Variscan suture zone in Gemericum: Contribution to reconstruction of geodynamic evolution and metallogenetic events of Inner Western Carpathians

ZOLTÁN NÉMETH

Geological Survey of Slovak Republic, Jesenského 8, 040 01 Košice; nemeth@gssr-ke.sk

Abstract. The finding of Variscan geosuture in the North-Gemeric zone, as well as microtectonic proofs of its kinematics, suggested a modified model of Variscan tectonic evolution of Inner Western Carpathians, having impact also on metallogenesis.

The northward inclined ductile shear zone, dividing Early Paleozoic rocks of Gelnica and Rakovec Groups of Gemericum, manifested kinematics of south-vergent Variscan exhumation. The Rakovec Group, partly representing subducted oceanic crust (active back-arc type?), was exhumed in dextral transpression on Gelnica Group, as the former marginal lithology of the basin during the young stage of its evolution.

We suppose that thermal processes in collisional régime were sufficient for increase of thermal gradient, metamorphism and metallogenic processes. Geodynamics of Inner Western Carpathians from the time of Ordovician riftogenesis till Mesozoic is interpreted to be a product of the heat flow caused by the same linear source of convectional heat.

Key words: microtectonics, exhumation, metallogeny, geodynamic evolution, Gelnica and Rakovec Groups, Gemericum

Introduction

The research of the boundary zone between the Early Paleozoic Gelnica and Rakovec Groups of Gemericum was motivated by the multivariant interpretation of lithotectonic relations in this zone:

1. Angular discordance of rocks of Rakovec Group to those of Gelnica Group due to the Spiš phase of folding (Fusán et al., 1955).
2. Continual sedimentary and volcanic development from Gelnica Group to Rakovec Group (this finding was the reason of distinguishing the only one Volovec Group, Grecula, 1982).
3. North-vergent Variscan overthrust of the northern part of Gelnica Group, i.e. Kojšov nappe on Rakovec Group (Rakovec nappe; Grecula, 1982).
4. Finding of mylonitic zone on the boundary between both groups (Fig. 1), northern inclination of kinematically active oldest secondary foliation and proofs of the presence of higher to high-pressure metamorphic overprint of a part of Lower Paleozoic and partly Carboniferous rocks in the North-Gemeric zone (Hovorka et al., 1988; Radvanec, 1998, 1999) led to origin of subduction-exhumation model of the rocks of the Rakovec zone being interpreted like the Variscan suture zone (Németh, 1999).

The additional data of recent research, preferably about kinematics in this zone, should add arguments for or against above mentioned interpretations.

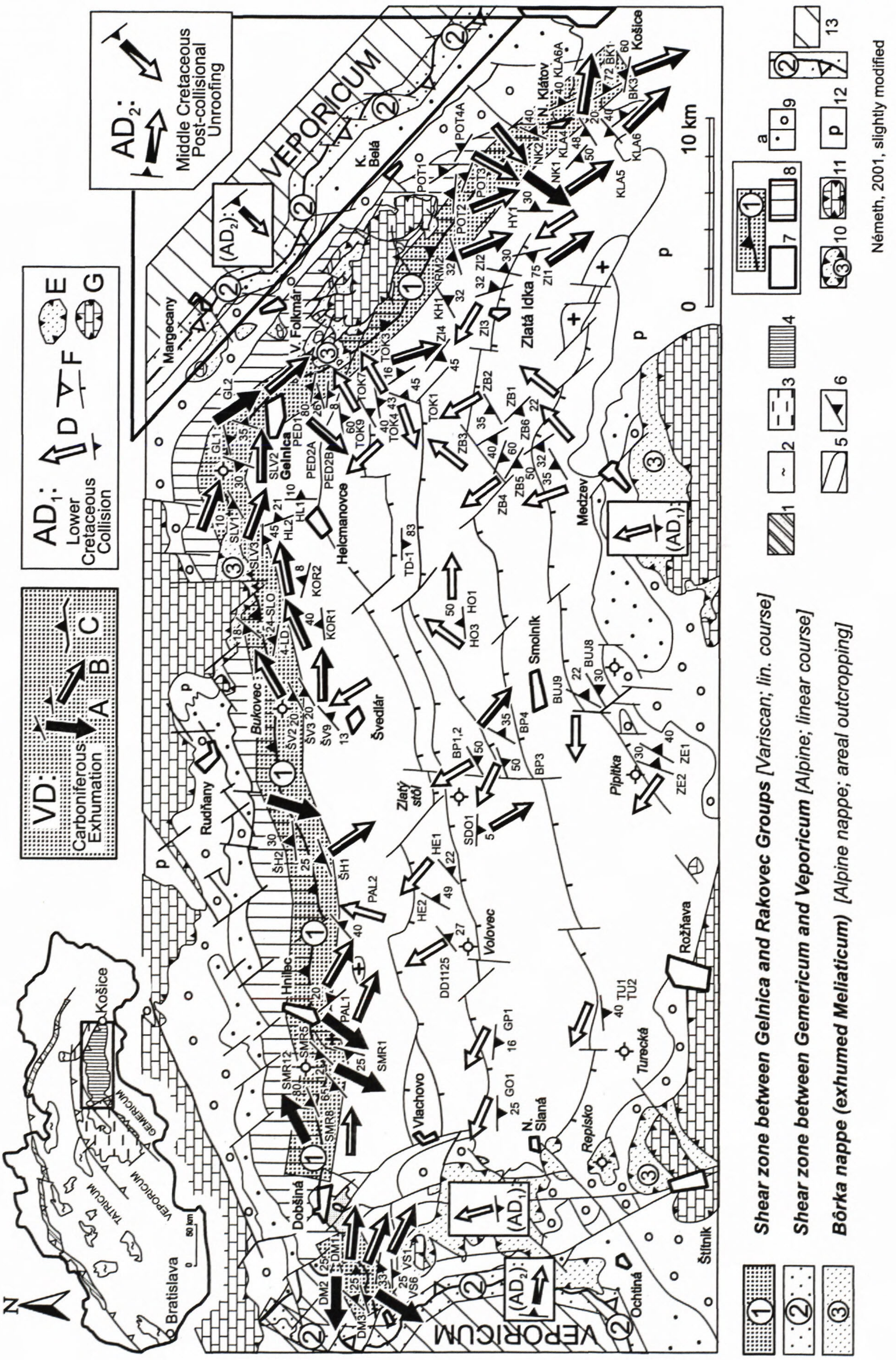
All topographic orientations, stated in the text are relative and used for simplification of mutual azimuthal relations of tectonic units of Inner Western Carpathians. The orientations "northern" and "southern" etc. is valid only for Tertiary and younger space relations. In the case of older geological events they are the relative ones, but simplify explanation of mutual relations of lithostratigraphic units in older evolution. The rotation of the crustal segments (microplates) during long-time evolution is widely known and proved with results of paleomagnetic survey.

