MATSUOKA et YAO, *Saitoum* sp., *Stichocapsa japonica* YAO, *Transhsuum* sp., *Unuma latosicostatus* (AITA).

The species *Protunuma japonicus* begins the occurrence in UAZ 7, which is of the range Upper Bathonian to Lower Callovian (BAUMGARTNER et al., 1995), the species *Tricolocapsa plicarum, Stichocapsa japonica* and *Parvicingula dhimenaensis* ssp. A sensu BAUMGARTNER et al., 1995 terminate occurrence in UAZ 8, which is of the range Middle Callovian - Lower Oxfordian (ibidem). It results that the association represents the stratigraphic range of UAZ 7 - UAZ 8 - Upper Bathonian to Lower Oxfordian (ibidem).

Problematic is, howerer, the occurrence of the species *Unuma latusicostatus* (AITA), the stratigraphic range of the occurrence of which is UAZ 2 - UAZ 5 - Upper Aalenian to Lower Bathonian according to BAUMGARTNER et al. (1995). Probably it is necessary to shift the last occurrence of this species to a younger age.

This lenticular body, on the basis of recent investigations considered to belong to Meliaticum, is lying above quartzites ad rauwackes of the Foederata Series. Above the body there are varied red-violet sandstones (Seisian - Lower Campilian), clayey limestones and predominantly grey - greenish-grey shales (Upper Campilian), further Triassic dolomites (age not determined in greater detail), light, metamorphosed Triassic limestones (age not determined in greater detail), light weakly metamorphosed micro-crystalline limestones with crinoid detritus to crinoid limestones, finger-like (laterally) alternating with grey to yellow-grey well-bedded, clayey weakly metamorphosed limestones with claystone layers of ochre colour and with cherts, reminding of Pötschen limestones. From the both last mentioned members of the succession, Norian conodonts were obtained near the elev. point Ondrejisko and in Spišský potok determined by Havrila and Pevný: *Metapolygnathus abneptis* (HUCKRIEDE), *M. spatulatus* (HAYASHI), *M. bidentatus* (MOSHER), *M. posterus* (KOZUR - MOSTLER), *Gondolella steinbergensis* (MOSHER). A part of these weakly metamorphosed rocks was in the past assigned to the Foederata Series.

It may be said that the lithology, age and geological position allows to assign the black pelites occurring SE of Ondrejisko to Meliaticum.

This, at north-vergency of the tectonic units (nappes, slices) would mean clearly that the Stratenská hornatina Mesozoic belongs to Silicicum.

## Summary

The complex of black shales and grey-green radiolarites (and serpenitites from Danková) occurring SE of Ondrejisko, which had been originally classified as Lower Triassic, was on the basis of proved Jurassic age assigned to Meliaticum.

On the basis of this and of the geological position of rocks assigned to Meliaticum elsewhere in the North Gemericum syncline (Dobšiná, Kurtova skala, Jaklovce, Veľký Folkmár and also Radzim) above Lower Triassic sediments and below light limestones of ? the Middle-Upper Triassic it may be assumed that: sediments of the Lower Triassic belong to the Gemericum cover and ? Middle-Upper Triassic carbonate masses of the Stratenská hornatina Mts. and of the tectonic outliers of Radzim, Dobšiná, the Jaklovce - Košická Belá area, are a partial nappe of Silicicum.

Therefore we may assume a similar succession of tectonic units as in Slovenský kras to exist in the northern part of Gemer.

The geological position of the Stratenská hornatina Meliaticum, in view of its occurrence above the Foederata Series SE of Ondrejisko, appears to be ambiguous and there is a possibility to regard it as the Jurassic of the Foederata Series. This is contrary to the geological position of Meliaticum, or the "Jaklovce Series", in the broader region (Radzim, Dobšiná, Jaklovce-Košická Belá), where it occurs always above Gemericum, as well as the lower metamorphic grade (evaluated macroscopically, and, preliminarily, also according to illite crystallinity by Dr. Šucha).

On the basis of the work by MANDL - ONDREJÍČKOVÁ (1991) we may state that the position of Meliaticum in the Odenhof tectonic window in the Northern Limestone Alps

is similar; it is lying here below the Schneeberg Nappe and the "Schurflings (i.e. Meliatic) are lying in Werfenian shales".

## References


ANDRUSOV, D. 1959: Geológia československých Karpát II. Vyd. Slov. Akad. Vied, Bratislava, 1-375.

ANDRUSOV D. 1968: Grundriss der Tektonik der Nördlichen Karpaten. Vyd. Slov. Akad. Vied, Bratislava, 1-189.

ANDRUSOV, D., BYSTRICKÝ, J. & FUSÁN, O.1973: Outline of the Structure of the West Carpathians. Guide-book for Geol. Excur. X. Congr. of Carpath.-Bal.Geol. Assoc.-Vyd. Geol. Úst. D.Štúra, Bratislava,1-44.

BAJANÍK, Š. & VOZÁROVÁ, A. 1979: Litofaciálna spätosť severogemeridného permu a spodného triasu v oblasti Margecian. Geol. Práce, Správy 73, GÚDŠ, Bratislava, 39-49.

BAJANÍK, Š., IVANIČKA, J., MELLO, J., PRISTAČ, J., REICHWALDER, P., SNOPKO, L., VOZÁR, J. & VOZÁROVÁ, A. 1984: Geologická mapa Slovenského rudohoria 1:50 000. GÚDŠ, Bratislava.

BAUMGARTNER, P. O., BARTOLINI, A., CARTER, E., CONTI, M., CORTESE, G., DANELIAN, T., DE WEVER, P., DUMITRICA-JUD, R.., GORIČAN, Š., GUEX, J., M. HULL, D., KITO, N., MARCUCCI, M., MATSUOKA, A., MURCHEY, B., O' DOGHERTY, L., SAVARY, J., VISHNEVSKAJA, V., WIDZ, D. & YAO, A., 1995: Middle Jurassic to Early Cretaceous Radiolarian Biochronology of Tethys Based on Unitary Associations. In: BAUMGARNER, P.O., O' DOGHERTY, L., GORIČAN, Š., URQUHART, E., PILLEVUIT, A. & DE WEVER, P. 1995: Middle Jurassic to Lower Cretaceous Radiolaria of Tethys:Occurences, Systematics, Biochronology. Mémoirs de Géologie (Lausanne), 23,1-1143.

BIELY, A. 1989: The Geological Structure of the West Carpathians.

BIELY, A. & FUSÁN, O. 1967: Zum Problem der Wurzelzonen der subtatrischen Decken. Geol. Práce, Správy 42, GÚDŠ, Bratislava, 51-64.

BYSTRICKÝ, J. 1982: The Middle and Upper Triassic of the Stratenská hornatina Mts. and its relation to the Triassic of the Slovak Karst Silica nappe (the West Carpathians Mts. Slovakia). Geol.Zbor. Geol.carpath., 33,4, Bratislava, 437-462.

BYSTRICKÝ, J., JENDREJÁKOVÁ, O. & PAPŠOVÁ, J. 1982: Príspevok k stratigrafii triasu Stratenskej hornatiny. Mineralia slovaca, 14,4, Bratislava, 289-321.

HAVRILA, M. 1993: Výskum panvových a svahových sedimentov bielovážskej sukcesie a paleogeografia hronika. Manuscript, archív GÚDŠ, Bratislava, 1-49.

HÁBER, M. & HOVORKA, D. 1978: Sulfidická mineralizácia na kontakte ultrabázika ofiolitového typu so sedimentami spodného triasu na Dankovej (Spišsko-gemerské rudohorie). Manuscript, Geofond Praha, Bratislava.

HÓK, J. & KOVÁČ, P. 1995: Výsledky štruktúrneho výskumu vnútorných Karpát a ich interpretácia . Manuscript, archív GÚDŠ, Bratislava.

HOVORKA, D. 1979: The West Carpathians in complete ophiolites. In: M.Maheľ (ed.) Czechoslovak and Global Tectonics, Veda, Bratislava, 155-166.

HOVORKA, D. 1985: Ultramafic Rocks of the Western Carpathians, Czechoslovakia.

JAROŠ, J., KRATOCHVÍL, M. & ZLOCHA, J. 1981: Drobno-štruktúrna analýza vnútornej stavby serpentinitových telies v Spišsko-gemerskom rudohorí. Mineralia slov., 13, 6, Bratislava, 527-548.

KAMENICKÝ, J. 1951: O hadci pri Dankovej. Geol. sbor. II, Bratislava.

KAMENICKÝ, J. 1957: Serpentinity, diabázy a glaukofanické horniny triasu Spišsko-gemerského rudohoria. Geol. práce, Správy 45, GÚDŠ, Bratislava, 3-71.

KLINEC, A. 1976: Geologická mapa Slovenského rudohoria a Nízkych Tatier 1:50 000. GÚDŠ, Bratislava.

KORDIUK, 1941: Über das Alter der Slowakischen Serpentinite. Zentralblatt für Min. Geol. u Paläont. Abt. B, Stuttgart.

KOZUR, H. & MOCK, R. 1973: Zum Alter und zur tektonischen Stellung der Meliata-Serie. Geol. Zbor. Geol. carpath., Bratislava, 365-374.

MAHEĽ, M. 1957: Postavenie Stratenskej hornatiny v severo-gemeridnej synklinále. Geol. práce, Zošit 46, Bratislava, 155-187, 208-213.

MAHEĽ, M. 1967: Regionální geologie ČSSR - II. Západní Karpaty, sv.1. Vyd. Úst. geol. Praha, 1-486.

MAHEĽ, M. 1986: Geologická stavba československých Karpát. Paleoalpínske jednotky I. Veda, Bratislava, 1-503.

MAHEĽ, M. - VOZÁR, J. 1971: Príspevok k poznaniu permu a triasu v severogemeridnej synklinále. Geol.Práce, Správy 56, GÚDŠ, Bratislava, 47-65.

MELLO, J. 1979: Sú tzv. vyššie subtatranské príkrovy a silický príkrov súčasťou gemerika? Miner. slov., 11, 3, 279-281.

MOCK, R. 1993: Problematika meliatika v oblasti Spišsko-gemerského rudohoria a v Slovenskom krase. Správa za rok 1993. Manuscript, archív GÚDŠ, Bratislava, 1-22.

VOZÁROVÁ, A. & VOZÁR, J. 1988: Late paleozoic in West Carpathians, GÚDŠ, Bratislava, 1-314.

VOZÁROVÁ, A., FEJDIOVÁ, O. & SALAJ, J. 1993: Začiatok mezozoického sedimentárneho cyklu. Manuscript, archív GÚDŠ, Bratislava.

ZOUBEK, V. 1957: Hranice gemeríd s veporidami. Geol. práce, Zošit 46, Bratislava, 38-50.0

SLOVAK GEOLOGICAL MAGAZINE

# Volcanism in the Mesozoic of the Outer and Central Western Carpathians

JÁN SPIŠIAK

Geological Institute, Slovak Academy of Science, Severná 5, 974 01 Banská Bystrica, Slovak Republic

*Abstract.* Within the time span from the Upper Barremian till the end of the Albian volcanic activity is documented (approx. 100 Ma) in various tectonic units of the Western Carpathians. Volcanic activity are present in the form of hyaloclastites. Dykes or even lava flows are present in lesser amount known. Alkaline basalts/basanites are known to appear in the cover of Mesozoic units (in the Malé Karpaty Mts., Tatry Mts. and the Nízke Tatry Mts.) as well as in a unit of nappe position (the Krížna nappe). But in the Malé Karpaty Mts. and Nízke Tatry Mts. there are sills penetrating variscan granitic massifs.The mineral compositions of alkali basalt/ basanites from different units are very similar. Olivines, pyroxenes and less frequently amphiboles form phenocrysts.There are also other minerals according to the rock type: Ti-biotite, nepheline, analcime, plagioclase, leucite, ore minerals, spinel and others. The majority of lava flows have fine-grained devitrified matrix, the content of which usually does not exceed 40 per cent of the rock.Geochemical studies came to the conclusion that volcanics have the characteristics of alkaline basalt - basanites. Even the application of the principle of immiscible melts is very probable. In the studied volcanics especially the processes of fractional crystallization and assimilation of underlying rock strata (rock fragments) affected the variability of rock types.

Key words: Jurrasic-Cretaceous, alkali basalt/basanites, mineralogy, petrology

## Introduction

In the Western Carpathians, alkaline rocks of various types, predominantly of Cretaceous age, occur in some Mesozoic tectonic units (Silesicum, Tatricum, Krížna and Choč Nappes). These rock, in spite of not having a great areal extension, are of key importance for the definition of geotectonic conditions in the time of their formation approx. 100 Ma). In the Outer Western Carpathians (teschinite-picrite association), the volcanites are more differentiated (from picrites to syenites), while mostly only basanite-type rocks (rarely picrites) or their volcanoclastics are found in the Central Western Carpathians. In the Inner Carpathians, rocks of this type (alkaline basanites) do not occur in the Mesozoic. Here they are Upper Triassic volcanites of the Jaklovce development of the Meliata Group.

## Geological setting

Alkaline volcanic rocks of the Outer Western Carpathians are related in space to the upper part of the Tešín-Hradište Formation. It is a classic area of occurrence of the teschinite or teschinite-pikrite association. The volcanic activity probably took place in several stages, the volcanic activity reaching the maximum in the Barremian to Albian. A characteristic feature of the whole association is the predominance of shallow subsurface sills and veins over effusive or volcanoclastics rocks. The maximum of volcanic activity is concentrated in the upper Tešín Beds and sandstones to conglomerates of the Hradište type. Opinions on the age of the volcanic activity differ, however, the majority of authors accepts Lower to Middle Cretaceous age. The products of the volcanic activity are various types of intrusive, effusive and extrusive rocks (picrite, basalts-basanites, teschinites and monchiquites). On the basis of mineral composition they are further divided into more, less abundant types (fourchites, ouachites etc., for details see PACÁK, 1926; ŠMÍD, 1978; HOVORKA and SPIŠIAK, 1988). The pre-tectonic, synsedimentary character of the magmatic activity in the Lower Cretaceous of the Silesian Unit sedimentary basin has been proved. The type of sediments occurring in the Cretaceous of the Silesian Unit and the Magura Unit of the Outer Western Carpathians indicates their sedimentation in basins the substratum of which was continental- or subcontinental-type crust. Evidence of this is also turbidite sedimentation, suggesting the existence of a mature basin. The predominance of sills and dikes over effusions on the bottom of the basin is the reflection of the bathymetry of the Silesian Unit sedimentation basin. The sedimentation type - alternation of clayey shales with fine-grained sandstones (distal facies), along with a low proportion of amygdaloidal types,

is proof of the penetration of volcanics into an environment with a great height of the water column (over 200 m).

In the Central Western Carpathians, primitive Mesozoic alkaline volcanism is known from the Tatric (envelope) units, the Krížna and Choč Nappes (the occurrence of picrite at Poniky; SLAVKAY, 1965). Besides these, penetrations of basanite dikes into granitoid rocks have been also reported (HOVORKA et al. 1982 - Malé Karpaty Mts., SPIŠIAK et al. 1991 - Nízke Tatry Mts.). The products of the volcanic activity are low-differentiated rocks of basalt/basanite type, rarely picrites, volcanoclastic rocks are represented substantially (hyaloclastites etc.). A detailed geological setting has been presented in HOVORKA and SPIŠIAK (1988).

In the Inner Western Carpathians, alkaline volcanism does not occur in the Mesozoic, but basalts are present here as a component of the ophiolite sequence (HOVORKA and SPIŠIAK, 1993)

## Petrology and mineralogy

The products of the Mesozoic magmatic activity in the area of the Outer and Central Western Carpathians are intrusive, effusive and extrusive rock types. The most frequent forms are sills and dikes, with a thickness of X dm to X m. The majority of Mesozoic alkaline rocks (with the exception of picrites) are characterised by the presence of a fine-grained devitrified matrix (up to 40 %). Olivines, pyroxenes and less amphiboles form phenocrysts and locally they accumulate into golomerophyres. The Mg/Mg+Fe ratio in olivines varies from 0.86 to 0.87. Clinopyroxenes (Cpx) are the determining and dominant minerals in all rock types. Besides phenocrysts of various shape and size, they form also microlites in the devitrified matrix. A characteristic feature of the clinopyroxenes is sector and oscillation zoning. Cpx microlites have a composition corresponding to the rim of phenocrysts. According to the IMA pyroxene classification (MORIMOTO 1988), they correspond to diopside, the differences in their composition being indicated in the classification by different adjectives (aluminian, calcian, ferroan etc.). According to POLDEVAART and HESS (1951) the predominant part of Cpx corresponds to salite. On the basis of various discrimination diagrams (LE BAS 1962, LETERRIER et al. 1982 etc.) the studied clinopyroxenes correspond to pyroxenes from alkaline (peralkaline) rocks (see HOVORKA and SPIŠIAK 1988, SPIŠIAK and HOVORKA in press). The modal proportion of amphiboles varies in relation to the rock types or their evolution. The highest modal contents are in thin basanite dikes. Similarly as pyroxene, amphibole forms phenocrysts (usually smaller than Cpx) with observable zoning. Besides rare sector zoning, oscillation zoning is typical, with Ti, Al and Fe increasing, and Si and Mg decreasing from core to the rims. In the IMA amphibole classification (LEAKE 1978) they correspond to kaersutite or low-silicium kaersutite. Dark micas occur mostly in picrites as large flakes - their composition corresponds here to phlogopites, and also in thin basanite dikes, where they form tiny flakes (Ti-biotite).

From other minerals, rarely present are alkali feldspars (orthoclase) - only in some varieties of leucocratic rocks nefelinite syenites, MAHMOOD 1973). Plagioclases are also rare and their composition depends on the rock type and its genesis. Their basicity varies from $An_{5-8}$ in spilites to $An_{40}$ in teschenites, or $An_{60}$ in basanites (KUDĚLÁSKOVÁ 1982). Feldspars are mostly strongly altered (sericitisation). They occur locally also in resorbed non-carbonate xenoliths, where they may constitute even an essential mineral phase (SPIŠIAK et al. 1991). In this case they form thin, frequently zoned laths (basicity decreasing from centre - $An_{32}$ - to the rim - $An_{21}$). Depending on the rock type, other minerals are also represented: nepheline, analcime, pseudoleucite, spinel, ore minerals and others.

Even though Mesozoic alkaline rocks of the Western Carpathians have a very variable mineral and modal composition, the chemical composition is, except for end members, similar. In the Outer WC, a wider differentiation range of rocks is found (from picrites to syenites), while in the Central WC the rock composition corresponds mostly to basanites (rarely picrites). Generally, determining is the low $SiO_2$ content in the rocks (approx. 41 wt.%) and high contents of $TiO_2$ and $P_2O_5$ (3.2 and 0.8 wt.%, respectively). Characteristic features of these rocks are also: increased contents of Cr (280 ppm) and Ni (190 ppm), increased contents of incompatible elements, such as Ba (650 ppm), Sr (700 ppm) and LREE, increased contents of Nb (78 ppm), V (245 ppm) and Zr (305 ppm).

The age of these rocks (K/Ar data - approx. 100 Ma and paleontological data, e.g. KOTANSKI and RADWANSKI 1959, BUJNOVSKÝ et al. 1981, HOVORKA and SPIŠIAK 1988) is similar. The setting of these rocks has been affected by extensional tectonic conditions in the units where they occur (Silesian Unit, Tatricum and Fatricum, HOVORKA - SPIŠIAK, 1989). Our results indicate that approx. 100 Ma ago, in these units there was extensional, non-subduction, supra-continental regime. The character of magmatism and its similarity to all other parts of the Alpine-Carpathian region suggests extensional tectonic conditions (rifting) in all mountain ranges of the Alpine-Carpathian-Balkan sector of the Tethyan Neoeurope.

Based on the alkaline character of the volcanic rocks we assume that the volcanism was related to an initial rifting zone. However, the riftogenesis lasted only a short time, compression processes started in the next period, closing the volcanic vents. In reality, these were not continuous subaquatic effusions of trap type, or linear eruptions, but a system of linearly arranged eruption centres. Astenolith upbulging in this weakened zone is inferred - it was volcanism above hot spots or above a mantle plume.

## References


BUJNOVSKÝ, A., KANTOR, J. & VOZÁR, J. 1981: Radiometric dating of Mesozoic basic eruptive rocks of the Krížna nappe in the NW part of the Low Tatra. Geol. carpath., Bratislava, 32, 221-230.

HOVORKA, D., PITOŇÁK, P. & SPIŠIAK, J. 1982: Mesozoic basalts of the Malé Karpaty Mts. (The Western Carpathians) - Their significance for the tectonic interpretation of the Variscan granodiorite Massif. Veroffentlichungen des Zentralinst. f. Physik der Erde, Potsdam, 5-13.

HOVORKA D. & SPIŠIAK J. 1988: Mesozoic volcanism of the Western Carpathians (in Slovak with English abstract). Veda, Bratislava 263 pp.

HOVORKA, D. & SPIŠIAK, J. 1989: Paleogeographic aspects of West Carpathians Mesozoic volcanic activity. In: Evolution of the Northern margin of Tethys. Vol II, Occasional public. ESRI, New series, No 4, Columbia Univ. (South Carolina), 125-131.

HOVORKA, D. & SPIŠIAK, J. 1993: Mesozoic Volcanic Activity of the Western Carpathian Segment of the Tethyan Belt: Diversities in Space and Time. Jb. Geol. B-A., 136, 4, 769-782.