Methodology

The result of this study are based on the regional structural/microstructural research following former regional field mapping in the Gemeric region in the scale 1 : 10 000 and assembling of the geological maps of the Nort-Gemeric zone in the scale 1 : 25 000.

The ductile shear zone dividing rocks of Lower Paleozoic Gelnica and Rakovec Groups was firstly found by the field observation. Microstructural analysis was used for finding of deformation gradient of rocks and azimuthal orientation of tectonic transport. The mylonitization of various protoliths caused the origin of the shape preferred orientation (SPO) and the lattice preferred orientation (LPO) of rheologically active minerals. The LPO was investigated by optical microscope using the gypsum plate and U-stage.

For calculation of differential stresses, causing deformation of carbonates, we have used the paleopiezometrical methods of Twinning incidence (It) and Twin density (D; Rowe and Rutter, 1990).


VD: Carboniferous Exhumation
A B C
AD1: Lower Cretaceous Collision
D F
E G
AD2: Middle Cretaceous Post-collisional Unroofing
VEPORICUM
Shear zone between Gelnica and Rakovec Groups [Variscan; lin. course]
Shear zone between Gemericum and Veporicum [Alpine; linear course]
Bôrka nappe (exhumed Meliaticum) [Alpine nappe; areal outcropping]
10 km
Németh, 2001, slightly modified
Košice
Bratislava
TATRICUM
VEPORICUM
GEMERICUM
50 km
Dobšiná
Hnilec
Rudňany
Bukovec
Švedlár
Gelnica
Helcmanovce
Margecany
V. Folkmár
K. Belá
N. Klátov
Zlatá Idka
Smolník
Medzev
Pipítka
Rožňava
Zlatý stôl
Volovec
Vlachovo
N. Slaná
Turecká
Repisko
Štítnik
Ochtiná

Obtained data

Recent areal course of boundary zone between Gelnica and Rakovec Groups (in redefined sense; Németh, 2001, Fig. 2; Németh in Mello, ed., 2000) involves a strip of tectonites passing from the wider southern vicinity of the Ostrá hill (1014) through Smrečinka (1266), Hnilec village, southern vicinity of Pálenica hill (1115), Nálepkovo, Švedlár forest, Bukovec (1127), Lacemberská valley, eastwards from Slovinky village, Krompachy hill (1025), south of Žakarovce, eastwards of Gelnica town to the Široký hŕbok elevation point (731), Vyšný Klátov and village Bukovec (the schematic course of the zone is depicted in Fig. 1).

Outcrops along the contact zone of Gelnica and Rakovec Groups demonstrate moderate dip of oldest secondary foliation to the N, NNW as well as NNE and generally subhorizontal E-W trends of lineation. In the eastern part of Gemericum, where the contact zone of both groups is bended to SE, the above described structural settings follow this bend. The foliation there dips to NE and mineral lineations have SE-NW to SSE-NNW trends. Mesostructures indicate the oblique overthrusting of the rock mélange of Rakovec Group on volcano-sedimentary rock piles of Gelnica Group.

To compare the deformation gradient of rocks directly from the shear zone with character of deformation in the lower levels of the Gelnica Group and possible tectonic overprint of southermore parts of Gemericum, we firstly examined characteristics of rocks unaffected by the studied shear zone.

Tectonites from the Gelnica Group away of studies shear zone

Siliciclastic rocks and rocks of volcanic affiliation

Less deformed siliciclastic rocks are outcropping on the south of Gemericum and were sampled on the Zelená skala hill located to SE of Pipítka (1225) elevation point (**ZE1**, S_2 = *120/40;* **ZE2**, S_2 = *110/30*; microstructural indications of tectonic transport are to NW) and from the Bujaková hill to the south of Smolník town (**BUJ8**, S_2 = *150/30*; **BUJ9**, S_2 = *118/22*, transport to the west). The quartz clasts with the low degree of deformation manifested local pressure solution, weak rotation, rare undulose extinction and the origin of subgrains. The LPO was not observed. In accordance with the mesoscopic penetrative cleavage the rough foliation planes originated in the microscale, being highlighted by the Qtz-Ser fine-grained aggregates. The sporadic plagioclases were twinned in high angle to originating rough foliation.

The next studied samples of quartzites and sandstones from the internal parts of the Gelnica Group were taken from the upper termination of the Zábava valley to the north of Medzev village. The fine/medium-grained and usually banded samples demonstrated a partial recrystallization by the grain boundary migration (GBM). In the pressure shadows we detected the onset of polygonization. Microfolds in foliation planes indicate prevailing transport either top-to-the-NE (**ZB1,** S_2 = *225/22;* **ZB3,** S_2 = *240/40*) or top-to-the-NW (**ZB2,** S_2 = *330/35*), both being the product of north-vergent compression. The transport top-to-the-NNW (**ZB7,** S_2 = *330/35*) and ENE (**ZB6,** S_2 = *235/32*) was indicated also by synthetic shears. The banded ultramylonitic quartzites are penetrated with thin veins of Alpine type (Czo, Lxn, coarse-grained Ms). LPO of quartz in the sample **ZB7** indicated dominating medium temperature prism <a> slip, corresponding with the origin newly grown biotite as the passive marker of rough foliation.