KOTANSKI, Z. & RADWANSKI, A. 1959: Fauna z Pygope diphya i limburgity w tytonie wierchowym Osobitej. Acta geol. pol., IX, Warszava, 519-534.

KUDĚLÁSKOVÁ, J. 1987: Petrology and geochemistry of selected rock types of teschenite association, Outer Western Carpathians. Geol. Carpath. Bratislava, 38, 5, 545-573.

LEAKE, B. E. 1978: Nomenclature of amphiboles. Min. Mag., 42, 533-563.

LE BAS M. J. 1962: The role of aluminium in igneous clinopyroxenes with relation to their parentage. Amer. J. Sci., 260, 267-288.

LE BAS, M. J. 1989: Nephelinitic and basanitic rocks. J. Petrology, 30, 1299-1312.

LETERRIER, J., MAURY, R. C., THONON, C., GIRARD, I. & MARCHE, L. M. 1982: Clinopyroxene composition as a method of identification of the magmatic affinities of paleo-volcanic series. Earth Planet. Sci. Lett., 59, 139-154.

MAHMOOD, A. 1973: Petrology of the teschenite rock series from the type area Cieszyn (Teschen) in the Polish Carpathians. Rocz. Pol. Tow. Geol., Krakow, 43, 2, 153-212.

MORIMOTO, N., FABRIES, J., FERGUSON, A.K., GINZBURG, I.V., ROSS, M., SEIFERT, F.A., ZUSSMAN, J., AOKI, K. & GOTTARDI, G. 1988: Nomenclature of pyroxenes. Amer. Mineralogist, 73, 1123-1133.

PACÁK, O. 1926: Sopečné horniny na severním úpatí Beskyd moravských. Čs. akad věd a umění, tř. matem-přírod. věd, Praha, 27, 98 s (in Czech with English summary).

POLDERVAART, A. & HESS, H. H. 1951: Pyroxenes in the crystallization of basaltic magmas. J. Geol., 59, 472 pp.

SLAVKAY, M. 1965: Vulkanogénne horniny okolia Poník. Čas. min. geol., Praha, 10, 3, 249-259 (in Slovak, Engl. abstract).

SPIŠIAK, J., ARVENSIS, M., LINKEŠOVÁ, M., PITOŇÁK, P. & CAŇO, F. 1991: Basanite dyke in granitoids near Dúbrava, Nízke Tatry Mts., Central Slovakia (in Slovak with English abstract). Mineralia slov., 23, 339-345.

ŠMÍD, B. 1978: Výzkum vyvřelých hornin těšinitové asociace. PhD thesis, Ústř. Ústav Geol., Praha. 130s (in Czech with English summary).

SLOVAK GEOLOGICAL MAGAZINE

# Detrital Analysis of the Paleogene flysch deposits of the Levoča Mts.: evidence for sources and paleogeography

JÁN SOTÁK, JURAJ BEBEJ AND ADRIAN BIROŇ

Geological Institute, Slovak Academy of Sciences, Severná 5, 974 01 Banská Bystrica

*Abstract.* Detrital composition of the deep-sea fan deposits of the Levoča Mts. reflects a collision-orogen provenances. In the perisutural part of the basin (Šambron-Kamenica Zone), the flysch formations are significantly enriched with ophiolitic detritus. They even contain sandstones with high proportion of detrital serpentinites, glassy clasts and spinel grains. Petrofacial composition of serpentinic sandstones ($Q_{25}F_8L_{67}$, Lv = 62%) falls to the field of magmatic-arc related arenites (DICKINSON et al., 1983) or oceanic-arc related arenites (VALLONI, 1985). Ultramafic sources are also evidenced by saponitic or corrensitic clay cementation as well as by high Cr and Ni concentrations in mudrocks. Higher up the source lithology of deep-sea fans was significantly changed. Compositional change is recorded by high amount of plutonic, metamorphic and volcanic detritus ($Q_{61}F_{15}L_{24}$), which suggests the recycled-orogen provenance. Temporal evolution of detrital modes from ophiolithic- and carbonate-rich petrofacies to plutoni-metamorphiclastic sandstones reflects progressive exhumation of crystalline basement rocks in the source area of the deep-sea fans.

*Key words:* Central Carpathian Paleogene, deep-sea fans, sandstone petrofacies, provenance, source lithologies

## Introduction

The study of detritus from flysch formations provides important information on the composition and activity of sources and thus on the general paleogeography of basins. For the identification of sources in the Central Carpathian Paleogene of the Levočské vrchy Mts., information has been obtained especially from the analysis of pebble composition of conglomerates, petrofacial analyses of arenites, the composition of heavy mineral associations and the study of alteration of lithic components to clay minerals.

## An outline of the paleogeography of the Central Carpathian Paleogene of the Levočské vrchy Mts.

The Levočské vrchy Mts. are a part of the Spiš-Šariš Basin, which does not have a uniform paleogeographic development. The basin shows an asymmetric bottom configuration due to trenchward tilting (Šambron Depression) and oblique antithetic faulting (Poprad Depression). Both depressions are structures of intensive Upper Eocene subsidence, in which the thickness of the sedimentary infill increases up to 3500 m. The Šambron Zone and the Poprad Depression display the Podhale-type of Upper Eocene sedimentation, in the development of Šambron Beds (=Szaflar Beds). The Šambron Beds are formed of dark shaly claystones and thin-rhythmic flysch, with thick intraformational bodies of conglomerates and breccias. The continuity of the Šambron Zone with the Podhale Paleogene is also documented by the polar variation of the paleocurrent directions, the main one from the E and the opposite from the W.

The central part of the Levočské vrchy Mts. and the Hornád Depression was overlapped by transgression probably only in the Lower Oligocene (the nummulite base is missing). Marine transgression progressed here through flat approns of alluvial deposits (Kluknava Beds). Transgressive lithofacies is represented here by the Tomášovce Beds, containing a fauna of gastropods, bivalvians (Gryphaea) and foraminifers (*Heterostegina*-type forms). The transgressive formations are covered by a claystone lithofacies, which equalised the sedimentation in the whole basin. The sedimentation of claystones, laminated mudstones and muddy turbidites led to the undersaturation of the basin (underfilled basin - PITMAN and ANDREW, 1985). The claystone lithofacies represents actually the Lower Oligocene sub-flysch, which is the presage of a powerful onset of deep-sea fan sedimentation.

The Upper Oligocene cycle of the development of the Spiš-Šariš Basin is characterized by sedimentation in the deep-sea fan environment (MARSCHALKO, 1981). In this time, the basin had a transparent paleocurrent system coming from the east of the Šarišská vrchovina Hills (the entrance of a submarine valley) to the west and northwest (MARSCHALKO, 1966). The deposition system of the basin had developed all parts of the deep-sea fan zones, according to the model of MUTTI and RICCI-LUCCHI (1972). The slope of the deep-sea fan occupies the area of the Šarišská vrchovina Hills and the eastern margin of the

Levočské vrchy Mts. The slope and channel facies are formed of thick conglomerates and chaotic slump bodies (associations F and A), surrounded by levee sandstone facies. Towards the Levočské vrchy Mts., the cone passes into a system of depositional lobes. The covering of the claystone lithofacies by prograding lobes is gradual. Transitional formations above the sub-flysch have the character of medium-rhythmical flysch sequences and they contain already Egerian nanoplankton communities. The structure of the lobes is characterised by upward-thickening flysch sequences, beginning with claystones and thin-rhythmical flysch sediments (associations E and D) and ending with turbidite sandstones (association C) and channelized sandstones (association B). However, accumulation of sand in the depositional lobes became gradually uncompensated with rate of subsidence. Therefore, the lobe systems were growing up into an elevated ramp with a convex-upward relief, which alleviated the dip slope of cone. Due to this cone geometry, the dense cohesive currents were not able to pass into turbulence. From these non-turbulent currents, the top sandstone lithosomes of the Levočské vrchy Mts. were deposited, representing the final stage of the development of deep-sea cone, referred to as "suprafan" (NORMARK, 1970).

The lower part of the deep-sea fan occures in the Poprad Depression and the near-klippen area. The Upper Oligocene flysch has distal character in these areas, documented by the non-cyclic structure of fringe lobes (Ke¾marok Beds), thin-rhythmical to laminated development of turbidites and basinal facies of claystone lithology. With progressive progradation of cone in the stage of "suprafan" development these distal zones were in some places also overlapped by active fronts of sandstone lobes.

## Sources of flysch detritus

The sources of flysch detritus in the Paleogene of the Spiš-Šarišarea exhibit different activity and composition. In the Eocene, the most active sources worked during the accumulation of conglomerates and breccias in the thick intraformational bodies of the Šambron Beds. Their material is composed predominantly of Mesozoic carbonates of Central Carpathian units, differently in the Plavnica area (predominant dolomites) and Lipany area (prevalence of Upper Jurassic - Lower Cretaceous pelagic limestones). In the arenite component of breccias, there are however abundant fragments of basic volcanites (the borehole Šambron PU -1) and in the Lipany area also ultramafics (Lipany-6). The presence of volcanoclastic material in the breccias is reflected also in the specific character of their matrix. The breccias are characterised by greenish colour, caused by the presence of smectite (saponite) and mixed-layer chlorite/smectite (corrensite). These minerals appear as fibrous aggregates, formed by diagenetic alteration and recrystallization of protomatrix. Chloritization of smectite took place in environments with high Mg (and/or Fe) concentrations. In the case of Šambron Bed breccias, the source of Mg may be inferred from the abundance of mafic detrital material. The greenish breccias with smectite and corrensite occur in the borehole Šambron PU-1 (1480 - 2000 m) and in the Lipany area especially in the borehole Lipany-6 (2328 - 2430 m). It is however noteworthy that identical breccias were found also in the Poprad Depression near Toporec (samples from hydrogeological boreholes). We stress the presence of smectite and corrensite also in view of their importance for the determination of the fluid and pressure regime in the intraformational bodies. The intraformational breccias occur in claystone formations with high degree of postsedimentary alteration (ordered R3 mixed-layer illite/smectite, estimated temperature about 170°C; POLLASTRO, 1993). However, in the intraformational breccias persistence of highly expandable clay minerals indicates a considerably lower temperatures of post-sedimentary alteration (T<100°C). The slowing-down of diagenetic processes is characteristic of a rock environment with fluid overpressure (JABOYEDOFF and JEANBOURQUIN, 1995). From this viewpoint, the diagenetic system in the intraformational breccia bodies, which are the best colector rocks in the Central Carpathian Paleogene of Levočské vrchy Mts. (RUDINEC, 1992), was originally overpressured.

In the surface structure of the Šambron Zone, the composition of conglomerates is partly different. Besides carbonates of the Central Carpathian units, the pebble material also contains substantional amounts of granitoids and crystalline rocks (gneisses, micaschists, amphibolites, quartzites, etc.). However, specific components of the conglomerates are folded dark phyllites, calcareous phyllites and marbles, reminding of rocks from the Iňačovce-Kričevo Unit. The presence of breccias and conglomerates in intraformational bodies of the Šambron Zone indicates that besides axial currents (E-W) there existed also a lateral input of coarse-grained detritus. The source of detritus is inferred in fault-bound and seismotectonically strongly active slopes of basin. The accumulated scarp sediments slipped into the basin and, propelled by gravitation, entered the calm environment of pelitic and turbiditic sedimentation of the Šambron Beds (gravity mass movement). It is probable that the source of this detritus were the slopes of the active Central Carpathian plate, however, it is not clear, whether they were downfaulted outwards (southern slopes of the basin) or inwards (structural high of the northern collisional edge). This source probably had also a littoral Paleogene cover, as it contributed a large amount of shallow-water biodetritus (nummulites, coralline algae, bryozoans etc.) and pebbles into the basinal facies of the Šambron Beds.

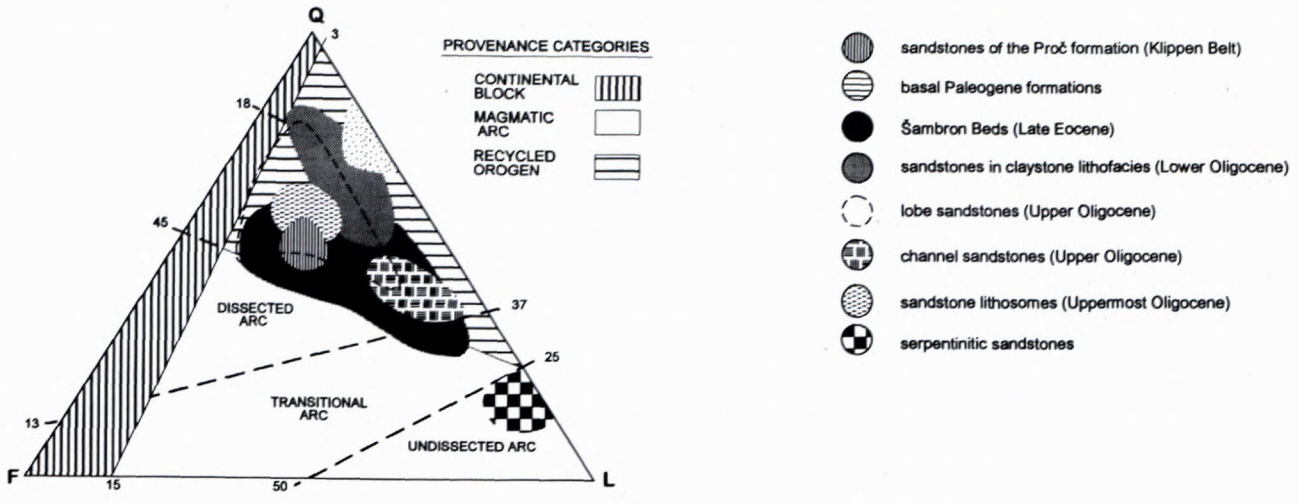



*Fig. 1 Q-F-L plot of sandstones from the deep-sea fan deposits of the Levoča Mts.*

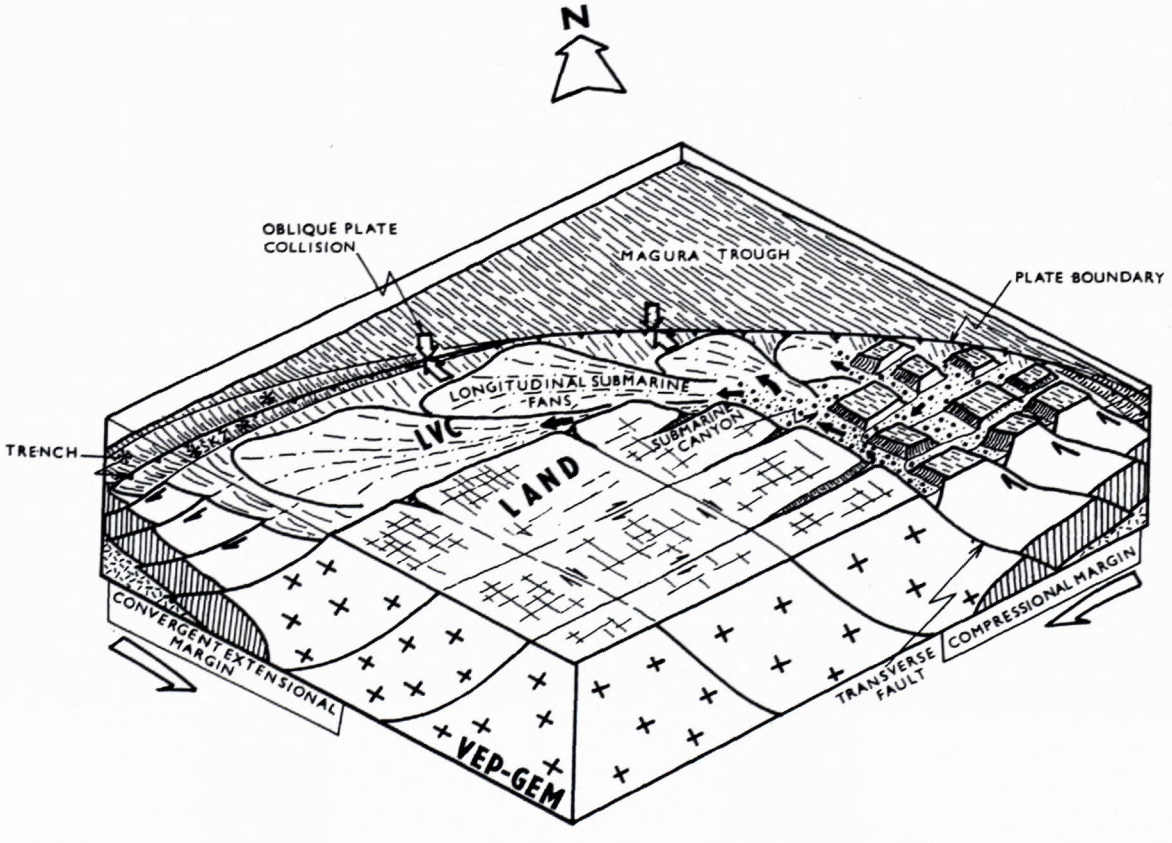



*Fig. 2 Blockdiagram demonstrating the evolution of the East Slovakian collisional zone in the Late Oligocene. Oblique plate interaction caused both compression and extension in the hangingwall of a subduction zone. Compressional margin above the Iňačovce-Krichevo zone, in which the Middle Eocene sediments were also underplated, had been strongly emerged and tectonically eroded. The convergent extensional margin of the Centrocarpathian plate was occupied by fore-arc basin (Central Carpathian Paleogene), which was supplied by the longitudinal submarine fans. From the North the fore-arc basin was formed at distance of active subduction (perisutural basin). The plate margin had been pushed gradually foreward and produced compressional structures at the front. Abbrevations: LVC - Levoča basin,ŠKZ - Šambron-Kamenica Zone, Gem - Gemericum, VEP- Veporicum.*

Sandstones of the Šambron Beds contain approximately a balanced share of siliciclastic and lithic components (Q/L) at a low proportion of feldspar (F/L). These parameters are plotted in the diagram for geotectonic provenances of sandstones on the boundary of recycled orogeny and magmatic arc fields (Fig. 1). In sandstones of younger, Upper Oligocene formations of the Šambron Zone, oceanic sources play a greater role in the detrital composition of sandstones. In the most distal facies of flysch, occurring on the contact of the Šambron Zone with the Klippen Belt, there were recorded also occurrences of serpentinitic sandstones (SOTÁK & BEBEJ, 1995, 1996). They are flysch deposits with a high concentration of serpentinite detritus, clasts of devitrified and pelagonized glass and a specific type of diagenetic minerals (saponite, corrensite, opal-CT etc.). The dominance of serpentinite grains results here in the increased portion of unstable lithic components (Lv), which shift the sandstones into the area of the magmatic arc and subduction complexes provenance. The origin of the detritus of the serpentinitic sandstones may be thus derived from oceanic crust sheets dragged out on the collisional edge of the Central Carpathian plate in the subduction trench zone (Fig. 2). The sediments of the Šambron Zone are generally very rich in spinel detritus (up to 80% of the heavy fraction of sandstones at localities near Plavnica and Kamenica), having apparently the same origin.

The study of conglomerates in the central and southern parts of the Levočské vrchy Mts. showed a change in the composition of carbonate detritus (predominance of Upper Jurassic - Lower Cretaceous limestones - e.g. pelagic calpionella limestones with pyroclastic admixture, Jurassic spotted limestones, Malmian microoncolithic limestones, shallow-water Neocomian limestones, Urgonian-type limestones, etc.) and higher-up also in diminishing of carbonates and increasing of plutonic and crystalline rocks. However, volcanites display a relatively homogeneous distribution both in conglomerates and flysch sandstones of the Levočské vrchy Mts. They are represented by various types of basalt, felsitic volcanites, porphyries, volcanoclastics, andesites, etc. In the east of the Šarišská vrchovina Hills we recorded in sandstones the presence of unaltered volcanic clasts, which are probably neovolcanic in origin. In view of the fact that the first phases of volcanism in Eastern Slovakia occurred evidently only in the Eggenburgian, the presence of neovolcanic clasts in the detritus of flysch sandstones is an important stratigraphic indicator (it confirms some biostratigraphic determinations of Lower Miocene sediments in the eastern part of Šarišská vrchovina Hills - MOLNÁR et al. 1992).

Similarly as in the composition of conglomerates, sandstone petrofacies of the Levočské vrchy Mts. display a trend of gradual decrease of carbonate detritus and increase in the amount of detritus from the crystalline basements. With younger age, the sandstones are shifted in the discrimination diagram from the recycled orogeny field (sandstones of the claystone lithofacies) to the proximity of the continental block provenance (sandstones of progradational loges and of the suprafan). A similar trend is reflected also in the heavy mineral composition, the spinel associations of the Šambron Beds being represented in younger formations by transitional garnet-chromium spinelid associations, which is in the progradational lobe and lithosome zone replaced by garnet-tourmaline associations. The determined inverse trend of detritus distribution is explained in literature by the exposure of lower crustal levels in exhumed structures of orogenes (CRITELLI and LE PERA 1994). This interpretation may be accepted, as the sources of Upper Oligocene deposits of the Levočské vrchy Mts. and Šarišská vrchovina Hills were exposed in the east, where exhumation of the Iňačovce-Kričevo unit took place in this time (Fig. 2)

*Acknowledgements:* The study has been partly supported by Grant 4077 (Slovak Academy of Sciences).

## References

CRITELLI, S. & LE PERA, E., 1994: Detrital modes and provenance of Miocene sandstones and modern sands of the southern Apennines thrust-top basins (Italy). Jour. Sed. Research, A64, 4, pp. 824 - 835.

DICKINSON, W. R., BEARD, L. S., BRAKENRIDGE, G. R., ERJAVEC, J. L., FERGUSON, R. C., INMAN, K. F., KNEPP, R. A., LINDBERG, F. A. & RYBERG, P. T., 1983: Provenance of North American Phanerozoic sandstones in relation to tectonic setting. Geol. Soc. Am. Bull., 94, 222 - 235.

JABOYEDOFF, M. & JEANBOURQUIN, P., 1995: Mixed-layer clays and scaly fabrics as indicators of overpressures within accretionary prisms and melanges. Abstract supplement No. 1, Terra nova, vol. 7, p. 127.

MARSCHALKO, R., 1966: Geology and sedimentology of marginal lithofacies (Šarišská hornatina Mts.). Zbor. geol. vied, Západné Karpaty, 1, pp. 1 - 102 (in Slovak, English summary).

MARSCHALKO, R., 1981: Submarine turbidite fans in the Paleogene of Central Carpathians and the extent of flysch beneath the East Slovakian Neogene. In: Geologická stavba a nerastné suroviny hraničnej zóny Východných a Západných Karpát. Geologické dni J. Slávika, Koąice, pp. 47 - 63 (in Slovak, English summary).

MOLNÁR, J., KAROLI, S. & ZLINSKÁ, A., 1992: Oligomiocene of Šarišská vrchovina Mts. Geol. Práce, Spr. 95, Geol. Úst. D. Štúra, Bratislava, pp. 41- 45 (in Slovak, English summary).

MUTTI, E. & RICCI-LUCCHI, F., 1972: Le torbiditi dell' Appen nine settentrionale: introduzione all'analisi di facies. Memorie Societa Geologica Italiana, v. 11, pp. 161 - 199.

NORMARK, W. R., 1970: Growth patterns of deep-sea fans. Amer. Assoc. Petrol. Geol. Bull., 54, pp. 2170 - 2195.

PITMAN, W. C. & ANDREWS, J. A., 1985: Subsidence and thermal history of small pull-apart basins. SEPM Spec. Publ., 37, 45 - 49.

POLLASTRO, R. M., 1993: Considerations and applications of the illite/smectite geothermometer in hydrocarbon-bearing rocks of miocene to mississippian age. Clays and Clay Minerals, 41, 119 - 133.

RUDINEC, R., 1992: Oil and gas accumulations near Lipany in Eastern Slovakia and their specialites and problems. Miner. Slovaca, 24, 357-367 (in Slovak, English summary) .

SOTÁK, J. & BEBEJ, J., 1995: Plate tectonic provenance of serpentinitic sandstones from the Central Carpathian Paleogene (East Slovakia). Geol. Soc. Greece, Sp. Publ., No. 4/1, Athens, pp. 397 - 401.

SOTÁK, J. & BEBEJ, J., 1996: Serpentinitic sandstones from the Šambron-Kamenica Zone in Eastern Slovakia: an evidence for the deposition in a Tertiary collisional belt. Geologica Carpathica, 47, 3, Bratislava.

VALLONI, R., 1985: Reading provenance from modern marine sands. In. ZUFFA, G. G. (ed.) : Provenance of Arenites. NATO, ASI (Dordrecht), Series No. 148, D. Riedel, 309 - 332.

SLOVAK GEOLOGICAL MAGAZINE

# Neogene tectono-sedimentary megacycles in the Western Carpathians basins, their biostratigraphy and paleoclimatology

NATÁLIA HUDÁČKOVÁ[1], MICHAL KOVÁČ[1], VILIAM SITÁR[1], RADOVAN PIPÍK[1], KAMIL ZÁGORŠEK[1] & ADRIENA ZLINSKÁ[2]

[1]Department of Geology and Paleontology, Faculty of Natural Sciences, Comenius University, Mlynská dolina, Bratislava
[2]Geological Survey of Slovak Republic, Mlynská dolina 1, 817 04 Bratislava

*Abstract:* Sedimentary fill of the Western Carpathians Neogene basins was deposited during four main tectono-sedimentary megacycles. The Eggenburgian - Ottnangian marine to terrestrial megacycle could be characterized by transpressive tectonic regime in the frontal part of the orogen and transtensive tectonic regime in the back arc region. During the Karpatian - Lower Badenian and Middle Badenian - Sarmatian megacycles the transtensive basin formations were controlled by the Western Carpathians active elongation. The sedimentary environment was dominantly marine during the Karpatian and Badenian and mainly brackish during the Sarmatian due to isolation from the Mediterranean. The brackish to lacustrine sediments of the younger megacycle (Upper Sarmathian - Pannonian) were deposited during the back arc thermal collapse in extensive regime.

*Key words:* Neogene megacycles, tectonic regime, biostratigraphy environment, climate,.

## Introduction

The development of intramontane basins in the Western Carpathians was influenced by compressional tectonic regime connected with subduction of the basement of Carpathian externides and the formation of an accretionary prism of the flysch zone, as well as by extensional tectonic regime of back-arc rifting and subsequent thermal subsidence.

The sedimentary history of Western Carpathian intramontane basins during the Neogene may be divided, based on tectono-sedimentary megacycles, into four stages: Eggenburgian - Ottnangian, Karpatian - Lower Badenian, Middle Badenian - Lower Sarmatian, Upper Sarmatian - Pannonian (Pontian).

### Eggenburgian - Ottnangian stage

**Tectonic regime:** In view of the continuing tectonic extrusion of the lishospheric Western Carpathian fragment from the area of Alpine collision, and of the subduction in front of the orogen, a considerable role in the formation of Lower Miocene basin systems of the Central Carpathians played the transpressional tectonic regime. This regime controlled the sedimentation in relic fore-arc basins and wrench-fault furrow type basins in the front of the orogen. On the other hand, transtensional regime predominated in the back-arc area (southern Slovakia).

**Environment:** The Lower Miocene transgression from the Mediterranean area intruded through the Alpine and partly Carpathian foredeep into the area of the Vienna Basin. From there, sea progressed later into the Váh Valley (SALAJ & ZLINSKÁ 1991), flooding also the areas of the Bánovce Depression (BRESTENSKÁ 1980), Turiec and Horná (Upper) Nitra (GAŠPARÍKOVÁ 1972, KOVÁČ et al. 1989). The Eggenburgian transgression into the Western Carpathian area is characterised by calcareous nannoplankton associations of the NN2 zone, where *Discoaster druggi* appears for the first time and, at the end of the zone, the species *Triquetrohadulus carinatus* became extinct (STEININGER et al. 1985). The Eggenburgian age of the transgression in the area of the Carpathian foredeep is documented by shallow-water sediments with foraminifer thanatocenoses with the genera *Planulina and Cibicidesoides.*

Deep-water Eggenburgian sediments of the Lužice Fm. lower partin the Vienna Basin are characterised by communities of foraminifers *Batysiphon - Cyclammina*, with predominant agglutinated foraminifer species, such as: *Cyclammina praecancellata* VOLOSH., *C. rotundidorsata* (HANTK.), *Haplophramgomides vasiceki vasiceki* C.-Z., *Bathysiphon taurinense* SACCO and *Textularia gramen abbreviata* ORB., which, acccording to MURRAY (1991), lived in ecologic niches of the outer shelf to upper bathyal, in areas of cool, in nutriments rich currents.

In the Považie and Bánovce Depression region, sediments with equivalent age contain a deep neritic thanatocenosis, with *Marginulina - Lenticulina*, along with *Bolivina antiqua* ORB., *Lenticulina meznericsae* (CICHA), *Marginulina fragaria* GUMBEL, *Tenuitellinata angustiumbilicata* (BOLLI), *G. praebulloides occlusa* BLOW-

BANNER, *Cassigerinella boudecensis* POKORNÝ and *Cribrononion hiltermanni* HAGN (STEININGER & SENEŠ 1971 and BRESTENSKÁ 1980).

In the East Slovakian Basin, in the the Prešov Formation, we can find neritic foraminifer thanatocenoses, characterised by the genera *Bolivina, Bulimina, Valvulineria* and *Marginulina*, which in the west of the area pass into shallow-water, hyposaline communities with various species of the genera *Ammonia, Elphidium* and *Porosononion.* The Čelovce Formation, of Eggenburgian age, contains also foraminifer communities with *Uvigerina posthantkeni* PAPP, *Cibicidoides budayi* (C.-Z.) and *Bolivina tumida* CUSH., indicating insufficient aeration of marine water at the bottom (MURRAY 1991). Sediments of Ottnanngian age are missing in the East Slovakian Basin.

In the Novohrad - Nógrad Basin, in the orogene hinterland, we may observe desalination and shallowing of the sedimentary basin even to brackish development of the sediements in the Ottnangian. This environment is characterised by the occurrence of *Cribrononion hiltermani* (HAGN), *Lobatula lobatula* (WALKER ET JACOB) and *Melonis soldanii* (FICHT. et MOLL.). The emergence is documented here by Ottnangian deposition of terrestrial or lake sediments without foraminifers (ČECHOVIČ 1952, VASS et al. 1979). Marine ingression in the uppermost Ottnangian (VASS et al. 1987), which is well correlable with the global curve of sea level changes - the onset of the TB2 pericycle (HAQ et al. 1988) - documents opening of the Mediterranean sea ways. A sign of the ingression in southern Slovakia is the occurrence of marine nannoplankton species - *Cricolithus jonesi* COHEN, *Discoaster aulacos* GARNTER, *Helicosphaera ampliaperta* BRAMLETTE et WILCOXON and *Sphenolithus pacificus* MARTINI, further the occurrence of neritic types of benthic foraminifers, such as *Pappina parkeri breviformis* (PAPP et TURN.), *Cibicidoides borislavensis* (AISENSTAT), *Lenticulina cultrata* (MONTFORT), *Bolivina hebes* MACFAD., as well as the occurrence of planktonic foraminifer species *Globigerina praebulloides* Blow, *Globigerina woodi woodi* JENKINS and *Globigerinoides primordius* BLOW et BANNER.

The closing of Lower Miocene marine sea connections is in the Vienna Basin documented by shallow brackish environment characterised in the upper part of the Lužice Formation (Eggenburgian-Ottnagnian) by a typical euhaline foraminiferal community, with predominance of the *Cibicides* and *Elphidium* genera. An equivalent of the upper part of the of the Lužice Formation are in the Austrian part of the Vienna Basin the "Rzehakia (Onkophora) Beds" of Ottnangian age. In the western part of the Western Carpathians (Dobrá Voda, Bánovce Depression), dark, laminated clays sedimented in the Ottnangian, with remnants of fish, displaying considerably limited oxygen - content at the bottom (PAPP et al. 1973, KOVÁČ et al. 1991).

The marine transgression into the Carpathian foredeep and Vienna Basin in the Eggenburgian is documented by a mollusc association typical for the sublittoral zone. They are especially the species *Turritella turis, Pitar lilacinoides, Pholadomya alpina* and various species of the genera *Teredo, Balanus* and *Ficus* (STEININGER et al., 1971). Later on, with progressing transgression, there started to appear species characteristic for neritic parts: *Chlamys gigas* and *Aturia aturi.* The decrease of salinity in the Vienna Basin during the Ottnangian is documeted by remnants of mollusc shells of the genera *Rzehakia* and *Congeria*, occurring in the upper part of the Lužice Formation. In foredeep sediments of Ottnangian age, there are also mollusc species characteristic of an evironment with lower salinity: especially *Limnocardium moravicum* and various species of the genera *Rzehakia, Congeria* and *Melanopsis* (STIENINGER et al. 1971).

In the Váh Valley and in the Horná Nitra area, the Eggenburgian transgression is well documented by mollusc fauna. The earliest transgression period is characterised by brackish mollusc associations of the genera *Tympanotonus, Melanopsis* and *Clithon*, and sometimes by the occurrence of *Crassostrea gryphoides* in the Horná Nitra area. Later on, predominant are species characteristic of shallow, normally saline sublittoral zone: *Pecten hornensis, Pitar lilacinoides* and *Taras rotundatus.* In the Váh Valley the succession ends with shallow-neritic sediments with the mollusc association of the *genera Astarte, Leda, Solen* and *Tellina.* After neritic sediments with *Panopea* and *Tellina planata*, the highest member of the succession of Eggenburgian age in the Horná Nitra area are again sublitoral sediments with *Turritella eryna*, proving the onset of sea regression from this area (STIENINGER et al. 1971). During the Ottnangian, the whole area was situated in brackish conditions, documented by the occurrence of molluscs *Limnocardium moravicum, Cardium sociale* and various species of the genus *Rzehakia* (STIENINGER et al. 1973).

Eggenburgian sea transgression in the South Slovakian Basin is supported by the occurrence of molluscs from the genera *Flexopecten, Calyptrea, Turritella, Ficus* and *Fussus*, characterising sublittoral to supralittoral zone (STIENINGER et al. 1971). Later on, bryozoan genera typical of deeper parts of the littoral - *Shizoporella* and *Retepora* - occur along with them. Early Ottnangian sediments of the South Slovakian Basin formed in the environment of limno-brackish to limnic basins, which is documented by the occurrence of molluscs *Limnocardium moravicum*, species of the genus *Rzehakia* and later limno-brackish to limnic species of the genera *Planorbis* and *Unio* (STIENINGER et al. 1973).

In the Fiľakovo Formation, at the village Mučín, there was found a rich fauna of sharks and whales of Lower Miocene age. The majority of species indicates sublittoral zone in a tropical to subtropical climate, but pelagic

species are common too; deep-water species are rare. The most frequently occurring were teeth of the *Synodontaspis acutissima*, *S. cuspidata* and *Isurus hastalis*, which are typical representatives of the near-shore zone in a warm sea. The more rare species *Isurus desori*, *Aetobatis aruatu* and *Squatina* sp. may be assigned to the same niche. In the transitional zone between the sublittoral and deeper littoral there lived *Carcharocles chubutensis*. Typical pelagic species found in this area are *Notidanus primigeneraus*, *Carcharoides catticus*, *Galeocerdo aduncus*, *Esistius triangularis*, *Squalus* sp. and the whale *Squalodon* sp. On the other hand, there are present also species living near the bottom, adjusted rather to cool water, especially in a greater even bathyal depth. A rarely occurring species is here the Lower Miocene shark *Mitsukurina lineata*, further *Carcharoides catticus* and the very rare *Isurus benedeni* (HOLEC et al. 1995).

In the area of the Ipeľ Basin, in the Dolina mine, in the overlier of the coal seam, there were found fragments of siren ribs of Upper Ottnangian age (HOLEC 1982).

**Climate:** *Lower Eggenburgian* (subzone MF-2) had a warmer climate than the cool Egerian. This is documented by the scarce occurrence of arctotertiary elements and rich representation of subtropic to tropic species. The micro-flora (spores and pollen grains) as well as macro-flora has tropic to subtropic character (PLANDEROVÁ 1990). The spores are represented by a fern group of the genus *Lygodium* and club-mosses of the genus *Lycopodium*. From coniferous plants there are representatives of the genus *Cathaya* and of angiosperms especially pollen of the family Sapotoaceae, Symplocaceae and Fagaceae. The macro-flora (loc. Veľká Čausa) is charaterised by the genera *Ficus*, *Fagus*, *Castanopsis*, *Laurus*, *Engelhardia*, *Daphnogene*, *Quercus* and *Persea*, from arctotertiary elements there are only *Ulmus* and *Zelkova* (NĚMEJC 1967). The landscape was in this time richly overgrown with xerophilous forests, except for areas near rivers and lakes, with hydrophilous or even morass flora.

*Upper Eggenburgian - Lower Ottnangian* (community subzone MF-3). In sediments of this zone, there occur pollen grains of angiosperms plants, such as *Carya*, *Myrica* and Sapotaceae, which are clearly tropical elements, along with *Magnolia*, Nyssaceae and Cyrillaceae, typical for tropics to subtropics. Macroremnants of flora, assigned to this zone, are known from the locality Lipovany. From this locality there are known plant impressions characteristic for hydrophilous tropical-subtropical plants, especially Lauraceae, further *Magnolia*, *Engelhardia*, *Quercus*, *Platanus*, from unigerminate palm trees (*Calamus*, *Chamemaerops*) and from conifers *Tetraclinis* and *Pinus*.

Ottnangian microflora is rich in genera as well as species, pointing to an optimum climate. The plants indicate the existence of large marshes in the south of Slovakia, overgrown with flora requiring humid soil.

*Upper Ottnangian - Karpatian* (zone MF-4). The terminal part of the Ottnangian differs by its plant cover. There disappeared especially tropical elements and they were replaced by elements of coastal mixed forests, with alders, oaks and chestnut trees. From this time, there are available only palynologic data (PLANDEROVÁ 1990). According to the occurrence of palynomorphs we may assume a cooler climate than in the preceding zone. The number of subtropical-tropical elements decreased, both of spore and seed plants. The percentage of arctotertiary species increased (*Ulmus*, *Carpinus*, *Betula*), as well as of intermediary species, especially conifers (*Pinus*, *Picea*, *Cedrus*) and deciduous trees (*Alnus*, *Carya*, *Ostrya*).

**Volcanism:** This time is characterised by rhyodacite volcanism in the back-arc area and basalt volcanism in the foredeep ( Northern Moravia ).

## Karpatian - Lower Badenian stage

**Tectonic regime:** Transpressional tectonic regime continued to accompany the forming of the Outer Western Carpathian accretionary prism. The marginal parts of the Central Western Carpathians were zones of transition from a transpressional to transtesional tectonic regime. In the Vienna Basin and in the Transcarpathian Basin, a sinistral and dextral system of strike slips formed, controlling the opening of basins deposition centres of pull-apart type.

In the hinterland of the orogen, the back-arc extension continued with its syn-rift stage in a transtensional regime.

The uplift of centralids led to the formation of a river network, oriented predominatly towards the externids in the Karpatian. Rapid subsidence of deposition centres of the basins led to deposition of clastics, frequently by grain-flow of material and turbiditic mechanism of transport.