The effects of thermal flow, related to the late Variscan granitization, have been found in quartzitic rocks from the wider eastern and northern surrounding of the Zlatá Idka village (**ZI1**, S_2 = *258/75*, top-to-the-SE*;* **ZI2**, S_2 = *102/30;* **ZI3**, S_2 = *72/32;* **ZI4**, S_2 = *216/45*).

The increase of dynamic recrystallization causing decreasing grain-size of the protolith (**ZI4**) was accompanied with origin of oblique foliation. The quartz c-axes orientation in **ZI4** demonstrated the prevalence of the medium temperature (300-400 °C) prism <a> slip with minor contribution of rhomb <a> slip. The pole figure asymmetry in the prism <a> slip part indicated not very distinct top-to-the-SSE shearing. Contrary to this, the

Fig. 1. Position of Variscan suture zone in the Alpine tectonic frame. The principal ductile shear zones are indicated with dotted areas and are numbered in circles. A-C - Variscan south-vergent exhumation of Rakovec Group on Gelnica Group, both Lower Paleozoic of Gemericum, during phase VD: A - tectonic transport demonstrated by microtectonics in mylonites of Rakovec Group in (allochthonous) hanging wall of ductile shear zone, B - tectonic transport demonstrated by tectonites of upper part of Gelnica Group in (autochthonous) footwall of shear zone, C - course of Variscan ductile shear zone, D-G - north-vergent Alpine tectonic transport: D - shearing exhibited by rocks of Gelnica Group, E - emplacement of Bôrka nappe (exhumed parts of Cimmerian Meliata-Hallstatt basin) on Gemeric rock sequences, F - Lower Cretaceous north-vergent transport of Alpine thick skinned Gemeric nappe on Veporicum produced also internal imbrication of the nappe, G - location of the Silica superficial nappe either on Bôrka nappe or Gemeric sequences. Alpine nappe piling thickened continental crust. Thermal effects caused post-collisional unroofing of Veporic core. 1 - Pieniny Klippen Belt, remnant of Late Cretaceous to Early Tertiary closure of Penninic-related oceanic domain, 2 - crystalline complexes of Tatricum, 3 - crystalline complexes of Veporicum, 4 - sedimentary and volcano-sedimentary sequences of Gemericum. 5 - lithological boundaries and faults undivided, 6 - azimuth of foliation, number indicates dip in degrees, 7-9 - Paleozoic sequences of Gemericum: 7 - Ordovician-Devonian rocks of Gelnica Group, 8 - Devonian-Lower Carboniferous? rocks of Rakovec Group; Variscan ductile shear zone divides lithologies of both lithostratigraphic units. 9 - cover sequences of Gemericum: a - Carboniferous, b - Permian. 10-11 - nappe overliers on Gemericum: 10 - Bôrka nappe, 11 - Silica nappe. 12 - Paleogene cover. 13 - Veporicum undivided.

Overthrusting of Gemericum on Veporicum is the result of Alpine compression during AD_1. The boundary zone between both, so-called Lubeník-Margecany line, is recently modified with post-collisional unroofing during AD_2.

bulk oblique foliation of Qtz + Ab + Ser ± Act aggregate, occurring in bands parallel with mesoscopic foliation, indicated top-to-the-NNW sense of shearing. In the case of tourmaline microlayers (app. 80 % of Tur and 20 % of Qtz + Ab), the bigger tourmalines as a rule crystallized in the direction of oblique foliation (top-to-the-NNW). The sample **ZI4** by this way demonstrates very complex deformation history (the first plastic deformation registered by quartz LPO indicates transport top-to-the SSE, the younger one by the oblique foliation as well as the majority of Tur grains indicate top-to-the-NNW shearing).

The dynamic recrystallization of quartz matrix of banded acid pyroclastics **KH1** (upper part of Hnilec Fm., S_2 = *150/32*) from apical parts of the Kojšovská hoľa massif (1246) manifested the top-to-the-W shearing.

The studied lithology in continual N-S trending profile through the Tokáreň forest consisted prevailingly from banded sandstones. Rocks, mainly protomylonites, demonstrated weak fabric asymmetry. Non-penetrative tectonic overprint was reflected in differing sense of tectonic transport (**TOK1**; S_2 = *110/45;* top-to-the-WSW; **TOK3** S_2 = *56/16* – ENE; **TOK4**; S_2 = *170/43* – ENE; **TOK7**; S_2 = *150/40* – NW). The ambiguity in azimuthal orientation demonstrates more probable a weak stress field occurring during deformation, than the registration of two deformational evens.

Flyschoid sandstones in the central part of the recent areal spread of the Gelnica Group (triangle among villages Vlachovo, Smolník and Helcmanovce) are outcropped in the Stará voda valley (**SDO1**; S_2 = *182/5*; top-to-the-SSE shearing) and in the Bystrý potok valley (**BP4**; S_2 = *120/35*; top-to-the-SE). Next outcrops in triangle demonstrated different orientation of the stress field and general vergency of shearing to NNW (green porphyroid from Dlhá dolina valley **DD1125**, S_2 = *142/27*, top-to-the-NW; green laminated sandstone south of Pálenica elevation point **PAL2**, S_2 = *140/40,* top-to-the NNE; porphyroid - Henclová north of Volovec elevation point **HE1,** S_2 = *140/22,* WNW; sandstone north of the village Švedlár **ŠV9,** S_2 = *140/13,* NW; green porphyroid from Bystrý potok valley **BP2**; S_2 = *140/50*; NW). The tectonic transport to WNW was found also in the case of sandstone **GP1** from Gemerská Poloma village (Martinkov potok stream, S_2 = *185/16*).