**Environment:** During the uppermost Ottnangian (zone NN4 of calcareous nannoplankton) marine transgression progressed from the orogene hinterland (southern Slovakia), through the Bánovce area to the Vienna Basin and to the Carpathian foredeep. In the southern Slovakia, similarly as in Hungary, some Ottnangian uvigerina faunas may be regarded as already Karpatian. On the base of the Karpatian, however, some typical Lower Miocene species disappeared (such as *Almaena osnabrugensis* (MUNSTER), *Cyclammina praecancellata* VOLOSH., *Planulina wuellerstorfi* (SCHW.) and *Uvigerina hantkeni* (CUSH.-EDW.). Renewed communication with the Mediterranean in the Karpatian has been confirmed by the occurrence of the largest amount of new Neogene foraminiferal species and high diversity of their communities. The typical neritic microfauna

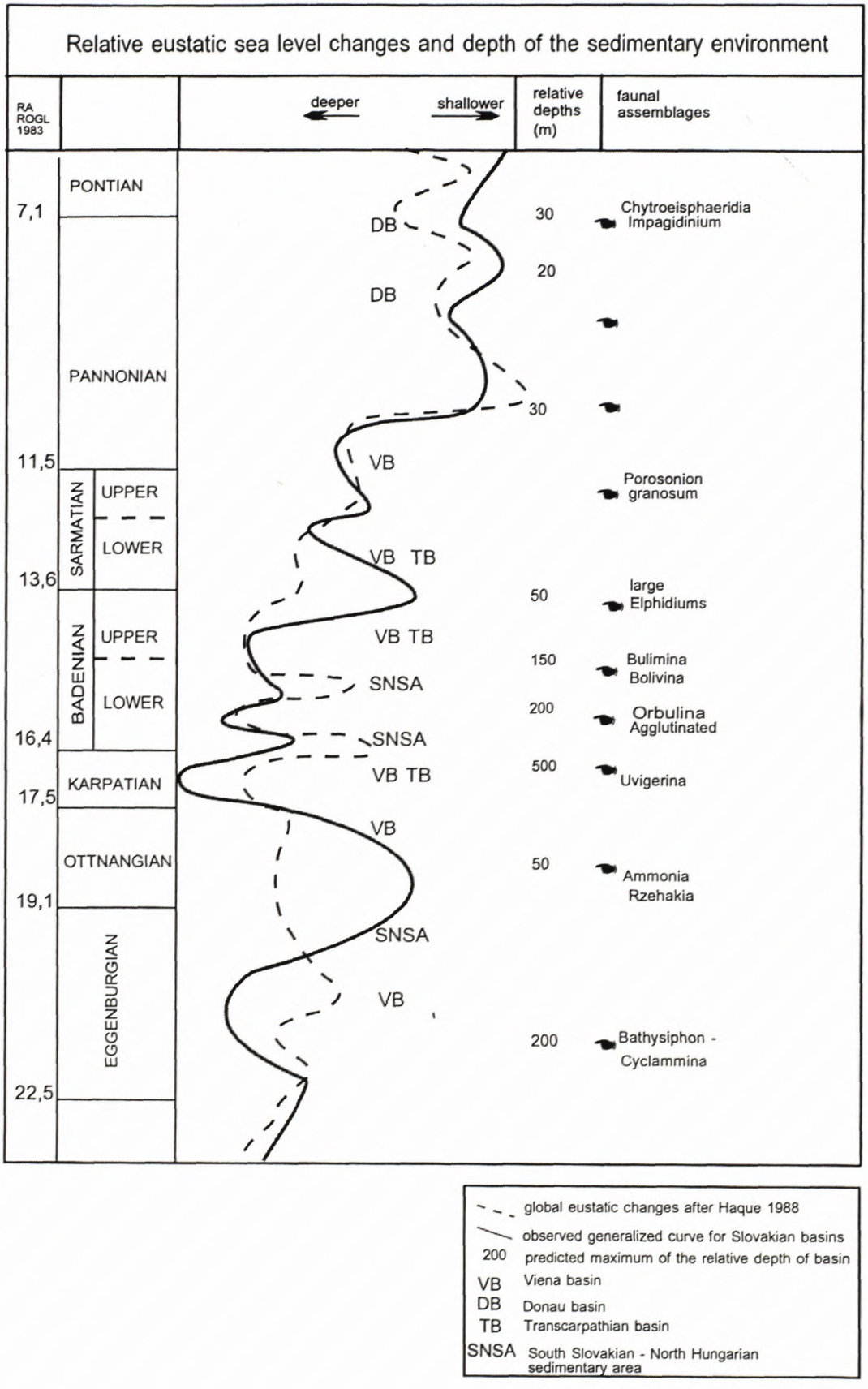



*Fig. 1: Relative changes of sea level and paleodepth of the Western Carpathians Neogene basins.*

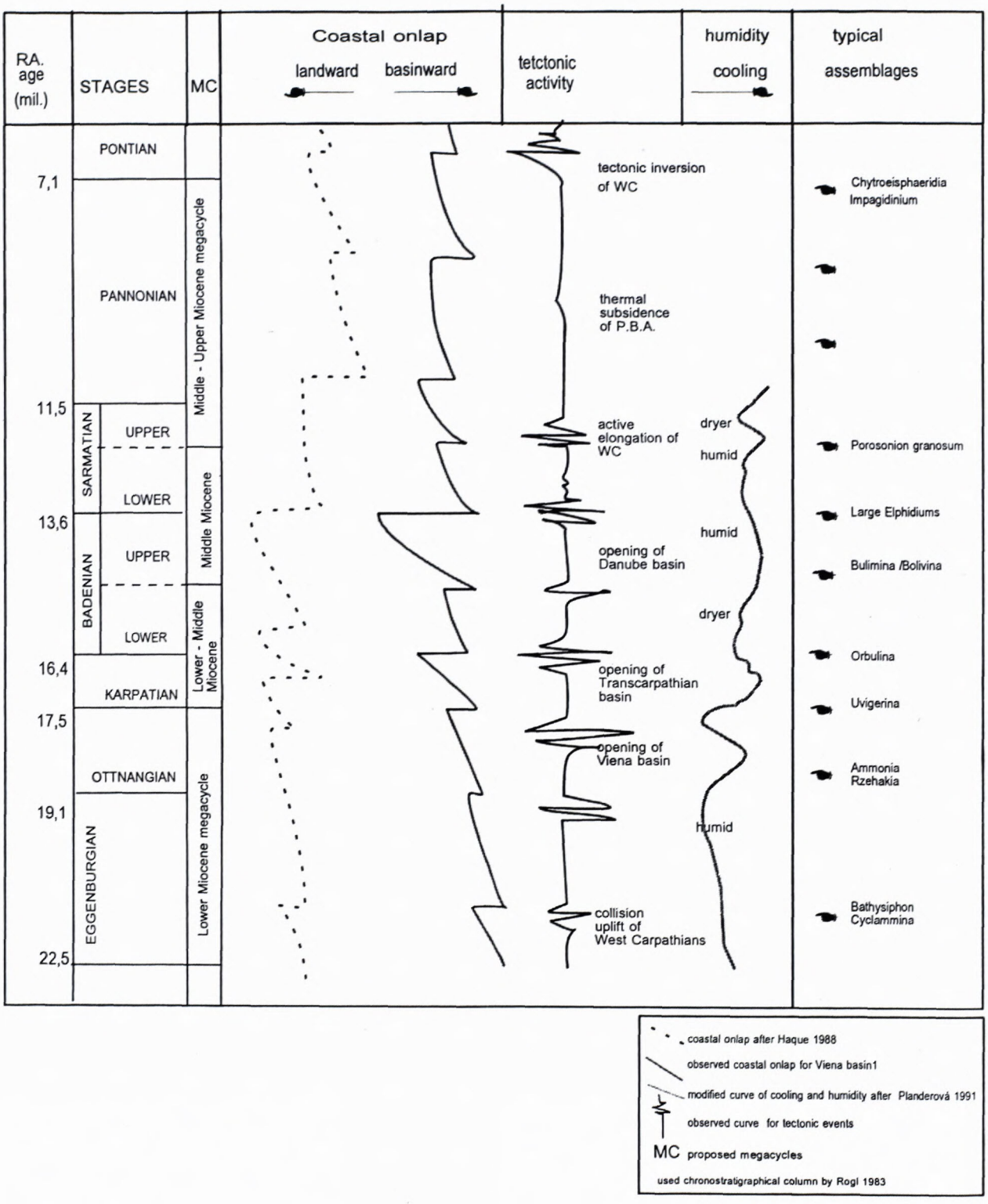



*Fig. 2: Transgresive - regresive cycles, tectonic activity, climatic changes and faunal assemblages depending on opening or closisng of the Paratethys marine sea connection with the Mediteranean.*

(even bathyal in the Bánovce Basin and in the northern part of the Vienna Basin) is euhaline and tolerant to oxygen depletion at the bottom. In thanatocenoses there are mostly *Uvigerina graciliformis* (PAPP et TURN.) *Pappina bononiensis primiformis* (PAPP et TURN.), *P. parkeri breviformis* (PAPP et TURN.), *Cyclammina karpatica* C.-Z. and *Reticulophragmium karpaticum* C.-Z. (CICHA et al. 1983).

In the Eastern Slovakia, hypersaline facies sedimented with very poor microfauna consisting of representatives of the genera *Elphidium, Melonis* and *Nonion*, sporadically also with *Uvigerina graciliformis* P.-T., *Ammonia beccarii* (L.) and *Bolivina dilatata* RSS. above neritic facies. The development of the East Slovakian Basin points to partial isolation from the intracarpathian sea, containing euryoxibiont communities, with predominant *Lenticulina inornata* (ORB.), *Dentalina intermedia* (ORB.), *Pappina bononiensis primiformis* (PAPP et TURN.) and numerous *Bulimina* species.

Stabilised marine environment along with ideal climate led to the appearance of new fauna groups during the Lower Badenian. This time is characterised by maximum number of foramininferal species, especially agglutinated and lagenerad forms. This fact was probably caused by subtropical climate in the Western Carpathian region and global sea level rise, which may be correlated with the short-term curve TB2-2.5 in the global marine level changes supercycle (HAQ et al. 1988).

Lower Badenian nannoplankton communities (zone NN5) are in all basins almost identical - they contain 39 nannoplankton species, such as *Braarudosphaera bigelowi* (GRAN et BRAARRUD) DEFLANDRE, *Coccolithus pelagicus* (WALLICH) SCHILLER, *Cyclococcolithus leptoporus* (MURRAY et BLACKMANN) KAMPTNER, *C. rotula* (KAMPTNER) KAMPTNER, *Discoaster aster* BRAMLETTE et RIEDES and *D. druggi* BRAMLETTE et WILCOXON. More diversified communities have been found at localities in southern Slovakia, with *Helicosphaera wallichi* LOHMANN.

Lower Badenian foraminiferal species, due to higher water temperatures in the sedimentation area, are more developed and richly ornamented (e.g. *Lenticulina echinata*). For the first time there occurred the plankton genera *Orbulina* and *Praeorbulina,* from benthos *Heterostegina.*

Foraminifer communities in the Vienna Basin indicate a bathyal sea depth, with a well aerated bottom, with typical occurrence of the genera *Orbulina* and *Praeorbulina* in the lagenerad zone (GRILL 1943). Along with them, there occur the species: *Lenticulina echinata* (ORB.), *L.. cultrata* (MONTF.), *Planularia antillea ostraviensis* VAŠÍČEK, *P. dentata* KARRER, *Vaginulina legumen* (L.) and *Uvigerina macrocarinata* PAPP et TURN..

Only the eastern part of the present Danube Basin area was flooded (the Želiezovce Depression), which communicated with the sea at the southern margin of the Central Slovakian neovolcanics. The sea attained locally (Bajtava, Modrany) neritic depth (PAPP et al. 1978), Marine sedimentation was frequently interrupted by the accumulation of volcanic material. The most frequently occurring foraminifers are *Valvulineria complanata* (ORB.), *Heterolepa dutemplei* (ORB.), *Globigerinoides trilobus* RSS. and *Orbulina suturalis* (BRONN.) along with the communities *Ammonia beccarii* (L.), *Asterigerinata planorbis* (ORB.) and *Nonion sp..*

In southern Slovakia, the basins attained sublittoral, at most shallow neritic depth. After the Lower Badenian, this area became a dry land (KOVÁČ et al. 1993).

In the East Slovakian Basin, in sediments of Lower Badenian age, marine foraminifer communities with *Orbulina suturalis* Bronnimann and *Orbulina universa* (Jedlitschka) occur rarely, indicating by their large lagenerad forms an autonomy of the basin, with a weakly aerated shallow neritic sedimentation environment.

The sedimentatry environment in the foredeep is characterised especially by rich associations of sublittoral marine mollusc species, with typical stenovalent species of the genera *Pecten, Chlamys. Teredo* and *Turritella* during the Karpatian. There are known also remnants of corals (especially the genera *Flabellum and Turbellastrea),* ciripedians (genus *Balanus)* and ostracods (e.g. *Cytheridea (C) paracuminata* ), CICHA et al. (1967). In the Lower Badenian the depth of the sea slightly increased, the environment became circalittoral, with typical species such as *Aporrhais pespelecani* and *Nassa dujardiny* (SENEŠ et al. 1978).

In the Vienna Basin, neritic environment with well aerated bottom predominated during the Karpatian, characterised by frequent finds of mollusc, sea urchins and ostracod shells. From molluscs, the most typical representatives of neritic associations are the species *Solemya doderleini* and *Aturia aturi,* from sea urchins especially *Brissopsis ottnangiensis* and the genus *Schizaster,* and from ostracods especially *Loxoconcha hastata* (CICHA et al. 1967).

During the Lower Badenian, terrestrial material along with remnants of land vertebrates entered locally the marine environment in the Vienna Basin. In the area of the Štokerau lime works (Devínska Nová Ves), there has been found a rich fauna of mammals which inhabited the steppe-forest and several species of small rodents. There are frequent finds of the species *Palaeoerinaceus* sp., *Sorex gradilidens, S. dehmi, Heterosorex sansaniensi* and *Seaptouyx edwardsi.* Further there have been found remnants of the bats *Rhinolophus delfinensis, R. similis, Pareptesicus priscus* and *Miniopetrus fossilis,* of the carnivores *Trocharion albanense, Amphicyon maior, Alopecondon leptorhynus, Hemicyon sansaniensis, Ursavus brevirhinus, Ailurictis jourdani* and *Pseudailurus* cf. *turnausensis,* the mastodonts *Zygolopnodon turicensis* and the odd-toed *Chalicotherium grande.* Rarely there have been found also fragments of primates - *Proplio-*

*pithecus vindobonensis,* fragments of the hornless rhinoceros *Aceratherium* cf. *tettradactylum* and of the nomad which had immigrated from America across the Bering Strait - *Anchitherium* (HOLEC 1978).

The marine connection renewed during the Karpatian is characterised by a communication with the Mediterranean, especially through the back-arc basin. A typical feature of this sedimentary environment is the occurrence of more deep-water neritic mollusc species, such as *Nuculana fragilis, Solemya dodorleini, Euspira catena helician* and *Aturia aturi* (SENEŠ et al. 1978). Normal salinity is proved by the presence of corals (frequent is especially *Flabellum senesi*) and sea urchins (common are species of the genus *Brissopsis)*, CICHA et al. (1967).

In Eastern Slovakia, a rich mollusc association of Karpatian age is found, represented especially by species and genera which are relatively rare in other basins, e.g. *Chlamys zitteli, Pinna squamosa, Ammussium, Aloidis* and *Thracia,* along with common species typical of the shallow neritic: e.g. *Solemyia doderleini* and *Nuculana fragilis* (SENEŠ et al. 1978). Very rich is the association of sea urchins (predominant species are those from the genera *Schizaster, Brissopsis* and *Trachyaster* ) and ostracods, frequent are especially *Cytheridea (C.) paracuminata* and *Hemicytherura*), proving circalittoral to neritic zone of a normally saline sea.

**Climate:** This stage is characterised by frequent oscillations of the climate, warming on the base of the Karpatian, replaced by subsequent cooling and repeated warming at the end of the Karpatian, which led to the return of warm-subtropic flora after the cooling in the Ottnangian-Lower Karpatian time. The dry land was covered by xerothermic plants, indicating an absence of morasses. New increase in thermophilous elements is obvious especially in comparison with the preceding zone, however, they are not as abundant as in the zone MF3. The proportion of arctotertiary elements remains the same. Microflora is represented by pollens - Cyrillaceae (ericoid forms), Schizeaceae (ferns with large spores) and palm trees, which is evidence of a warm subtropic climate. Macroflora (locality Stredné Plachtince) is known by the abundacy especially of Lauraceae, Myricaceae and *Engelhardia,* from conifers there is *Glyptostrobus* (NĚMEJC 1967).

**Volcanism:** The time of the Karpatian and Lower Badenian is characterised by volcanism which changed gradually from acid in the Lower Miocene, to intermediary and to basic during the Middle Miocene, reflecting the process of the contamination of magma by mantle masses in the back-arc area. Intensive dacite and rhyolite volcanism was active especially in the area of Central Slovakian Neovolcanics, Eastern Slovakuia and in the Danube Basin.

## Middle Badenian- Lower Sarmatian stage

**Tectonic regime:** Middle Miocene transpressional regime accompanied only the forming of the Outer Carpathian accretionary prism, while the last thrusting of nappes on the foredeep took place in the Lower Sarmatian (JIŘÍČEK 1979). The forming of the Western Carpathian basin structure was affected by the steepening of the subducted plate in front of the Eastern Carpathians, causing active elongation of the Western Carpathian internids in north-eastern and later eastern direction.

The forming of basins in the back-arc area was controlled by extensional regime. In the west, in the marginal part of the Western Carpathians, there predominated normal faults of NE-SW direction and ENE-WSW sinistral strike slips compensating the active elongation. Their influence was reflected in formation of partial depressions in the northern part of the Vienna Basin and northern embayment of the Danube Basin. The Transcarpathian Basin acquired in this time the character of an inter-arc basin, where sedimentation was controlled by NW-SE longitudinal faults and NE-SW to ENE-WSW transversal faults.

Deposition centres of Western Carpathian intramontane basins displayed a marked subsidence in the Upper Badenian to Lower Sarmatian.

Due to the elevation of the externids, as well as of the central part of the orogen, the orientation of the river network changed in this time, acquiring predominantly the direction towards the back-arc basin.

**Environment**: During the Middle Badenian, sea flooded the whole area of the Vienna and Danube Basins. The sediments contain diversified communities of nannoplankton (32 species) with discoasters (zone NN6) with long processes, such as *Discoaster deflandrei* BRAMLETTE. et WILCOXON and *D. aulacos* GARTNER, *D. nephados* HAY, *D. variabilis* MARTINI et BRAMLETTE. Foraminifer communities with *Spiroplectinella carinata* (so called *Spiroplectammina carinata* zone, GRILL 1941), *Cyclammina pleschakowi* PISCH., *Martinotiella communis* (ORB.), *Spiroplectinella (=Spiroplectammina) carinata* (ORB.), *Textularia gramen* ORB. and *Haplophragmoides vasiceki vasiceki* C.-Z. are documenting a neritic environment with euhaline conditions. Noteworthy in this zone is the occurrence of the genus *Pseudotriplasia,* the vertical range of which in the Carpathian basins is very narrow. Typical for plankton there are *Globigerina nepenthes* TODD, *G. decoraperta* TAKAYANAGI et SAITO, *Globoturborotalita druryi* (AKERS). The sedimentatry area is locally desalinated in the upper part (Molčíková 1960).

In the East Slovakian Basin, shallow, hypersaline environment predominated during the Middle Badenian, with sporadic occurrence of poor marine communities of small foraminifers - *Globigerina* aff. *bulloides* ORB.,

*Globorotalia scitula* BRADY, *Globigerinoides trilobus* (RSS.) and *Uvigerina aff. aculeata* ORB.

In the Upper Badenian, the Vienna, Danube and EasSlovakian Basins had almost the present shape and they were the marginal bays of a relatively shallow sea in the back-arc area. A general feature of these basins is the development of the *bulimina-bolivina* biozone (GRILL 1941) as a reaction to oxygen deficit. The above biozone is characterised especially by the species: *Bolivina dilatata dilatata* Rss., *B. dilatata maxima* C.-Z., *B. dilatata brevis* C.-Z., *Bulimina elongata* ORB., *Praeglobobulimina pupoides* (ORB.) and *Pappina neudorfensis* (TOULA). The marginal parts of the bays with marine-brackish environment (ammonia zone, GRILL 1941) is documented by foraminifer communities containing miliolid types: species of the genera *Quinqueloculina, Triloculina* and the species *Ammonia beccarii* (L.), which, in near-shore facies, pass isochronally into shallow-water brackish mono-communities with *Ammonia* (Čierna 1974). On the basis of lateral and vertical isochronal changes of communities we may assume the stratification of the water column, with a lower - anoxic and upper - hyposaline layer. The anoxia is however not present in all of the area.

During the Upper Badenian, some species of agglutinaged foraminifers became extinct and in the Lower Sarmatian they were substituted by miliolid foraminifers. The reduction in the number of benthic foraminifers may have been caused by the deterioration of the life conditions, related to the gradual interruption of marine connections at the end of the Badenian. The above mentioned changes were a reflection of the global lowering of the sea level in the TB2-2.4 cycle (HAQ 1988).

In the Sarmatian, due to the interruption of marine communication with the Mediterranean, gradual desalination took place, documented by a marked change in the communities of nannoplakton, organostenic plankton and foraminifers. Nannoplankton , exept for the borehole SŠ 37 at Pavlová, has been found only rarely - the species were *Cyclococcolithus leptoporus, Cyclococcolithus rotulus.* In the borehole SŠ 37 Pavlová, north of Štúrovo, rich nanoplakton communities have been found, containing, besides the already mentioned *Cyclococcolithus leptoporus* and *Cyclococcolithus rotulus*, many other species.

In the Lower Sarmatian, shallow-marine to brackish environment with decreased salinity (zone *Elphidium reginum* GRILL 1941) predominanted in all basins of the Western Carpathians, the typical species being *Anomalinoides badenensis* (ORB.), *Articulina sarmatica* (KARRER), *Elphidium acuelatum* (ORB.), *E. reginum* (ORB.), *E. macellum* (F.-M.), *E. crispum* (L.), *E. samueli* ZLINSKÁ. Locally, the tectonically affected deepening of the sedimentation area (e.g. in the Vienna Basin and the Mukachevo area) with manifestations of anoxia at the bottom, is documented by the developkent of mono-communities with *Anomalina badenensis* (HUDÁČKOVÁ - KOVÁČ 1993). In the Lower Sarmatian of the Vienna Basin we may observe mass occurrences of algae *Leiosphaera* sp. and *Mecsekia incrassata* S. - Szentai, which may be considered the result of a stress factor.

In sediments of Badenian age in the Vienna Basin there are abundant remnants of vertebrates. Finds of teeth of varius shark and ray species are predominant. The most frequent are shark teeth of the species *Hemispristis serra, Synodontaspis accutissima* and *S. cuspidata,* from rays there are *Aetobatis arcuatus, Miliobatis* sp. and *Dasyatis* sp. , as well as teeth of bony fish of the genera *Sparus, Pagrus, Cymbius, Saurocephalus, Spherodu, Phyllodus, Capitodus, Diplodus* and *Trigondon,* all of them inidcating shallow-water, sublittoral environment. Rarely there have been found remnants of the sea turtles *Trionyx* and *Psephophorus polygonus,* fragments of seals *Pristiphoca vetusta,* of the sirens *Metaxytherium* and *Thalatosirean,* as well as of the whale *Mesocetus hungaricus.* Washed down from dry land into the basin there were remnants of the primates *Sivapithecus (Dryopithecus) darwini,* of large terrestrial mammals *Zygolophodon turicensis, Deinotheriuim levius* (mastodonts), *Brachypotherium* cf. *goldfussi* (rhinoceros), *Amphicyon, Palaeogale* and small even-toed animals - *Hyotherium soemmeringi, Conohyus simmorrensis, Listriodon lockharti, Taucanamo sansaniense, Dorcatherium vindobonendse, Dicroceros elegans, Lagomeryx parvulus* and *Palaeomeryx eminans* (HOLEC 1986). In the central Slovakia (Horná Nitra area), below the coal seams in Nováky, remnants of large mammals have been found, of the species *Aceratherium innccisivum* KAUP. and *Zygolophodon turicensis* (mastodonts) along with bones and teeth of small mammals - *Demoricetodon brevis* SCHAUB., *Sciurus* sp., *Eumyarion latior* SCHAUB. et ZABFE, *Peridyromys hamadryas* (MAJOR), *Neoceometes brunonis* SCHAUB. et ZAPFE, *Glis* sp. and *Mioglis larteti* BAUDELOT (HOLEC 1985).