Contrary to the rheologically weak material (banded sandstones, volcanoclastics, pyroclastics and carbonates), more rigid and competent volcanic rocks demostrated very weak and undistinct tectonization only with primary stages of foliation development and mantled porphyroclasts being undistinctly rotated (**HL2** - rhyolite from the northern surroundings of the Helcmanovce village, S_2 = *70/21*; **HY1** - rhyodacite outcropped to NW of Nižný Klátov village, S_2 = *90/30,* top-to-the-NW).

Carbonates

Microstructural data from carbonates of Holec Beds demonstrate the north-vergent transpressional tectonic transport with azimuthal spread from WNW to E (outcrops north of Nižná Slaná **GO1**, S_2 = *180/25,* top-to-the-WNW; Holec elevation point to NW of Smolník town with two types of calcitic marbles: **HO1** S_2 = *355/50,* top-to-the-E, but **HO3** top-to-the-NE; Bystrý potok valley **BP3**, S_2 = *160/50*, top-to-the-WNW; Turecká massif NW of Rožňava **TU1**, S_2 = *140/40*, top-to-the-WNW).

Differencial stresses determined by the paleopiezometry from samples **GO1** (average grain-size 253.9 □m; using method Twinning incidence I_t σ = 88-110 MPa; Twin density D σ = 159-168 MPa), **HO1** (202.9 µm; It => σ = 208-210 MPa; D => σ = 231-233 MPa) and **HO3** (350.8 µm; It => σ = 141-154 MPa; D => σ = 197-203 MPa) belong to the lower part of the value range found from the ductile shear zones in Gemeric region (cf. Németh, 2001). The sample GO1 moreover demonstrated the grain boundary migration accompanied with the origin of deformation lamellae in some grains. The higher differential stress, recorded in the sample HO1 in comparison with HO3, caused the origin of microshears during the same plastic deformation of calcite grains.

Tectonites of (autochthonos) footwall of ductile shear zone

The flyschoid sandstones of the upper part of Hnilec Formation of Gelnica Group [redef. Hnilec Fm. (Németh, 2001; Fig. 2); according to the lithostratigraphy by Bajaník et al. (1981) these sandstones belong to the Smrečinka Formation of Rakovec Group] represented the suitable rheological environment for preferential strain softening and the origin of ductile shear zone dividing rock of Gelnica Group in the footwall and rock mélange of Rakovec Group in the hanging wall of the shear zone.

Mylonites of laminated flyschoid sandstones

Laminated sandstones from the northern vicinity of Švedlár (**ŠH1**, VS_1 = *340/25*, transport to SE) demonstrate strong chloritic foliation, asymmetric structures and oblique foliation of quartzy grains. Gypsum plate indicates strong LPO of quartz aggregates. The shearing orientation of mylonites of laminated sandstones (**ŠV2**, VS_1 = *322/20*, NE) corresponds to the transpressional deformation regime when taking into account the moderate rotation of rock block bearing studied outcrop about 30° counterclockwise. Mylonite of black laminated sandy schist, outcropping in the tight vicinity of the Bukovec (1090) elevation point (**ŠV3**, VS_1 = *330/20*), demonstrates top-to-the-E shearing.

The LPO of quartz grains of banded flyschoid sandstones (protomylonite - Slovinky village, **SLV2**, VS_1 = *290/30*; mylonite - Lacemberská dolina valley, **4LD**, VS_1 = *10/5;* ultramylonite - Perlova dolina valley, **PED2A**, VS_1 = *184/8)* demonstrated maximum in the area of low to middle-temperature prism <a> slip with contribution of basal <a> slip. The tectonic transport in the horizon of sandstones firstly occurred in their thin pelitic intercalations. According to the weak asymmetry of pole figures, but mainly according to microstructural indicators in phyllosilicates there was determined the prevailing eastern vergence of transport. The moderate shear bands and intrafoliation fold in quartzy undistinctly laminated phyllite (Perlova valley, **PED2B**, VS_1 = *344/26*) indicated transport to SW.

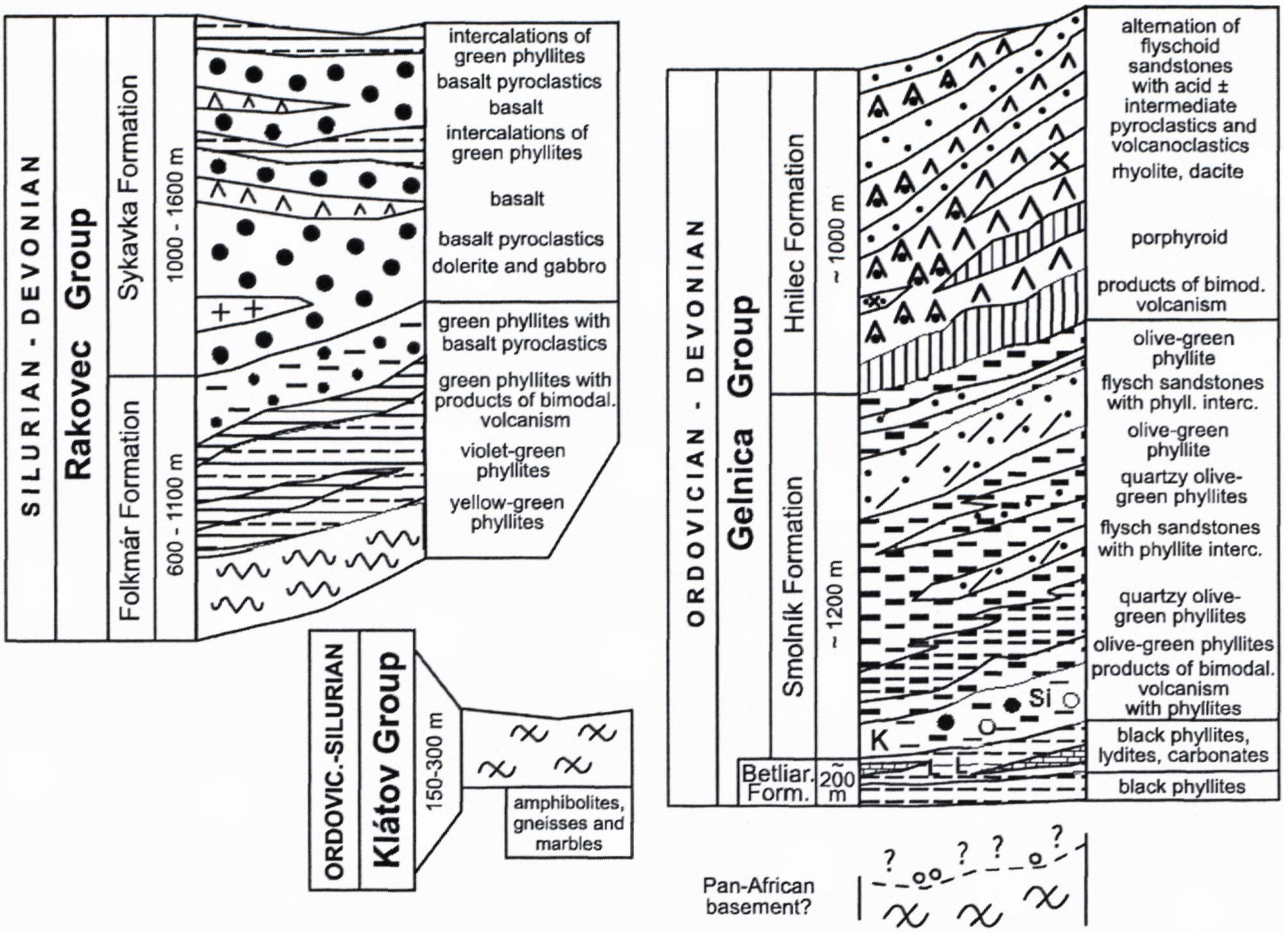


Fig. 2 Lithostratigraphy of the Lower Paleozoic of Gemericum (Németh, 1999, 2001).

The most prominent deformation process, found in banded psammites, was static recrystallization affecting the quarzy intercalations being formerly dynamically recrystallized. The first kinematic activity observed in representative samples (northern surrounding of Vyšný Klátov village **ČP6**, **ČP7**, **ČP8, KLA3**; N and NW surrounding of Nižný Klátov village **KLA5, KLA6A, POT1, POT2, POT3**; to the NE of Bukovec village **BK1A, BK1B, BK2, BK3A, BK3B**) was activity and recrystallization in pelitic intercalations (origin of white micas, their folding, pulling out of fragments from bordering quartzy intercalations, rotation of porphyroclasts). Next followed dynamic recrystallization of psammitic (quartzy) intercalations. The last process found from microstructures was the static recrystallization of quartzy intercalations accompanied with growth of large polygonal grains. They usually reached sizes being limited only by the distance between neighbouring pelitic intercalations. The former non-coaxial deformation was indicated by strain fringes found on pyritic grains. Oriented samples indicate top-to-the-SE and SSE shearing (**KLA5,** VS_1 *= 320/20*; **POT1,** VS_1 *= 56/46*; **POT2,** VS_1 *= 5/28*). Several samples (**POT4A,** VS_1 *= 32/36*) demostrate the direct overthrusting of hanging wall of shear zone, and the shearing top-to-the-SW has been found there.

Deformation gradient in laminated flyschoid sandstones strongly depends on their protolith. In the samples with lower content of pelitic component and strongly prevailing quartzy material the dynamic recrystallization has been accommodated by quartz grains. Because of lower percentage of phyllosilicates, and primarily lower amount of fluid phase liberating during phase transformation from clay minerals to phyllosilicates, the imprint of static recrystallization has been weaker (**KLA2A**).

Third mylonite type represents banded rock with prevailing albite in albite-quartz aggregates (having macroscopic appearance of banded keratophyre pyroclastics; **KLA2B**). The samples are without indications of static recrystallization with localization of deformation into penetrative foliation planes with phyllosilicates.

Mylonites of metapelites associated with flyschoid sandstones

Mylonite of grey metapelite from the Dobšinská Maša farmhouse west of Dobšiná (**DM1**; VS_1 *= 88/25*) indicates LPO of quartz aggregates under gypsum plate. Asymmetry of quartzy layer demonstrates top-to-the-E shearing. The bulk foliation of similar sample from Smrečinka hill (**SMR12**, VS_1 *= 320/65*, top-to-the-ENE) is represented with planar orientation of quartz grains flattened in XZ plane with oblique undulose extinction, corresponding with synthethic shears.

Mylonite of laminated green metapelite with younger contact metamorphic overprint (spotted shist), taken southwards of Hnilec village (**PAL1**, VS_1 *= 50/20*) con-

Slovak Geol. Mag., 8, 3–4(2002), 247–257

tains boudinaged asymmetric quartz lamines. They demonstrate top-to-the-ESE shearing, predating the contact metamorphism by Gemeric granite.

Mylonite of non-laminated metapelite (**20SLO**, VS_1 = *15/35*) exhibits extremely strong LPO of totally dynamically recrystallized quartzy aggregates. Because of rheologically homogenous material without laminae, all strain was accommodated by quartz grains with origin of oblique foliation.

Bulk foliation of pale-coloured mylonite (Perlova valley, **PED1**, VS_1 = *10/80*) is formed by newly formed sericite leaves. The undulose extinction of quartzy σ-porfyroclasts indicate ambiguous vergency of transport to E and W.