Mollusc communities are very well diversified in sediments of Middle to Upper Badenian age. A characteristic feature is the presence of stenotype genera, such as *Turritella, Conus, Cypraea, Pecten* et. (Seneš et al. 1978). For the first time, corals occur in greater quantity, especially in the foredeep - above all the genera *Siderastrea, Caryophyllia, Parites* and *Dendrophyllia*, pointing to a very warm, well aerated, normally saline sea in the circalittoral to infralittoral zoe. Remnants of sea urchins are frequent too, especially of the genera *Schizaster* and *Brissopsis,* proving as well the above conditions.

The mollusc thanatocenosis, especially in the Vienna Basin, shows a gradual decrease of salinity from a normally saline sea in the Upper Badenian (characteristic species: *Glycimeris pilosa, Pecten besseri* and *Venus multilamella*) through a slightly brackish environment in the Uppermost Badenian (species typical for such environment are *Corbula gibba, Hinia illovensis* and

*Glossus* sp.) to the strongly decreased salinity, brackish environment of the Upper Sarmatian (as evidence may be regarded the presence of *Pirenella picta* and various species of the genera *Cerithium* and *Cerastoderma).*

In the Vienna Basin, predominant fossils at the boundary of Badenian/Sarmatian became bryozoans, in some places with the sedentary worms *Serpula.* Bryozoan zoaria of the species *Pentalopora foliacea* (ELLIS et SOL, 1786) form monospecific accumulations, creating thus conspicuous, even reef bodies in the Devínska Kobyla area. Such bodies often consist also of the association *Celleporaria plamata (*MICH.) - *Serpula,* especially in the area of the southern Slovakian sedimentation area.

In the Sarmatian, due to gradual decreasig of salinity a monotype communities of molluscs and ostracods were formed. In the Vienna Basin there predominated molluscs of the genera *Calliostoma* and *Mohrrensternia,* more rare are species of the genera *Hydrobia* and *Pirenella.* A simlar mollusc community is known from the sediments of the East Slovakian Basin, where species of the genera *Cerithium, Hydrobia* and *Ervilia* are predominant. In the Danube Basin, sediments of Sarmatian age are known only from boreholes. From molluscs, predominant there are the genera *Cerastoderma, Modiolus* and *Mohrrensternia* (SENEŠ edit. 1974).

The marked decrease of salinity is indicated by the ostracod genera *Candona* and *Candoniella.* Later on, species bearing well the lower salinity of the Sarmatian sea appeared as well, such as *Cytheridea hungarica, Aurila méhesi, Loxoconcha fragilis* and *Miocyprideis janoscheki.*

**Climate:** *Upper Badenian* (subzone MF - 6). In this time, we may observe a decrease in the number of thermophilous elements, but the cooling was less intensive that at the end of the Egerian, or at the end of the Ottnangian. Relatively short intervals of warm humid climate occurred too, with morasses in which the coal seams of Handlová and Nováky deposited. Based on palynomorphs it may be assumed that in the Paratethys area, the era of ferns from the family Shiczeaceae and of the deciduous Sapotaceae (i.e. of clearly tropical elements) ended. PLANDEROVÁ (1990) concluded from palynological data - based on the lower proportion of spore plants - that a more xerophilous flora existed then. In microscopic associations, elements of intermediary flora types are prevalent, such as *Carya, Pterocarya*, Taxodiaceae and Cupressaceae. *Engelhardia (Momipites)* were still abundant. The arctotertiary component started to prevail (*Pterocarya, Ulmus, Alnus, Carpinus*). PLANDEROVÁ (1990) determined a greater proportion of Chenopdiaceae, i.e. of halophytes elements, indicating a generally dryer climate.

Macroflora from this time is characterised especially by the genera *Salix, Alnus, Betula, Quercus* and *Acer.* Lauraceae are represented by the genera *Daphnogene* and *Laurus.* Lauraceae started to recede, replaced by mixed forests of flood plain forrest type. The flora is generally more continental, with predominant mixed forests, which we may find at present in the Balkan peninsula. All above data are evidence of a dryer and cooler climate than in the Lower Badenian.

*Boundary Badenian - Sarmatian* Zone MF-7. At the end of the Badenian, the proportion of mountain plant species increased. The general character of plants was more xerophilous. Based on predominant species in the pollen range, we may assume a warm, temperate climate with oscillating dry periods, which were dryer than in the late Badenian. In the pollen range, predominant there are the families Polypodiaceae, Cyatheaceae (tree and herb ferns) and Lycopodiaceae. From conifers, *Pinus* and *Picea* are repsented by a lower percentage, more abundant are Cedrus, *Sequuioa* and *Tsuga.* Frequently found angiosperms are the palm *Arecipites* and the genera *Ulmus, Quercus* and *Castanea.* Elements of tropical plants, the spores Symplocaceae (wood plants of present tropics and subtropics) and Sapotaceae are missing.

Macroflora is known from the borehole VT-D-5 in the Nováky Basin (SITÁR et al. 1987) and partly from the inter-seam layers in the Handlová Basin. There are elements of hydrophilous to morass plants, e.g. Sphagnum and Lycopodium, from krytosemenné Byttneriophyllum. Besides these, a large amount of impressions have been found, of the genera *Myrica, Laurophyllum, Daphogene, Acer, Ulmus* and *Magnolia.* Tropical elements are missing, but Lauraceae are still represented, indicating cooling of the climate.

*Lower Sarmatian (* zone MF-8). In the pollen range, some conifers as well as angiosperms are predominant. From conifers there are mostly *Sequoia.* Representatives of krytosemenné may be regarded as the most important component of the flora. They are above all Juglandaceae, Oleaceae and Betulaceae. The spore-pollen community was very rich in species, therefore we may assume that in this time there existed an optimum climate for the development of thermophilous vegetation of mixed deciduous-coniferous forest type.

The richness of flora is documented by the abundant finds of leaf impressions. The impressions of Fagaceae, Juglandaceae and Betulaceae are predominat, however, freqent are also *Parrotia* and *Platanus.* Although representatives of Taxodiaceae or *Byttneriophyllum,* i.e. elements of hydrophilous plants, occur in this flora as well, we may conclude that this flora indicates rather a dry and warm climate.

**Volcanism:** The time of the Upper Badenian and Lower Sarmatian is characterised by a very intensive stage of andesite volcanism, especially in the area of the Central Slovak Neovolcanics and in the Transcarpathian

Depression. Besides intermediary volcanism, acid - rhyolite volcanism type was present in the back-arc basin as well.

## Upper Sarmatian - Pannonian (Pontian) stage

**Tectonic regime :** The syn-rift stage of back-arc extension was replaced by thermal subsidence of post-rift stage. At the end of this time (in the Pontian), as well as later in the Pliocene and Quaternary, there followed a period of tectonic inversion of the back-arc area, accompanied by the elevation of the Western Carpathian orogen. Intramontane basins became a part of the Pannonian basin system, in which, in spite of its isolation from the Mediterranean, we still feel the influence of global eustatic changes.

The central part of the Danube Basin (the Gabčíkovo and Komjatice depression ) still diplays a marked subsidence. Intramontane basins (the Vienna and Eastern Slovakian Basins) display a relative decrease of subsidence, controlled mostly by normal faults.

**Environment:** The decrease of salinity in Sarmatian sedimentation areas is proved by a marked depletion of calcareous nannoplankton communities of the genus *Coccolithophoridae* and, on the othern hand, enrichment of communities of flagellate algae with an organic cell wall. In sediments of the Vienna Basin we may record, after the Lower Sarmatian mass occurrence of the algae *Leiosphaera* sp., the occurrence of tiny algae *Mecsekia incrassata* and the dinocysts *Spiniferites bentori* (Ross.), which live in delta areas. From dinoflagellates, predominant communities are those of the zone *Spiniferites bentori* (Szuto & Szentai 1988), with a 60% proportion of the genus *Spiniferites (Spiniferites bentori* S.-Szentai, *s. bentori pannonicus* S.-Szentai).

Planktonic dinoflagellates of the genera *Chytroeisphaeridia* and *Gaonyaulax*, as well as others, prove the communication of the Vienna Basin area with a more open-sea environment and the existence of near-bottom currents (Hudáčková, Kováčová, in press).

The Middle and Upper Sarmatian was in all basins on the Slovak territory in brackish development (zone with *Elphidium hauerinum,* Grill 1941), typical species being *Elphidium aculeatum* (Orb.), *E. reginum* (Orb.), *E. samueli* Zlinská, *E. hauerinum* (Orb.). The Upper Sarmatian is almost in freshwater development (zone *Nonion granosum,* Grill 1941) documented by shallow-water brackish species - *Porosononion* ex gr. *granosum* (Orb.) and rarely with *Ammonia parkinsoniana tepida* (Cush.), *Elphidium hauerinum* (Orb.) and *Miliolina* sp.

Brackish to lacustrine sedimentation area during the Upper Sarmatian is characterised also by in species poor, in some places even monotype, but in specimens very rich mollusc associations. In the Western Carpathian basins, there gradually predominated *Melanospis impress, Congeria ornithopsis, Theodoxus intracaraticus* and *Congeria partschi* (Papp et al. 1985). From ostracods, there are present monospecific accummulations of the species *Cyprideis tuberculata.*

The lake-river environment of the Pannonian is characterised above all by the occurrence of a bivalvian from the genus *Unio,* a gastropod of the genus *Planorbis* and the caspic-brackish ostracods *Cyprideis tuberculata, Cyprideis pannonica, Cyprideis sublittorali, Cyprideis heterostigma, Cyprideis obesa, Hemicytheria lorentheyi, Hemicytheria folluculosa, Amplocypris recta, Amplocypris abscissa, Caspiolla unguiculus* and *Caspiolla preabalcanica.*

In Pannonian sediments near Pezinok there was found a remnant of *Trogontberia* and the ancient horse *Hipparion,* belonging to the biozone MN 11. *Hipparion* was found also in Topoľčany and Slepčany, and as a rarity on the boundary Pliocene/Pleistocene also in Nová Vieska in southern Slovakia (Holec 1981).

**Climate:** *Upper Sarmatian - Lower Pannonian* Zone MF-9. Pollen ranges from sediments of the Upper Sarmatian point to a depletion of spore plants from the families Polypodiaceae and Cyatheaceae and increase in the number of representatives from the families Lycopodiacea and Osmundaceae. From conifers, Pinus is especially abundant. angiosperms are represented by a large amount of grasses - Gramineae (*Typha*), further *Juglans* and *Betula* (Planderová 1990).

From leaf remnants there are predominant leaves of the genera Betulaceae, Ulmaceae and Cornaceae, from spore plants *Equisetum* and *Osmunda.* Some oak species receded - *Quercus* (Sitár 1994). Based on the occurrence of pollen grains of Chenopodiaceae, the small proportion of *Byttneriophyllum* and *Glyptostrobus*, we may assume a more dry and moderately warm climate.

*Upper Pannonian - Pontian.* In the pollen range, there are represented the spores *Equisetum* and abundant *Gramineae, Pinus, Fagus, Ulmus* and *Alnus.* macroflora is represented mostly by krytosemenné, above all the genera *Carpinus, Betula, Alnus* and *Quercus.* From more thermophilous plants, we may mention *Ginkgo adiantoides* and *Cercidiphyllum crenatum.* From conifers there occur species of the genera *Torreya, Picea* and *Juniperus.* The forests had the character of mixed deciduous forests with prevalent beeches, oaks and parotias.

**Volcanism:** Alkaline-basalt to basanite volcanism of Pontian to Quaternaty age occurs mostly at the margins of the Pannonian back-arc area.

*Acknowledgement*

We would like to thank Doc. Holec and Dr. Halásová for their help in the elaboration of the presented paper and their valuable comments. Our gratitude goes also to Dr. Vass for financial support by the project "Geodynamical model Stage II". We would like to thank in this way for everything once more.

## References


BOLTOVSKOY, E. (1976): Distribution of Recent Foraminifera of the South America Region. In: HEDLEY, R. H.- ADAMS, C.: Foraminifera 2, 171 - 236. Academic Press London-New York- San Francisco.

BRESTENSKÁ, E. (1980): Geological map and explanatory notes to region of the Bánovská kotlina basin 1:50 000. Manuscript, Geofond, Bratislava.

CICHA I. & ONDREJIČKOVÁ, A. & SENEŠ, J. & ŠPIČKA,V. & TEJKAL, J. & ZAPLETALOVÁ, I. (1967): Holostratotypus und Faziostratotypen des $M_3$ (Karpatien). 50 - 99. In: Seneš (edit): Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys Bd 1 ($M_3$ Karpatien). Bratislava.

CICHA, I. & ZAPLETALOVÁ, A, I. & MOLČÍKOVÁ, V. & BRZOBOHATÝ, R. (1983): Stratigraphical range of Eggenburgian - Badenian foraminiferain West Carpathian basins, Knih. Zem. plynu a nafty, Nr. 4, Hodonín, 99 - 144

ČIERNA, M. (1974): Mikropaläontologische und Biostratigraphische einiger Bohrproben aus der weiteren Umgebung von Rohožník. Acta Geol. Geogr. Univ. Comen., Geol.26, Bratislava, s. 113 - 187.

ČECHOVIČ, V. (1952): Geol´ogia juhoslovenskej Panvy. Geol. Práce, Správy, 33,1 - 33.

GAŠPARIKOVÁ, V. (1972): Mikrobiostratigrafia paleogénnych a spodnomiocénnych sedimentov pod stredoslovenskými neovulkanitmi pohoria Vtáčnik., MS, Geofond, Bratislava

GRILL, R. (1941): Stratigraphische Untersuchungen mit Hilfe von mikrofaunen im Wiener Becken und den benachbarten Molasse -Anteilen Oel und Kohle, 31, 595 - 602.

GRILL, R. (1943): Uber mikropaläontologische Gliederungsmoglichkeiten im Miozän des Wiener Becken, Mitt. Reichsanst., Bodenforsch., 6,Wien, 33-44.

HAQ, B .U. & HARDENBOL, J. & VAIL, P. R. (1988): Mesozoic and Cenozoic chronostratigraphy and cycles of sea level changes. In: WILGUS C. K., HASTINGS B. S., KENDALI C. G., POSAMENTIER H.,W., ROSS C.A. WAGONER J. C. (editors), Sea - Level Changes - An integrated Approach. Soc. Econ. Paleontol. Mineral., Spec. Publ., 42, 71 - 108

HOLEC, P. (1978): Fauna fosílnych vertebrát z oblasti Západných Karpát. manuskript Geofond, 78 s., Bratislava.

HOLEC, P. (1981): Occurrence of Hipparion primigeneraum (H.v. Meyer, 1829) (Mammalia, Equidae) remnants in the Neogene of the West Carpathians (Slovakia, Czechoslovakia). Geologický zborník - Geologica Carpatica 32, 427 - 447.

HOLEC, P. (1982): Säugetiere (Vertebrata, Mammalia) des Neogens und Quärtärs der Slowakei (CSSR) Ubersicht der Kenntnisse. Acta geol. et Geographica UC, Geologica 28, 207 - 217.

HOLEC, P. (1985): Finds of Mastodon (Proboscidea, Mammalia) Relics in Neogene and Quaternary Sediments of Slovakia (CSSR). Západné Karpaty ser. Paleontológia 10, 13 - 53.

HOLEC, P. (1986): Neueste resultateder Untersuchung von Neogenen und Quartären Nashärnern, Bären und Klein säugern in dem bereich der Westkarpaten (Slowakei). Acta Univ. Carolinae - Geologica 2, 223 - 231.

HOLEC, P. & HORNÁČEK, M. & SÝKORA, M., (1995): Lower Miocene Shark (Chondrichthyes, Elasmobranchii) and Whale Faunas (Mammalia, Cetacea) near Mužín, Southern Slovakia. Geologické Práce, Správy (Bratislava) 100, 37 - 52.

HUDÁČKOVÁ, N. & KOVÁČ, M. (1993): Zmeny sedimentačného prostredia východnej časti Viedenskej panvy vo vrchnom bádene a sarmate. Mineralia slovaca, 25, 202 - 210

JIŘÍČEK, R. (1979): Tectogenetic development of the Carpathian arc in the Oligocene and Neogene. In: M.Maheľ (ed.): Tectonic profiles of the West Carpathians. Konf. Symp. Sem., GÚDŠ, Bratislava, pp. 205 - 214.

KOVÁČ, M. & BARÁTH, I. & HOLICKÝ, I. & MARKO,F. & TÚNYI, I. (1989): Basin opening in the Lower Miocene strike-slip zone in the SW part of the Western Carpathians. Geol. Zbor., Geol. Carpath., 40, Bratislava, pp. 37 - 62.

KOVÁČ, M. & MICHALÍK, J. & PLAŠIENKA, D. & PUTIŠ, M. (1991): Malé Karpaty Mts. Geology of the Alpine - Carpathian Junction. Excursion guide. Bratislava, pp. 61 - 74

KOVÁČ, M. & MARKO, F. & NEMČOK, M. (1993): Neogene structural evolution and basin opening in the Western Carpathians. Geophysical Trans. (Budapest), 37, pp. 297 - 309.

MOLČÍKOVÁ, V. (1960): Příspěvek k ekologii tortonské mikropaleontologické z´ony aglutinancií v severozápadní částí Podunajské nížiny., Sb. ÚÚG, 27, 205 - 232

MURRAY, J. W., (1973): Distribution and ecology of living benthic foraminiferes. Heinemann Education books LTD. London, 1-274.

MURRAY, J. W. (1991): Ecology and Palaeoecology of Benthic Foraminifera, New York,1 - 397 N·MEJC F. (1967): Paleofloristick studie v neog,nu Slovenska. Sborn˝k n r. musea v Praze 23 B, 1, 1 - 32, Praha.

PAPP, A. & ROGL, F. & SENEŠ, J. (1973): Chronostratigraohie und Neostratotypen Miozän der Zentralen Paratethys M2. Ottnangien. Veda, Bratislava, 1 - 847

PAPP, A. & CICHA, I. & SENEŠ, J. (1978): Chronostratigraphie und Neostratotypen Miozän der Zentralen Paratethys M4. Badenien. Veda, Bratislava, 1 - 707

PAPP, A., JÁMBOR, A. & STEININGER, F., edit (1985): Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys Bd 7 ($M_6$ Pannonien). 635 s. Budapest

PLANDEROVÁ, E. (1990): Miocene microflora of Slovak Central Paratethys and its biostratigrafical significance, 1 - 144, GÚDŠ, Bratislava

SALAJ, J. & ZLINSKÁ, A. (1991): Early Miocene planktonic foraminifers of marly facies from Považská Teplá (West Carpathians). mineralia Slovaca, 23 (2), 173 - 178

PAPP, A., MARINESCU, F. & SENEŠ, J., edit. (1974): Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys Bd 4 ($M_5$ Sarmatien). 707 s. Bratislava

PAPP, A. , CICHA, I., SENEŠ, J. & STEININGER, F. edit (1978): Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys Bd 6 ($M_4$ Badenien). 594 s. Bratislava

SITÁR,V., PLANDEROVÁ, E. & ČIERNA, E. (1987): Knowledge on fossil flora of the Handlová - Nováky lignite basin obtained from the Vt-D-5 drillhore. Z padné Karpaty sér. paleontológia 12, 69-80, GÚDŠ, Bratislava

SITÁR, V. (1994): Miocene flora of Žiar Basin. Acta geol. Univ. Com. 50, 55 - 62, Bratislava

STEININGER, F., ČTYROKÝ, P., HÖLZL, O., KÓKAY, J., SCHLICKUM, W. R., SCHULTZ, O. & STRAUCH, F. (1973): Die Molluskenfaunen des Ottnangien. 380 - 615. In: Seneš, J. (edit): Chronostratigraphie und Neostratotypen, Miozän der Zentralen Paratethys Bd 3 ($M_2$ Ottnangien). 841 s. Bratislava.

STEININGER, F., ČTYROKÝ, P., ONDREJÍČKOVÁ, A. & SENEŠ, J. (1971): Die Mollusken der Eggenburger Schichtengruppe 356 - 593. In: Seneš, J. (edit): Chronostratigraphie und

Neostratotypen, Miozän der Zentralen Paratethys Bd.2 ($M_1$ Eggenburgien). 827 s. Bratislava.

STEININGER, F. & SENEŠ, ,J., edit (1971): Chronostratigraphie und Neostratotypen Miozän der Zentralen Paratethys. M1, Eggenburg. Veda Bratislava, 1 - 627

STEININGER, F. F., SENEŠ, J, KLEEMANN, K. & ROGL, F (1985): Neogene of the Mediterranean Tethys and Paratethys. Stratigraphic correlation tables and sediment distribution maps. Vol. 1. Publ.: Inst. of Paleont., Univ. of Vienna.