Mylonites of acid and intermediate pyroclastics and volcanoclastics

Volcanoclastics are present in intercalations of laminated flyschoid sandstones in the upper part of lithostratigraphic column of Hnilec Formation (intermediate rocks from the Korban altitude point west of Helcmanovce **KOR1**, VS_1 = *354/40* and **KOR2**, VS_1 = *15/8, top-to-the-ENE;* **VS1** eastward of Rejdová village, VS_1 = *178/25, top-to-the-ESE*). Acid volcanoclastics of Slovinky (**ZN-2-SLO**) demonstrate strong LPO and SPO in quartzy matrix without manifestations of static recrystallization. Feldspars are deformed by twinning.

Mylonite of coarse-grained volcanoclastics from Tokáreň mountain ridge (**TOK9**, VS_1 = 172/60, top-to-the-W) demonstrates SPO (flattening) of quartz and feldspar grains and wide anastomosing foliation planes with white mica.

Distinct asymmetric structures in mylonite of acid volcanoclastics with quartzy detrital bands and organic matter ("black porphyroid", Romanová valley to SW of Opátka village, **RM2**, VS_1 = *342/18*) indicate top-to-the-SSE shearing.

Mylonites of green phyllites

Mylonites of olive-green chloritic phyllites (**VS6**, the northern vicinity of the village Vyšná Slaná, VS_1 = *189/33*) and **SMR1**, the peak of Smrečinka hill, VS_1 = *285/25*; both top to the SSW; **ČP5A**, southward of Košická Belá village) contain in fine-grained Chl-Ser-Qtz matrix sporadical feldspar and quartz clasts (undulose extinction, recrystallization by GBM, deformation lamellae, subgrains, linear arrangement of fluid inclusions). Quartz clasts are dynamically recrystallized, showing boudinage, intrafoliation folding and strain caps.

In banded quartzy olive-green phyllite (Slovinky, **SLV1**, VS_1 = *330/10*, top-to-the-ESE) the phyllosilicate intercalations are transformed into bulk foliation. The intergranular spaces in quartzitic intercalations are filled with fibroidal fine-grained Qtz-Ser-Chl aggregate.

Tectonites from (allochthonous) hanging wall of ductile shear zone

For description of various types of mylonites in allochthonous part of shear zone (rocks of Rakovec Group), the different degrees of strain softening, relating mainly on protolith of mylonites, were used as a primary criterion.

Phyllitic mylonites

Sericite-chlorite phyllites (fine-grained aggregate Chl + Qtz ± Ab ± Ser) represented the softest medium of Rakovec Group. The dynamic recrystallization by GBM of thin quartzy intercalations, or sporadical clasts, caused their boudinage resp. total reduction. Recrystallized mica aggregates were usually folded and in mylonite they were present in foliation and shear bands as well as in the axial plane cleavage of microfolds. The quartz-chlorite syntectonic veins and younger pyritization and limonitization were also observed.

Oblique foliation among C-planes in violet-green phyllite (typical facies from Rakovec zone; Dobšinská Maša farmhouse, **DM3**, VS_1 = *160/25*) indicated top-to-the-W tectonic displacement.

The increasing degree of mylonitization of violet-green phyllites caused, together with their microstructural rebuilding, also the change of their colour to yellow-green. We explain this change by their total microstructural reworking with origin of very fine-grained aggregate Qtz-Chl-Phe-Ill (e.g. **1KRI** northward from Hnilec, or **GL2** northward from Gelnica, VS_2 = *108/76*, top-to-the-SE). The yellow-green phyllitic mylonites represent plastic environment surrounding rigid blocks (e.g. basalts). The same mylonite type we have found also in the underlier of Carboniferous conglomerates of Rudňany Fm. of Dobšiná Group.

Basalt pyrocklastics and volcanoclastics

Mylonite of basalt volcanoclastics (Dobšinská Maša farmhouse, **DM2**, VS_1 = *130/25*) has numerous synthetic shears with newly formed white mica and chlorite indicating top-to-the-E shearing. Twinned grains between individual synthetic shears demonstrate book-shelf sliding. Decomposition of old plagioclases is accompanied with origin of epidote-zoisite and crystallization of albite.

Plagioclases of protomylonite of basalt pyroclastics (Smrečinka elevation point, **SMR5**, VS_1 = *315/12*) are albitized, carbonatized and partly replaced by fine-grained aggregates of clinozoisite. The newly formed actinolites are a syn-tectonic product. Part of σ-porphyroclasts indicated dispacement to NE, but younger tectonic overprint top-to-the SW was indicated by crystallization of chlorite in synthetic shears and by deformation lamellae of plagioclases.

Matrix of mylonite of basalt pyroclastics (Smrečinka elevation point, **SMR8**, VS_1 = *337/80*) consisting from flattened Qtz + Ab grains with strong SPO, represent bulk continuous foliation. Moreover, the spaced foliation by chloritic bands and boudinaged strips of newly grown carbonate have the same course. In described mylonite the top-to-the-ENE tectonic transport is indicated by synthetic shears and plagioclase σ-porphyroclasts as well as occasional book-shelf sliding of their fragments.

The protomylonite of basalt pyroclastics (northern surrounding of Švedlár village, **ŠH2**, VS_1 = *354/30)* exhibits strong LPO of quartzy intercalations by gypsum plate. Nearly half of quartz grains demonstrates undulose extinction and origin of subgrains. According to numerous synthetic shears tectonic transport top-to-the-SSW has been distinguished.

Lenses of carbonates with oblique twinning in mylonite of basalt pyroclastics (to the north of Gelnica, **GL1**, S_2 = *166/35*) indicate vergence of shearing top-to-the-SE. Preferred orientation of anizometric minerals contributes to planar-linear setting (SL tectonite) of rock.

Synmetamorphic deformation (fluid driven deformation) of basalt pyroclastics **NK1** (eastern surrounding of Nižný Klátov village, S_2 = *220/20*, top-to-the-SW) is documented with segmented plagioclases having albitized fractures. Spaced foliation is formed with chlorite and elongation of newly formed actinolites.