SZUTO & SZENTAI, M. (1988): Microplankton Zones of Organic skeleton in the Pannonian s.l. stratum complex and in the Upper part of Sarmatian Strata, Acta Bot. Hung., 34 (3-4), 339 - 356

VASS, D., KONEČNÝ, V. & ŠEFARA, J. (1979): Geologická stavba Ipeľskej kotliny a Krupinskej planiny. GÚDŠ, Bratislava, 145p.

VASS, D., ELEČKO, M., KANTOROVÁ,V., LEHOTAYOVÁ, R. & KLUBERT J. (1987): Prvý nález morského otnangu v juhoslovenskej panve. Mineralia slov., 19, 5, pp. 417 - 422.

SLOVAK GEOLOGICAL MAGAZINE

# Young Tertiary rotation of the megaunit Pelso and neighbour units of the West Carpathians.

DIONÝZ VASS[1], IGOR TÚNYI I[2]. & EMÖ MÁRTON[3]

[1] Geologická služba SR, Mlynská dolina 1, 817 04 Bratislava, Slovakia
[2] Geofyzikálny ústav SAV, Dúbravská cesta 1, 842 28 Bratislava, Slovakia
[3] Columbus u.17-23, H-1145 Budapest, Hungary

*Abstract.* The 80°counterclokwise (CCW) rotation of the remanent magnetism declination masured on 54 sites of the lower Miocene rocks in Southern Slovak depressions and in North Hungarian Central Range has been generated on the background of the Afrorabian and Euroasian lithospheric plates convergenc. The collision and subduction provoked the tectonic escape of the crustal and/or lithospheric fragments or terranes from the Alpine and Dinaric domain. The escape started in late Cretaceous and finished after Egerian and before late Eggenburgian (Early Miocene). The tectonic escape gave rise to the astenosphere and it was the reason of the crust upheaval, later on relieved by rifting. The relaxation of the lithosphere after a long compression and/or transtension gave way to the CCW rotation of the rock mass in two rotational events: during the late Ottnangian - early Karpathian, 18-17 Ma B.P. (50°CCW) and during the Early Badenian 16-15,5Ma B.P.(30°CCW). During the first event the Eastern part of the Pelso megablock rotated. The second event seized the whole Pelso unit (including the Transdanubicum).

Key words: declination rotation, West Carpathians, Pelso megablock, Early Miocene, tectonic escape, astenosphere rise, crust upheaval, rifting.

Paleomagnetic investigations of 54 sites in the Southern Slovakian depressions and Northern Hungarian Central Range showed important counterclokwise (CCW) rotation which took place during the Early Miocene.

The driving force of the Tertiary tectonic developement in the Alpine-Carpathian-Pannonian (Alcapa) area was the convergence of the Afroarabian and Euroasian lithospheric plates (ZIEGLER 1988). The collision of the Bohemian Massife with the Apulian promontory forced the large crustal fragments to escape from the Alpine and Dinaric domain to the South -East, pushing them from behind. Simultaneously the roll-back effect of the subduction in front of rising Outer Carpathians operated as a pull in front of the escaping terranes (CSONTOS et al.,1992),(fig.1). The escaping terranes were joined latter in the Pelso megaunit, including the Transdanubicum, Mid-Hungarian mobile belt, Bükk and Gemericum (DANK & FÖLÖP 1990), (fig.2).

The escape was controlled by the strike-slip faults of a large lateral shear (several hundred kms), such as Gailtal - Balaton line, or Mid-Hungarian line and/or by faults with smaller lateral displacement - several tens kms - such the as Raaba, Diösjenö, Plešivec-Rapovce lines (Fig.2). The tectonic escape is well documented particularly by the lateral translation of the Late Permian to Late Triassic facial zones, showing the 500 km translation between the NW Dinarides and Bükk-Gemericum

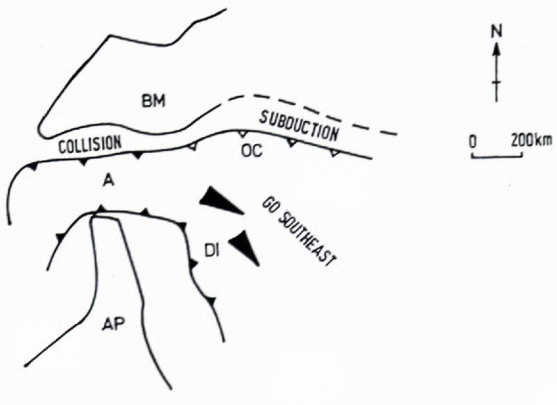



*Fig.1 The convergence of the Afroarabian and Euroasian lithospheric plates caused the tectonic escape from the Alpine (A) and Dinaric (Di) domain.The convergence provoked the collision of the Apulian promontory (AP) with the Bohemian Massive (BM). The collision was an impulse of the tectonic escape pushing from behinde Alpine and Dinaric terranes escaping to the East. The subduction of the Polish Platform (PP) in front of the rising Outer Carpathians (OC) operated as suction, or pull in front of the escaping crustal and/or lithospheric fragments. (after LORENZ et al.,1993, modified)*

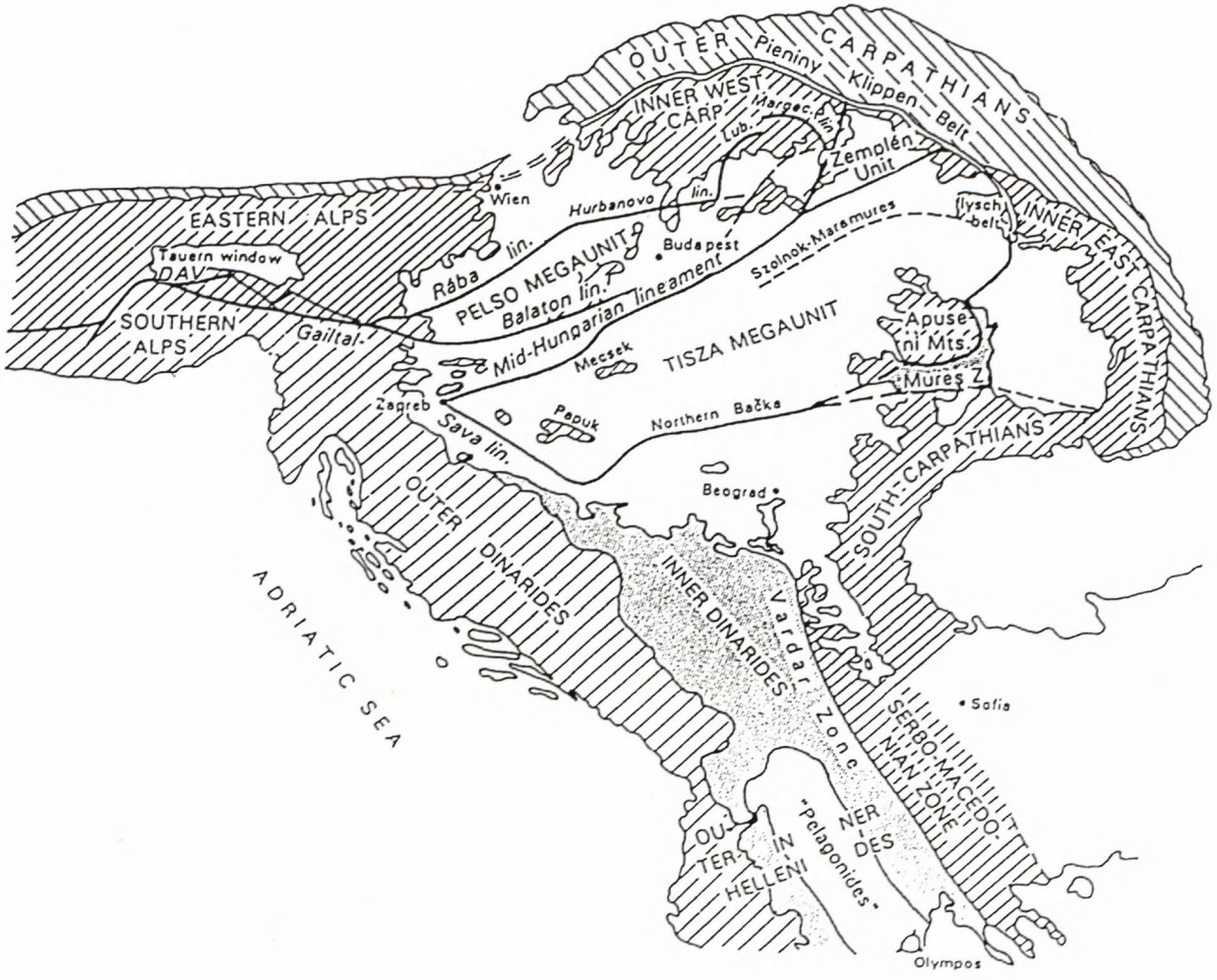



*Fig.2 The Pelso megaunit composed of several individual terranes having the facial zones amputated by strike - slip faults. The continuation of the facial zones may be found in Southern Alps and NW Dinarides (after HAAS et al.,1995).*

and 450 km between the Southern Alps and Transdanu-bicum (KÁZMER & KOVÁCS 1985, HAAS et al.,1995). The Central Western Carpathian units were also affected by the forces causing the tectonic escape, however, the facial zones of the Alps and Central Western Carpathi-ans do not show such a large disruption, but their lenght was several times multiplied (HAAS et al.,1995).

The tectonic escape started after the Cretaceous folding in the Alps, it was accelerated after the pre-Oligocene folding and finished after the Egerian in the earliest Miocene. Of course, the escape was not a uniform motion. The Gemeric terrane approached the Central Western Carpathians in the Late Eocene (clastic material coming fromum Gemeric is present in the Central Carpathian Paleogene (MARSCHALKO 1968). On the other side the Slovanian and Buda Paleogene, were disrupted by a dextral strike-slip on the Gailtal-Balaton line with lateral translation of approx. 300 km after the Egerian (after the earliest Miocene).

The large shifting of the crustal and/or lithospheric fragments, if sufficiently rapid, caused in the mantle a horizontal stress gradient activating the flow of the ductil astenospheric mass. The mantle material escaped from the area of large crustal loading to an area of lesser isostatic pressure. Convectional currents are generated in the astenosphere. The astenosphere activated in this way was rising. Conductive heating from the mantle plume, heat transfer from the magma generation and convective heating forced the lithosphere to thin (ALLAN & ALLAN 1992). If the heat fluxes from the lithosphere were large enough, relatively rapid thinning of the lithosphere would cause isostatic uplift of the lithosphere including the surface of the crust (SENGÖR & BURKE 1978, BAKER & MORGAN 1981, MORGAN & BAKER 1983, TURCOTTE 1983, KEEN 1985, fide ALLEN & ALLEN 1992).

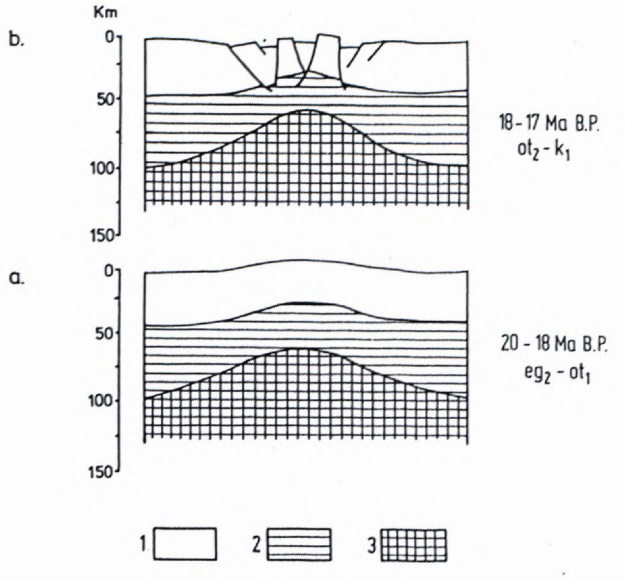



*Fig. 3 Two phases of the rifting provoked by the rising astenospehere in the Pannonian realm after the tectonic escape of the Pelso megaunit from the Alpine-Dinaric domain.*
*3a The astenosphere rise as result of the isostatic instability caused by lateral shifting of the escaping crustal and/or lithospheric fragments cca 20-18Ma B.P. The astenosphere rise provoked an uphaeval of the crust in Pannonian realm.*
*3b The transition of the crustal rise into tectonic collapse: the begining of the rifting in proper sense, cca 18-17Ma B.P.*

| | | |
|---|---|---|
| *1 crust* | *Ma B.P. millions years before present* | |
| *2 upper mantle* | *k* | *Karpathian* |
| *3 astenosphere* | *ot* | *Ottnangian* |
| | *eg* | *Eggenburgian* |

The conditions of astenosphere activation were fulfilled by the Tertiary tectonic escape in the Alcapa region. The heat flux es from the activated astenosphere warmed in relatively short time the crust which began to rise (first step of the active rifting in the sense of SENGÖR and BURKE 1978 and others fide ALLEN & ALLEN 1992), (Fig.3). The first manifestation of crust upheaval in the Pannonian area 20 Ma B.P. was the sea regression and disapearance of the Fiľakovo/Pétervására marine basin (VASS 1995). The sea regression was followed by exclusively continental sedimentation. The crust heating was signalised also by the generation of crustal magmas giving rise to areal acid volcanism in the Pannonian area (PANTÓ et al., 1966, SZABÓ et al., 1992, LEXA et al.,1993).

From the begining of the tectonic escape (at least from the begining of are Oligocene aprox 36 Ma B.P. till the crust upheaval (20-19 Ma B.P.), the whole escaping area was under the influence of compressional, transpressional and/or transtensional forces (fig.4). In the late Ottnangian (aprox.17 Ma B.P.), these forces were replaced by extensional ones, caused by the acceleration of the crust extension reflected in the first manifestation of tectonic collapse or rifting itself (the second step of active rifting). Evidence of this is the sea transgression into the Bántapusta and Borsod areas (KOKAY in PAPP et al., 1973, BOHN-HAVAS 1985) and the sea excursions into the Novohrad/Nógrad Basin (N. Hungary - S. Slovakia, VASS et al.,1987). The stress relaxation and the areal extension, well proved by structural measurements (VASS et al.,1993, FODOR in MARTON & FODOR 1995) gave space for the CCW rotation. The rotation exhibits two phases (Fig.4): the First 50°CCW during the Late Ottnangian - early Karpathian (18-17 Ma B.P.) and the second during the early Badenian (16-15,5Ma).

The rotation may be explained by two models:

1. The whole or a large part of the megaunit Pelso rotated (Fig.5). The rotation moved the megaunit at least 500 kms to the North. Such a model is supported by the shallow paleomagnetic inclination (i.e. rocks acquired the remanent magnetisation in the areas closer to the Equator as they are situated at present. The rotation covers 2,5Ma and the rate of movement was aprox 2cm/year, which is comparable with recent crustal dynamics. The rotation assumed the crust or the elastic lithosphere, but not the deeper litosphere and risen astenosphere. Because of this evidence the continuation of rifting is missing in the rotated terranes. To the contrary, they were permanently rising from the Middle Badenian till present. Crustal extension and rifting during the Middle Miocene occured in the area abandoned by the rotated Pelso megaunit

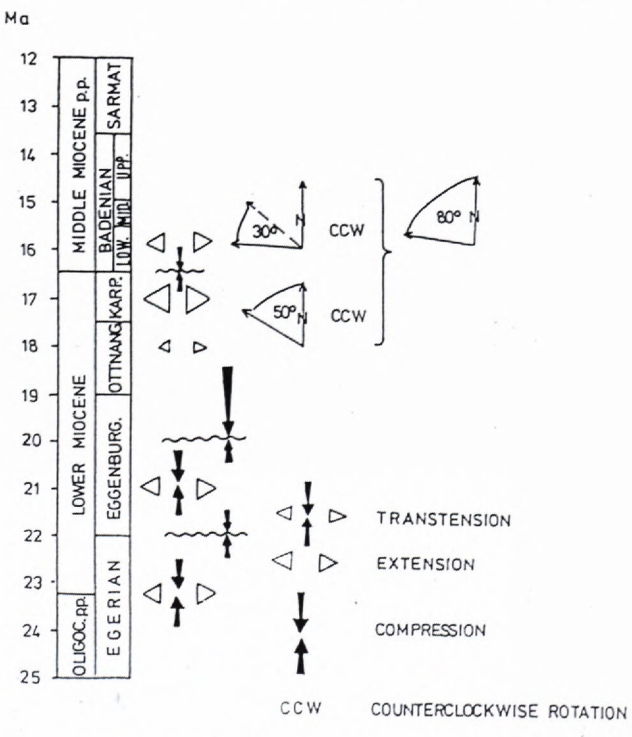



*Fig. 4 The time-table of the paleostress and the rotations events during the early Miocene in the South Slovakian depressions and North Hungarian Central Range.*

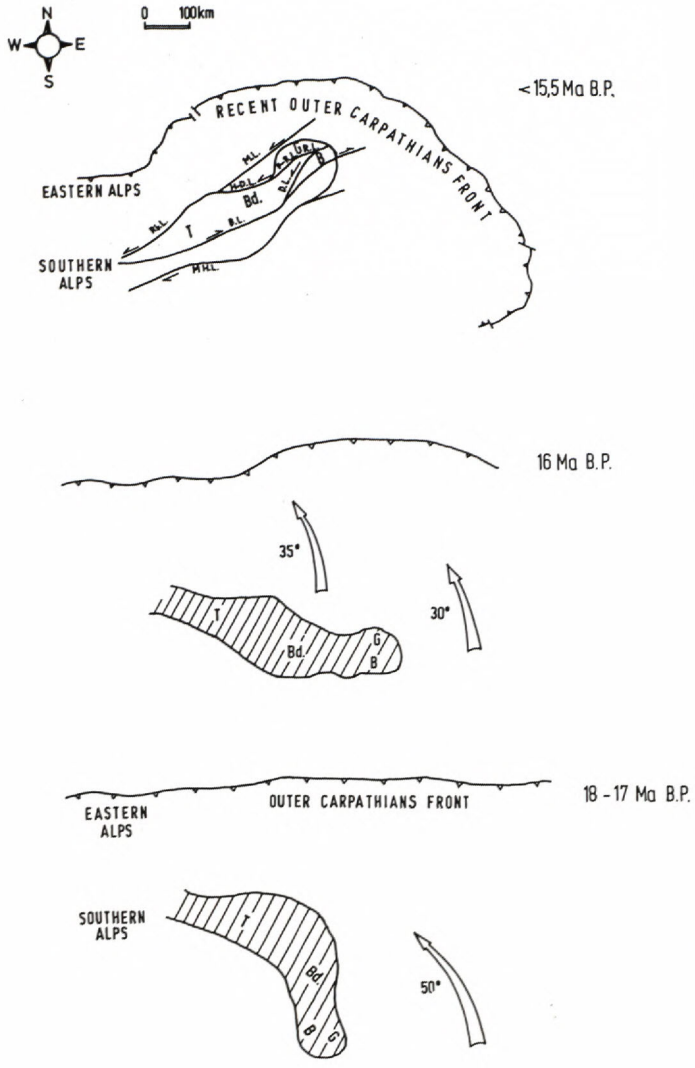



*Fig. 5 Model of the whole Pelso megaunit rotation. The rotation took part when the Carpathian arc was formed B.L.-Balaton line, D.L.-Darnó line, H.-Dj.L-Hurbanovo-Diósjenö line, MH.L-Midhungarian line, M.L.-Muráň line, P.-R.L.-Plešivec-Rapovce line, R.L.-Rožňava line, Rb.L-Raaba line, T-Transdanubicum and Mid Hungarian mobil belt terranes, B-Bükk, G-Gemeric, Bd-unit between Transdanubicum and Bükk Mts.(Burda unit).*

(area of Nagyalföld, area on the southern perifery of the Transdanubian Central Range and Nord Hungarian Central Range (comp. ROYDEN in ROYDEN & HORVÁTH et al.,1988).

2. The megaunit Pelso brought along its own basic tectonic structure in vertical (nappes), as wel as lateral (large wrench faults) from his Alpine-Dinaric home. The rotation took place afterwards as individual rotations of several blocks of smaller size confined by second-order crustal and or supercrustal faults oblique or perpendicular to the main wrench faults accomodating the tectonic escape before the rotation (comp. MÁRTON & FODOR 1995).

The rotations finished after the early Badenian, as the middle Badenian andesites in the area do not show any indications of the rotation (see for ex. ORLICKÝ et al.,1995).

## References


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

BOHN-HAVAS M., 1985: A study of Ottnangian molluscs from the Eastern Borsód Basin. Geol. Hung. ser. paleont. 48, Budapest, 100-177

CSONTOS L., NAGYMAROSY A., HORVÁTH F. & KOVÁC M., 1992: Tertiary evolution of the Intra-Carpathian area: a model. Tectonophysics, 208, Amsterdam, 221-241

DANK V. & FÜLÖP J., 1990: Magyarország serkezetföldtani térképe. Magyar All. Föld. Intézet, Budapest

HAAS J., KOVÁCS S., KRYSTYN L. & LEIN R., 1995: Significance of Late Permian-Triassic facies zones in terrane reconstructions in the Alpine-North Pannonian domain. Tectonophysic 242, Amsterdam, 19-40

KÁZMÉR M., & KOVÁCS S., 1985: Permian-Paleogene paleogeography along the Eastern part of the Insubric-Periadriatic Lineament system: evidence for continental escape of the Bakony-Drauzug Unit. Acta Geol. Hung. 28(2): 71-84

LEXA J., KONEČNÝ V., KALIČIAK M. & HOJSTRIČOVÁ V., 1993: Distribúcia vulkanitov karpato-panónskeho regiónu v priestore a čase. Geodynamický model a hlbinná stavba Západných Karpát. (edit. M. RAKÚS - J. VOZÁR), Konferencie-sympóziá-semináre, Geol. Úst. D. Štúra, Bratislava, 57-69 (In Slovak, Engl. res.).

LORENZ C. et al., 1993: Late Rupelian paleoenvironments (30-28 Ma). In J. DECOURT, L. RICON & E. VRIELYNCK (eds.): Atlas Tethys Paleoenvironmental Maps. Beicip-Franlab, Renil - Malmaison.

MARSCHALKO R., 1968: Facies distribution, paleocurrents and paleotectonics of the Central West Carpathians. Geol. Zbor., Geol.carpath.19/1, Bratislava, 69-94

MÁRTON E. & FODOR L., 1995: Combination of Paleomagnetic and stress data a case study from North Hungary. Tectonophysic 242, Amsterdam, 99-114

ORLICKÝ O., TÚNYI I. & VASS D., 1995: Paleomagnetické vlastnosti šiatorských andezitov a pieskovcov fiľakovského súvrstvia v ich kontaktom dvore. Mineralia slov. 27, Bratislava (In Slovak, Engl. res.).

PANTÓ G., ILKEY-PERKI E., GYARMATI P., MOLDVAY P. & FRANYÓ F., 1966: Geological map of Hungary, 1:200 000. Sátoraljaújhely, Budapest (in Hungarian).

PAPP A., RÖGL F., SENEŠ J. (edit)., 1973: Chronostratigraphie und Neostratotypen Miozän d. Zentralen Paratethys Bd. III. Ottnangian, Vydavateľstvo SAV, Bratislava, 1-841

ROYDEN L. H. & HORVÁTH F., (edit.) 1988: The Pannonian Basin a study in Basin evolution. AAPG Mem. 45, Tulsa, U.S.A. 1-394

SZABÓ C., HARANGI S. & CSONTOS L., 1992: Review of Neogene and Quaternary volcanism of the Carpathian-Pannonian region. Tectonophysics, 208, Amsterdam, 243-256

VASS D., 1995: The origin disappearance of the Hungarian Paleogene Basins and the short term Lower Miocene Basins in the Northern Hungary and Southern Slovakia. Slov. Geol. Mag. 1, Bratislava, 81-95

VASS D., ELEČKO M., KANTOROVÁ V., LEHOTAYOVÁ R. & KLUBERT J. 1987: Prvý nález morského otnangu v juhoslovenskej panve. Mineralia slov. 19, Bratislava, 417-422.

VASS D., HÓK J., KOVÁČ P. & ELEČKO M., 1993: Sled paleogénnych a neogénnych tektonických udalostí v juhoslovenských kotlinách vo svetle napäťových analýz. Mineralia slovaca 25, Bratislava, 79-92 (In Slovak, Engl. res.).

VASS D., REPČOK I., BALOGH K. & HALMAI J., 1987: Revised radiometric time-scale for the Central Paratethys Neogene. Ann. Inst. Geol. Publ. Hung. 70, Budapest, 423-434

ZIEGLER P. A., 1988: Evolution of the Artic-North Atlantic and the Western Tethys. A. A. P. G. Mem., 43, 1-198

SLOVAK GEOLOGICAL MAGAZINE

# Gravimetric map of the western part of Slovakia and its possible interpretations

VIKTÓRIA SZALAIOVÁ, JAROSLAV ŠANTAVÝ

GEOCOMPLEX a.s., Geologická 21, 822 07 Bratislava

*Abstract.* The aim of our contribution is to characterise briefly the most important gravity anomalies in the northwestern protrusion of the Pannonian Basin, or the anomaly of the Vienna and Danube Basins. The contribution contains also quantitative interpretations of two profiles. We also discuss the problems of the Kolárovo anomaly, which is, from the viewpoint of the intensity of gravity field manifestations in the area under study, the most marked structural phenomenon. The general gravity field image is documented by a map of total Bouguer anomalies and a map of residual anomalies with indication of horizontal gravity gradients.

*Key words:* gravimetric measurements, gravity anomalies, Bouguer anomalies, gradient, geophysical and geological interpretation, Danube basin.

## Introduction

The area under study was the subject of a large number of geophysical measurements. From gravimetric measurements and interpretations we should erhaps mention the works concerning regional gravimetric mapping on the scale 1:200 000 (IBRMAJER 1963) and 1:25 000 (team of authors). In the last time, profile measurements have been carried out in the Vienna Basin, aimed at direct carbohydrate survey (MIKUŠKA et al. 1992-1995). These works have been realised on behalf of the company Nafta Gbely a.s. and they are not accessible in the Geofond files. From more recent works dealing with the region under study there were carried out investigations within the project MGII (Maps of geophysical indications and interpretations): MGII Danube Basin - Northwest (PANÁČEK 1987), MGII Chvojnícka pahorkatina Hills (SZALAIOVÁ et al. 1994), MGII Tríbeč (LANC et al. 1995). An interpretation of the Danube Basin in the southern part of the area has been carried out within the project DANREG, which is still continuing. In 1996, a part of the project Geodynamic Model of the Western Carpathians - A synthesis of the deep structure of the Western Carpathians - Western Slovakia was realised by SZALAIOVÁ & ŠANTAVÝ. In the last mentioned study there are summarised the results of gravimetric works carried out for different purposes. From other works we shall mention the project Bratislava - Environment (HRICKO et al. 1993), where, besides detailed gravimetric measurements, other geophysical measurements were realised as well.

## Qualitative interpretation

For the purpose of a qualitative interpretation of the gravity field, we calculated from data of regional gravimetric mapping 1 : 25 000 a map of total Bouguer anomalies (TBA), for the reduction density 2.67 kg.dm$^{-3}$ (Fig. 1). These measurements were evaluated in several technical reports, in which there are described the methods of field work, there is calculated the precision of the measurements and the gravity anomalies are briefly evaluated. A list of regional gravimetric mapping on the scale 1 : 25 000 has been presented in SZALAIOVÁ & ŠANTAVÝ (1996). Besides the TBA map derived maps were calculated too for the purpose of qualitative interpretation (Fig. 2): the map of residual gravity anomalies r = 4000 m, map of regional anomalies and the map of horizontal gravity gradients calculated for r = 4000 according to Blakely.

The first look on the TBA map allows to distinguish intensive regional anomalies. Positive anomalies are regularly alternating with negative ones, and it is important to note the almost parallel positions of the principal axes of the anomalies, both positive and negative ones.

Positive anomalies are caused by the Tatric rock complexes of the "core" mountain ranges. They are the anomalies of the Malé Karpaty, Považský Inovec, Tríbeč Mts. The hidden elevation of the pre-Tertiary underlier in the area of Kolárovo, the so-called "Kolárovo anomaly", is caused by heavier rocks (approx. 2.9 - 3.00 kg.dm$^{-3}$), probably ultrabasic, ultramafic rocks, amphibolites etc. (BIELIK et al. 1994). Quantitative interpretation - modelling of the Kolárovo anomaly - was carried out by BIELIK et al. (1994). In the TBA map for the reduction density of 2.67 kg.dm$^{-3}$, it attains an amplitude of +28 mGal, and in the uncovered gravity map, after removing the effects of Tertiary complexes, the amplitude increases to +74 mGal.

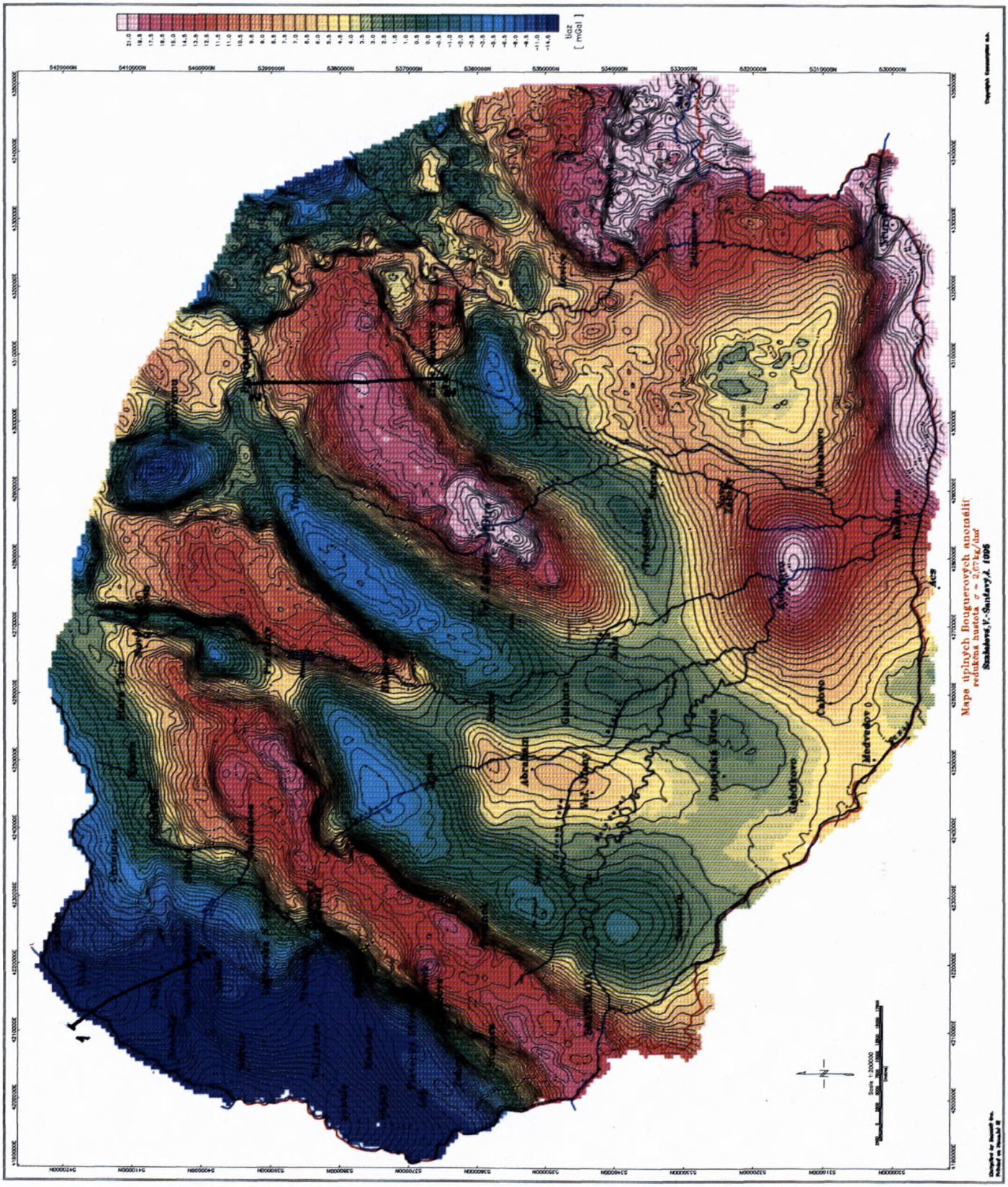
A relatively good correlation between gravity field amplitudes and depths of the underlier ascertained by boreholes may be observed here. It is interrupted only in the area of Kolárovo, Komárno and Čalovo, due to the presence of a basic body in depth, and the C and MOHO discontinuities being nearer to the surface plays a role too. Another positive anomaly is the anomaly situated approximately on the axis Medveďov - Šahy. It is caused by the protruding outlier of the Hungarian Mid-mountains, and it is often referred to as the Pelsso Unit, separated by the Ráb-Hurbanovo line from the Tertiary filling of the Danube Basin. It is built predominantly of Mesozoic rock complexes. The positive anomaly occurring approximately to the east of the Štúrovo-Želiezovce-Levice line is caused by the effects of the pre-Tertiary underlier, which is lying here near to the surface. An interesting positive anomaly occurs in the area Abrahám - Veľké Úľany. It is caused by pre-Tertiary rocks of the Považský Inovec Mts. In TBA as well as derived maps, in the northern part of the anomaly, we may follow a sharp linear gradient of E-W direction, indicating strike-slip tectonics between Abrahám and Trnava.

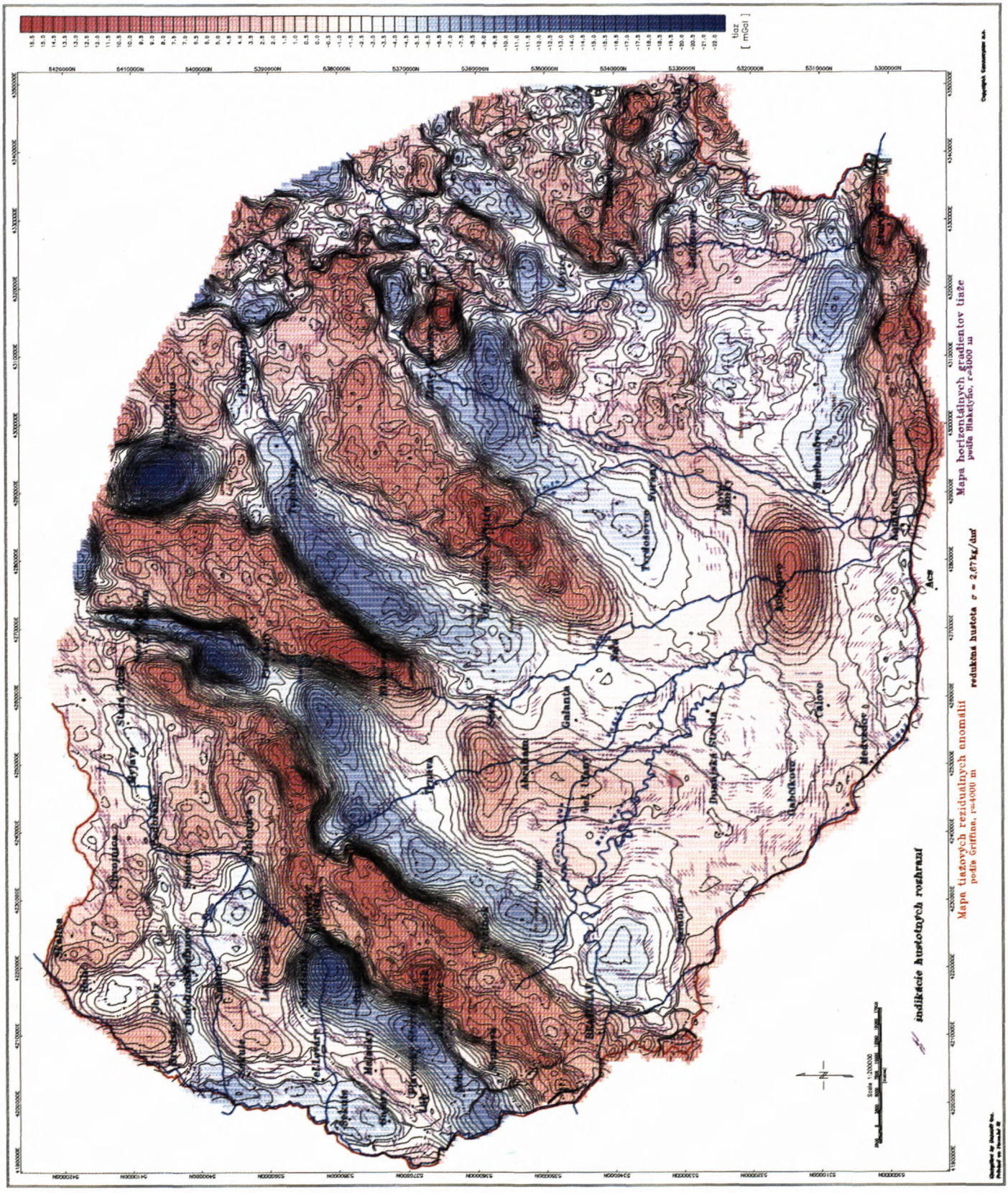
Negative anomalies correspond to light rock complexes of the Tertiary sedimentary filling of the Danube Basin, built predominantly of gravel-sand and clayei rocks. According to the intensity and geometry of isolines, we may estimate the thickness of the sedimentary complexes and their distribution in space. This is however not a rule. We shall present it on the example of the Gabčíkovo anomaly. In its area, as it is evident from the TBA map, there is a relatively positive gravity anomaly, even though according to borehole investigations and seismic interpretations, the pre-Tertiary underlier occurs in great depth. This phenomenon could be explained by the presence of neo-volcanic complexes in the Tertiary filling of the basin, which is confirmed by magnetometric measurements (GNOJEK & PUTNA in DŽUPPA 1993). The most marked negative anomalies correspond to depressions: the Blatná, Rišnov (frequently called the "Topoľčany Bay"), Bánovce, Komjatice and Dubník Depressions. The gravity anomaly in the area of Trnava, which is a part of the Blatná Depression, has, according to PLANČÁR and IBRMAJER (in FUSÁN et al., 1971) regional character and its source, judging from regional gravity anomaly maps for r = 12 and 20 km, is lying very deep. Neogene depression between the core mountain ranges and the depression on the eastern side of the Tríbeč Mts. display an amplitude of -10 to -20 mGal, while in other parts of the Danube Basin, in their southward continuation, it is only -2 to -6 mGal.

The gravity field is influenced by the presence of heavier masses in the underlier (the crust) and the MOHO- discontinuity is in the whole area under study approximately in the same depth. We may state that morphologic elements of the relief of the pre-Tertiary basement are very well reflected in the image of gravity field anomalies. Faults in the substratum show in the gravity field as a marked gravity gradient, in the sigmoidal bending of the isoanomalies at greater distances. In the residual anomaly and horizontal gradient map (Fig. 2) (SZALAIOVÁ & ŠANTAVÝ 1996) we may see a marked manifestation of density boundaries in NE-SW direction, which mostly correlate well with the known tectonic lines. The density difference between the Komárno uplifted block and the Dubník plateau is well visible too. This effect is partly obliterated by the effects of the Kolárovo anomaly. A more complex image occurs in the area of Levice. It is caused by neo-volcanites, and especially by the decreased thickness of the Tertiary filling, which enhances the effects of the pre-Tertiary structure of the area.

The Vienna Basin area (Fig. 3) is from the viewpoint of geophysical studies, especially seismic measurements, one of the most thoroughly studied areas in Slovakia. We shall briefly discuss the principal gravity anomalies of this area.