Basalts

Outcrop of basalts (Slovinky area, **SLV3**, S_2 = *180/45*) without any tectonization represent a rigid block, flowing in plastic phyllitic environment. The calcite rhombohedrons are the main constituents of rock together with albitized plagioclase porphyroblasts and fine-grained aggregates of chlorite and epidote-zoisite with strips of ilmenite and sporadic clinozoisite.

Discussion

Variscan geodynamic evolution

The origin of *Rakovec geosuture* of variegated lithological composition (being characterized below) is a product of Variscan evolution. The geosuture is divided from the Gelnica Group with ductile shear zone having moderate to medium northern dip. Generally, the northern inclination of the rock boundaries in this zone was proved also by the results of geophysical measurements (cf. Grecula a Kucharič, red., 1992). Moreover, the presence of the rock boundary inclined northward was in this zone indicated by seismic profiles G1a/92, G1b/92 and G2/93 (Vozár et al., 1998). The microstructural investigation of mylonites from described boudary zone proved two principal directions of tectonic transport - in autochthonous footwall of ductile shear zone, i.e. in the upper part of the Gelnica Group, the general vergency of tectonic transport to ESE prevailed (black-white arrows in Fig. 1). The allochthonous hanging wall of ductile shear zone (tectonic mélange of Rakovec Group) indicated the transport directions generally to south, but locally there was recorded also their large azimuthal spread (black arrows in Fig. 1). Our findings prove the general southern-vergency of Variscan tectogenesis. The south-vergent structures are in Gemericum common, including fold structures of this orientation.

From the evolutionary viewpoint the Lower Paleozoic rock sequences of Gemericum can be generally divided into two large groups:

A. The Lower Paleozoic rocks of Gelnica Group in "cover" position on the rigid block of the older crystalline block of "southern" Pan-African? provenience were in Upper Carboniferous deformed by generally south-vergently displaced exhuming mélange. We do not suppose the higher thickness of sediments of Gelnica Group in the pre-exhumation era than 5 km. To this corresponded the diagenesis in upper part of the rock pile of Gelnica Group and the greenschist facies in its lower part.

B. Rocks of Rakovec group were dragged into various depths of subduction zone. The age of subduction-exhumation processes (Devonian to Vestphalian) is supposed. Dating of the upper time boundary is based only on the finding of the metamorphic pressure peak of 12 kbars in a matrix of a part of sediments of the Rudňany Fm. (Radvanec, 1998). It indicates, that also part of Westphalian sediments was locally affected by metamorphism in subduction régime and consequently exhumed (cf. Chemenda et al., 1996, 1997). The Upper Devonian radiometric ages from the Klátov Group (cf. Cambel et al., 1990) which tectonometamorphism is given to relation to the early stages of subduction processes, indicate the lower time limit of subduction. The subduction slab was inclined northward below the rocks of recent Tatro-Veporic terrane (Fig. 3). The differential relative movement of rocks occurred in the subduction slab. Interpreting the kinematics in a converging terrane we suppose, that deepest position in subduction zone was reached by rocks of the "northern near-Veporic" part of a Lower Paleozoic basin, located to the north from the spreading zone. Incorporation of the mid-oceanic ridge into subduction zone meant the beginning of subduction of the Gemeric - Rakovec (southern) part of the Lower Paleozoic basin, while the source of the convectional heat was that time located below Veporicum and initiated the reverse rolling back of rock masses (occasionally also with the fragments of the mantle rocks) in subduction channel back to the surface. Approaching of crystalline rocks of (southern) basement, being present beneath the rocks of Gelnica Group, decelerated the subduction. The collision caused the origin of a geosuture. In its recent erosion cut we can find:

1. Former sediments and volcanic rocks of the Rakovec Group, in marginal parts of the basin occasionally with preserved lithostratigraphy. Their low degree of metamorphism and tectonization was the result of their position in the northern lateral continuation of the Gelnica Group, as well as the minor incorporation to the subduction zone. The transition between the Rakovec and Gelnica lithologies was documented already by Grecula (1970, 1982) and was the reason for distinguishing of the uniform Volovec Group for the whole Lower Paleozoic rocks of Gemericum. The lithological transitions are observable in the area of Perlova dolina valley eatwards of Gelnica town.

2. The subducted sediments and volcanites from the Rakovec Group, being exhumed from the deeper parts of the subduction zone. They are characteristic with higher tectonization. Metamorphism in the facies of actinolitic schists (e.g. in the strip south of the line Holý vrch hill (1016) and Suchinec (909) northward of Lacemberská dolina valley).