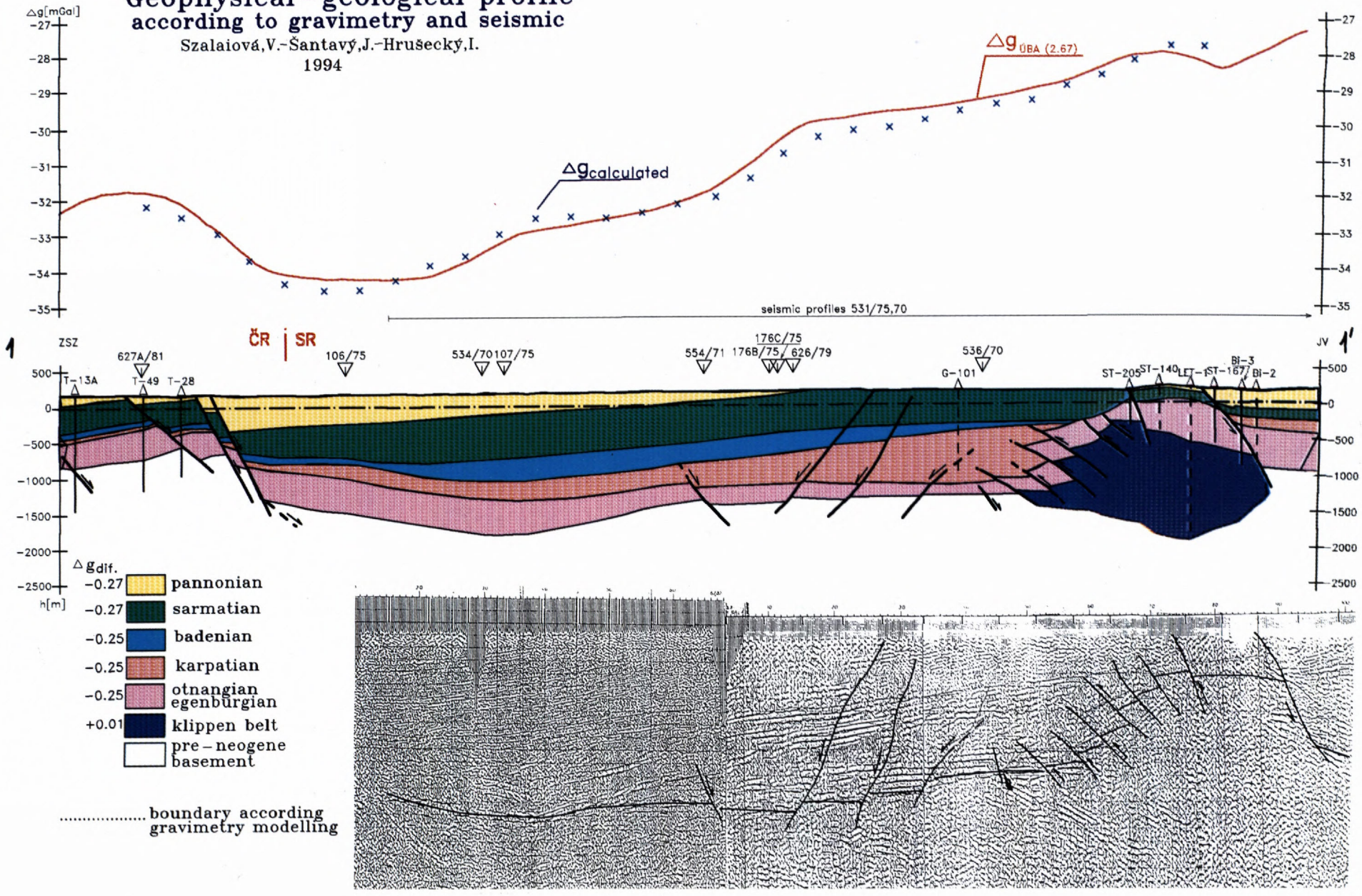
The most prominent gravity anomaly occurs in the area of the Kúty Depression (as much as -40.5 mGal). Its centre is situated in the surroundings of Kúty and the depression is tectonically restricted. In north it is restricted by the Hodonín-Gbely fault, forming, together with the Lužice-Brod fault, the Hodonín-Gbely horst. The depression is defined by the Svätý Ján fault. Another marked negative anomaly (-34.5 mGal) - the Kopčany Depression - is found at the village Kopčany. We assume it has tectonic boundaries, as on its southern side there is a marked gravity gradient. In the south-west of the area, in the surroundings of the town Šaštín-Stráže, there is a relatively positive anomaly (-24 mGal). Its northern boundary is from the TBA map not clear. This anomaly is caused by the presence of rocks of the Choč unit, having higher natural density, which is confirmed by the boreholes Ša 9, 10 and 11. The Štefanov elevation is overlapping with the Šaštín gravity field anomaly, which is deep-seated and affects the structural image of this area. Between Štefanov and Šaštín there is a tectonic contact of the Flysch Belt, the Klippen Belt and the belt of Mesozoic nappes, forming the southern part of the Vienna Basin. Among areally extensive anomalies there are also two anomalies east and west of the village Smrdáky. According to their interpretation (TOMEK 1975) and boreholes, the basement of this area is the Klippen Belt. As derived from the TBA map, several tectonic lines are cross-cutting here. This location should be interpreted in a greater detail, i.e. field measurements should be carried out here. The area west of the village Osuské up to Šaštín-Stráže is characterised by a gravity gradient, representing the downthrow of the basement of the Neogene along tectonic N-S lines into the Brezová Depression. Downthrows along these faults are synsedimentary (ĎURICA et al. 1986) and thus the thickness of sediments on equally old blocks may be different.


tiaž
[ mGal ]
Mapa úplných Bouguerových anomálií
redukčná hustota σ = 2,67 kg/dm³
Szabóová, F.-Šantavý, J. 1995
Abrahám
Dejdíková Kresla
Kubišiná
Čajkov
Medvedov
Rhabanovo
Kráľovce
Ács
Zemianska Olča
Zemianske Sady
Zemianske Kostoľany
Jelka
Jelka
Jelka

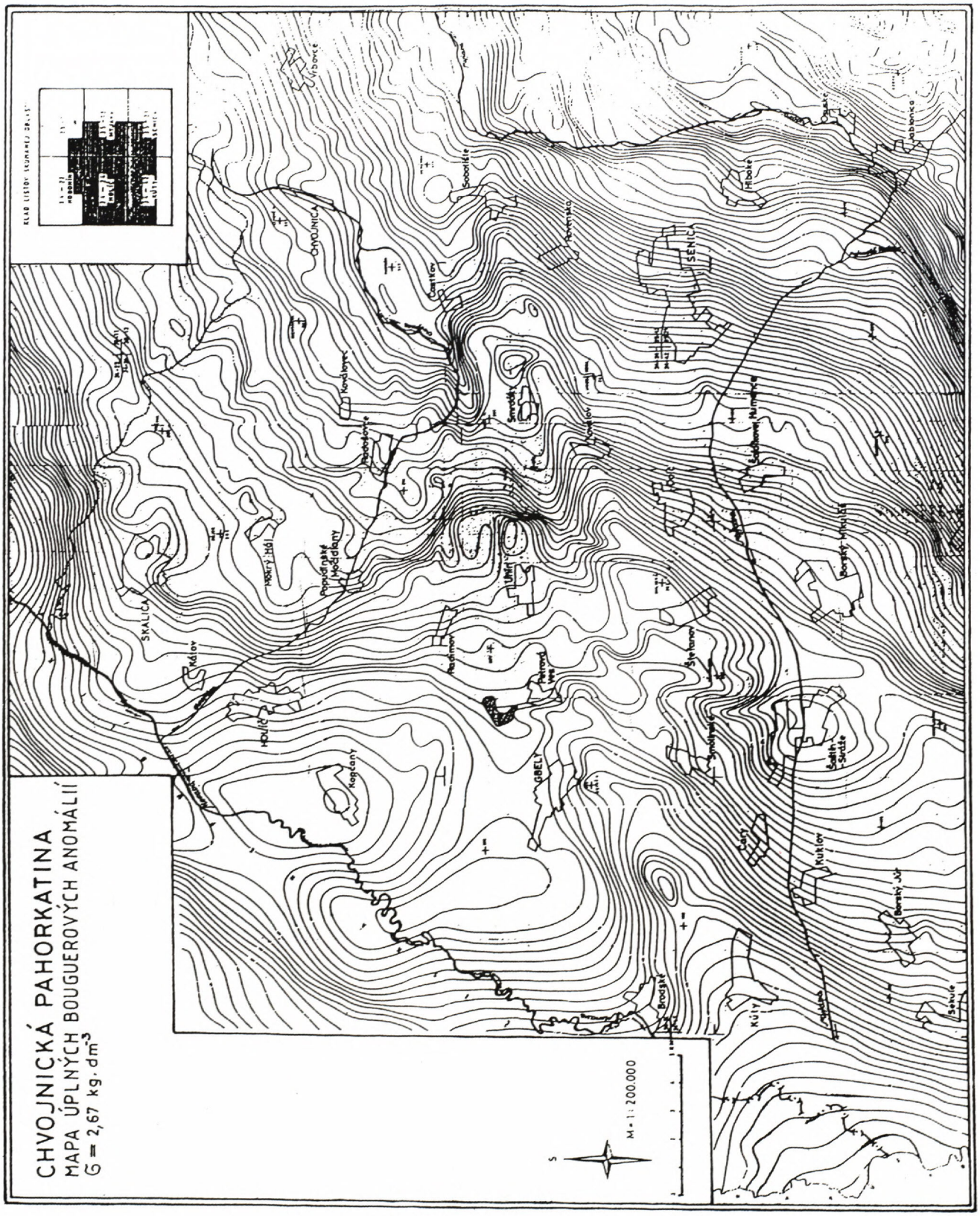

tiaž
[ mGal ]
Mapa tiažových reziduálnych anomálií
podľa Griffina, r=4000 m
redukčná hustota σ = 2,67kg/dm³
Mapa horizontálnych gradientov tiaže
podľa Blakelyho, r=4000 m
indikácie hustotných rozhraní
Mierka 1:200000

# Geophysical – geological profile
## according to gravimetry and seismic

Szalaiová,V.–Šantavý,J.–Hrušecký,I.
1994



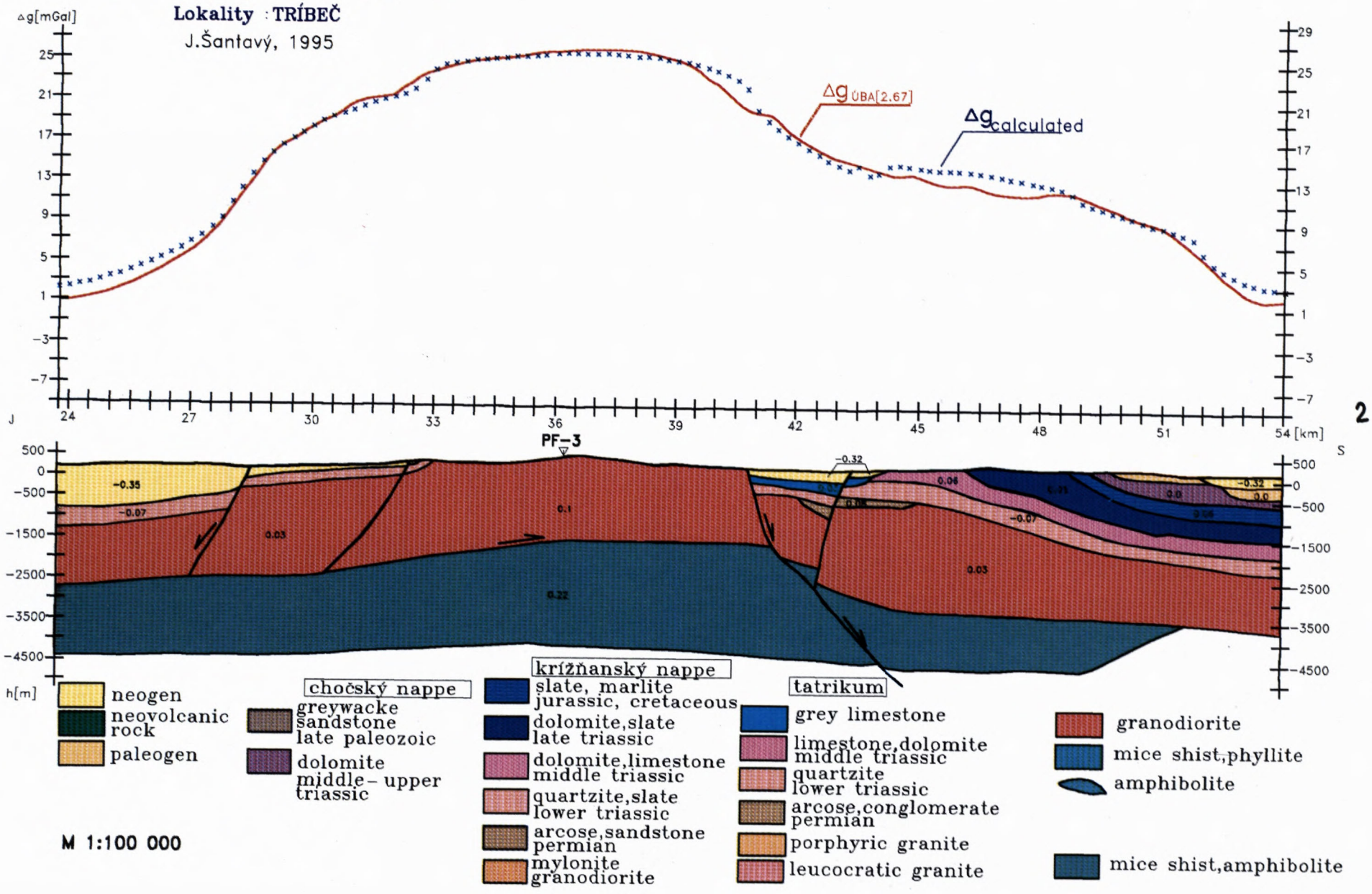

SLOVAK GEOLOGICAL MAGAZINE


CHVOJNICKÁ PAHORKATINA
MAPA ÚPLNÝCH BOUGUEROVÝCH ANOMÁLIÍ
σ = 2,67 kg.dm⁻³
M = 1:200.000
CHVOJNICA
SENICA
SKALICA
GBELY
Kuklov
Kúty
Brodské
Kopčany
Kálov
Hlohovec
Smrdáky
Kovalov
Hiboké
Jablonica
Sobotište
Rovenska
Častkov
Popudinské Močidlany
Mokrý Háj
Radimov
Petrová Ves
Štefanov
Smolinské
Čáry
Borský Mikuláš
Borský Jur
Sekule

# Gravity profile PF - 1

**Lokality : TRÍBEČ**

J.Šantavý, 1995




SLOVAK GEOLOGICAL MAGAZINE

## Quantitative interpretation

As examples of a quantitative interpretation, we present the profile interpreted in the Vienna Basin - the part of Chvojnícka pahorkatina Hills (Fig. 4) and the profile situated across the core mountain range Tríbeč (Fig. 5).

The profile on Fig. 4 is crossing, from WNW, the Gbely-Hodonín Horst, the Kopčany Depression and it continues in SE direction towards the Klippen Belt. It is practically the seismic profile 531/70, 75, prolonged in WNW to the borehole T-13A. The profile displays gradual sinking of the structural elements of the Gbely-Hodonín Horst towards the Kopčany Depression. The profile 531/75 is located on the axis of the Kopčany Depression and it characterises its deeper part. In the area of Radimov it joins the profile 531/70, which continues to the Štefanov elevation and across the elevation to the Kováloy Depression. The surface of flysch is gradually rising towards the above elevation, from the depth of 1250 m on the normal Jánsky fault block, to approx. 600 m in the borehole Št-205. In the cross-section there is interpreted the crossing of the Farská and Jánske faults on the peak of the elevation (Bílek & Hrušecký 1988).

The profile on Fig. 5 is situated in N-S direction, approximately from Partizánske to V. Klíž to Lovce. Regional gravity measurement revealed a marked positive anomaly (TBA for the reduction density 2.67 kg.dm$^{-3}$), with a marked gradient on the southern margin of the Tríbeč Mts. It is possible to interpret quantitatively this anomaly only in the case of the presence of granitoid rocks with a great thickness, or of a heavy body below the granitoid rocks. As we do not have exact data on the thickness of granitoids in this area - there are no data available from a deep borehole - we interpret the thickness of the granitoid body in the model as approx. 2000 m, with a differential density of +0.03 kg.dm$^{-3}$, which, lithologically, may correspond to quartz diorites. Below the diorites, we modelled a body with a differential density of +0.22 kg.dm$^{-3}$ (Šantavý in Lanc et al. 1995). Its origin and composition is unknown, but it could be a micaschists-amphibolite block with a thickness of approx. 2500 m. We assume the above-mentioned heavy body to occur below the whole Tríbeč massif, and to continue and thin out towards the Komjatice Depression in the south. In west it is thinning out towards the Topoľčany bay, and northwards its thickness decreases to about 1500 m. The boundary at approx. 40.5 km corresponds to the Skýcov deep line.

## Conclusion and discussion

In the presented paper we attempted to characterise, especially qualitatively, the principal gravity anomalies in the Danube Basin. In the TBA map the greatest effects are caused by core mountains, built of the Tatricum crystalline complex and its cover sequences, as well as the anomaly around Kolárovo, the probable source of which are ultrabasic rocks (Bielik et al. 1994). The interpretation - 3D modelling - yielded results on the probable distribution of the source of the Kolárovo anomaly in space. It has been determined that the anomalous body is asymmetric, elongated in the direction east-west, with its upper boundary in the depth of 5-6 km and lower boundary at 13 km (Bielik et al. 1994). According to Bezák et al. (1995) the Kolárovo anomaly is interpreted as a suture of Meliaticum which, during the disintegration of the orogen (extension), allowed astenospheric matter to ascend. The problems of the interpretation of the Kolárovo anomaly were addressed by a number of specialists and with increasing knowledge and new exact data we shall probably go back to them more frequently.

Besides the Kolárovo anomaly, we should notice the orientation of positive and negative anomalies to NE, which is very clear also in derived maps - the map of horizontal gradients and map of residual anomalies. In the TBA map we can follow also the probable horizontal strike slip of the block of the southern continuation of the Považský Inovec Mts. between Abrahám and Trnava. We think that interesting and new data for the qualitative interpretation could be gained from modelling on seismic profiles measured by the company MAXUS (Dallas, USA), which was carried out for the purpose of carbohydrate survey.

## References


Bezák, V., Šefara, J., Bielik, M. & Kubeš, P., 1995: Stavba litosféry Západných Karpát : geofyzikálna a geologická interpretácia. Mineralia Slovaca, 27, 169-178 (In Slovak, Engl. res.).

Bielik, M., Sitárová, A., Marková, M. & Levashov, S., 1994: Interpretation of the Kolárovo gravity anomaly by the option method. Acta geologica Universitatis Comenianae, 50, 37-43

Bílek, K. & Hrušecký, I., 1988: Výskum geologickej stavby a akumulácií ropy a plynu spodného miocénu gbelsko-hodonínskej hraste. Manuscript VVNP š.p. Bratislava (In Slovak)

Džuppa, P., edit., 1993: Geofyzikálny prieskum " Podunajsko". Manuskript. Geocomplex a.s. (In Slovak)

Fusán, O. (edit.), 1971: Geologická stavba podložia zakrytých oblastí južnej časti Západných Karpát. Zbor. Geol. vied, Západné Karpaty,15,173 (In Slovak, Engl. Res.).

Hricko, J., (edit.), 1993: Bratislava - životné prostredie. Abiotická zložka. Manuskript Geocomplex a.s. Bratislava (In Slovak)

Ibrmajer, J., 1963: Regionálne gravimetrické mapovanie 1: 200 000. Geofyzika Brno.

Lanc, J., Ardová, M., Filo, M., Husák, Ľ., Kubeš, P., Piovarči, M., Szalaiová, V., Šantavý, J. & Šefara, J. 1995: Mapa geofyzikálnych indícií a interpretácií - región Tríbeč. Záverečná správa. Geocomplex a.s. Bratislava (In Slovak).

MIKUŠKA, J., KUČERA, I. & LESAY, V. 1992 - 1995: Viedenská panva - priame vyhľadávanie uhľovodíkov. Nafta a. s. Gbely

PANÁČEK, A., FILO, M., GNOJEK, I., HALMEŠOVÁ, S., HUSÁK, Ľ., MUŠKA, P., OBERNAUER, D., PĚNIČKOVÁ, M. & PRIECHODSKÁ, Z.: 1987 : Mapa geofyzikálnych indícií a interpretácií - región Podunajská nížina - severovýchod. Záverečná správa. Geocomplex a.s.

SZALAIOVÁ, V., ARDOVÁ, M., FILO, M., GRETSCH, J., HUSÁK, Ľ., PAVLÍKOVÁ, S. & ŠANTAVÝ, J., 1994: Mapa geofyzikálnych indícií a interpretácií - región Chvojnícka pahorkatina. Záverečná správa. Geocomplex a. s. Bratislava (In Slovak).

SZALAIOVÁ, V. & ŠANTAVÝ, J., 1995: Geofyzikálna preskúmanosť slovenska - gravimetria. Manuskript. Geocomplex a.s. Bratislava (In Slovak)

SZALAIOVÁ,V. & ŠANTAVÝ, J., 1996: Syntéza hlbinnej stavby Západných Karpát. Oblasť Západné Slovensko. Etapová správa. Geocomplex a.s. Bratislava

TOMEK, Č., et al. 1975: Jednotné zpracování a interpretace tíhových podkladů vídeňské pánve a přilehlého pásma vnitřních flyšových Karpat. Manuskript. Geofyzika Brno

SLOVAK GEOLOGICAL MAGAZINE

## Instructions to authors

General instructions

The editorial Board of Geological Survey of Slovak Republic accepts manuscripts in English language.

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 text** should be arranged as follows: full name of the author(s); title of the paper, number of supplements (in brackets below the title, e.g. 5 figs., 4 tabs.); key words - maximum 5 words arranged successively from general to special terms; abstract (max. 15 lines presenting principal results); 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 typology, 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. Mišík & Sýkora, 1981). The name(s) is followed by a comma. 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 atc. should be written without a period. Compass bearings 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. Required is A4 page size, 30 text lines with 60 characters, including spaces, typed with line spacing No. 2. The author should mark these parts of a text which 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. Greek characters should be written by hand and followed by their description in parentheses, e.g. (sigma, omega, etc.). Indices and exponents should be properly marked.

If the text is delivered on a diskette (3.5" or 5.25"), it is necessarry to send also one hard copy. The publishers shall accept the following text formats:
*.doc (Word for Windows 6.0), *.txt (DOS text formatted or unformatted, T602), *.wp5 (WordPerfect 4.2, 5.0, 5.1), *.wri (Write for Windows), *.602 (T602).

Tables and figures

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

In contributions delivered on a diskette, tables may be written using a text editor (Word for Windows, Word Perfect, T602), or a spreadsheet (Quattro Pro, Excel) and delivered as a separate file. Characters in the table should not be less than 8 point large.

**Figures** should be presented in black-and-white, in exceptional cases also in colour. 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, contrasting, 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, *.hpg. Other formats are to be consulted with the editors.

References

- list of references should only include papers cited in text
- the items are to be listed alphabetically, with hanging indent in the second and following lines

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

Example

Cícha I. & Seneš J., 1971: Probleme der Beziehung zwischen Bio- und Chronostratigraphie des jungeren Tertiärs. Geol. Zbor. (Bratislava), 56, 2, 529 - 640.

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

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

Manuscript

- proceedings should be cited as follows:
  1. family name and initials of author(s)
  2. publication year
  3. title of paper
  4. title of proceedings
  5. editor(s)
  6. place of publishing
  7. publishing house
  8. page range
  9. non published reports should be denoted "manuscript" and the place of archive should be given.

Proofs

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

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

Final remarks

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

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

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

3. To refer to our Magazine please use the following abbreviations: Slovak Geological Mag. No ....., D. Štúr Publ. Bratislava.