Slovak Geol. Mag., 8, 3– 4(2002), 247 – 257

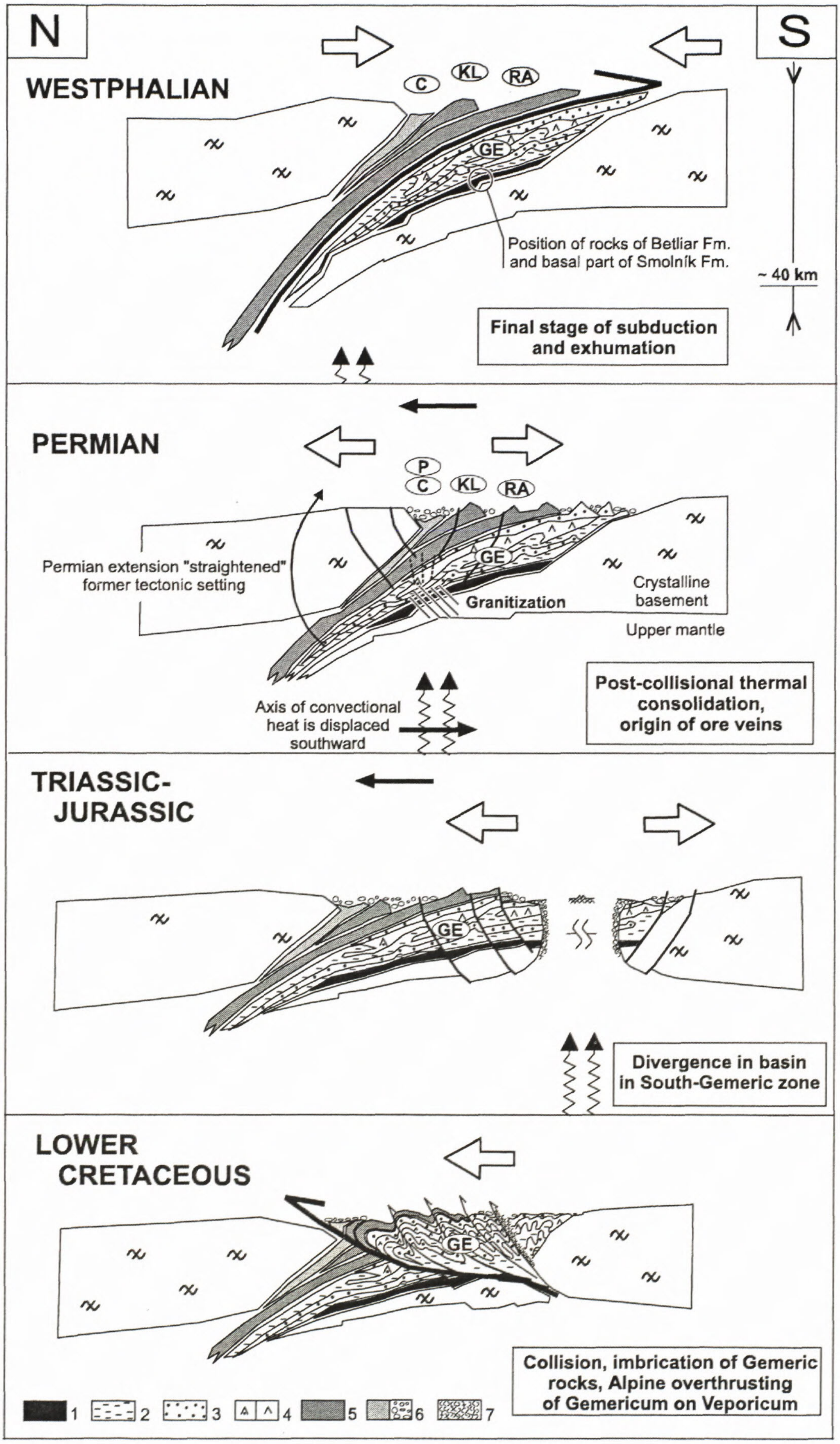


Fig. 3

3. Former sediments and volcanites of Rakovec Group exhumed from deeper parts of the subduction zone. In the case of mafic rocks there were indications of higher-pressure metamorphism (Hovorka et al., 1988; Rakovec area). Radvanec (1999) found the mantle origin and ultra-high pressure metamorphism of a part of these rocks. "Floating" rigid blocks of mafic rocks in plastic mylonitic environment of green phyllites. *[Among other indications we argue also with tectonometamorphic "transformation" of violet-green phyllitic facies into mylonites of co-called yellow-green phyllites in the zone between the altitude point Suchinec (909) and the Slovinky village northward of Lacemberská dolina valley].*

4. Part of Westphalian rocks of the Rudňany and Zlatník Formations with the demonstrations of metamorphic recrystallization recenly outcropping in segments in the zone from Sykavka to the area of Závadka village as well as in surrounding of Rudňany village (cf. Radvanec, 1998). A great deal of rocks from the Rudňany and Zlatník Fms. does not exhibit the metamorphic recrystallization because of their external sedimentation area regarding to subduction zone. They were not included into subduction process. *[For example the preservation of intercalations of black schists with well-known biostratigraphic occurrences in the area of Dobšina; review is presented by Vozárová and Vozár, 1988.]*

5. Rocks of Klátov Group with higher-temperature overprint probably represented the "near-Veporicum" part of subducted Lower Paleozoic basin with the original position northward of spreading zone. *[Rocks of recent Rakovec Group, accepting this interpretation, represented the distant - opposite part of the Lower Paleozoic basin, i.e. southward of the spreading zone.]* This former position of rocks of Klátov Group allows to suppose that they belong among the first rocks affected by tectonometamorphism in generating subduction zone at the beginning with unstable thermal regime (big dispersion of K-Ar tectonometamorphic ages from amphibolites of Vyšný Klátov and Dobšiná areas with predominance of Upper Devonian ages; Cambel et al., 1990). By the same reason, the rocks of Klátov Group belonged among first exhumed rocks and served the clastogenic material for Carboniferous sediments of Črmeľ Group, and mainly, to Rudňany conglomerates. The early exhumation of rocks ranked to Klátov Group, serving clastogenic material for sediments of Črmeľ Group in Eastern Gemericum, was sedimentologically proved by M. Grecula (1998, Fig. 24 in l.c.).

The thickness of the rock column of Gelnica Group on its footwall icreased after exhumation (south-vergent overthrusting) of Rakovec Group rocks (+ Klátov Group and part of Westphalian) sediments. Thickness of the allochthonous (exhumed) body probably did not overreach 1 km. Despite, in collided terrane we suppose a bigger thickness of hanging wall due to the partial shifting of southern margin of converged basin (i.e. Gelnica Groupon ist former crystalline basement) into subduction slab, that caused the collisional ending of subduction-exhumation process. In collisional orogen there started the resetting of thermal régime and the deeply intrenched isograds into the zone of subduction slab started to be straightened.

The Permian period is therefore the era of thermal effects, with high probability tied with the presence of elongated thermal source of convectional heat beneath the collided terrane in the North-Gemeric zone (closed Rakovec basin with geosuture and mutually approached margins of the former basin, that is "Veporic" rocks in hanging wall and Gelnica Group rocks in footwall). The linear thermal source beneath the collided terrane represent the same heat source which primarily caused in Ordovician-Devonian spreading and divergence in the Lower Paleozoic basin. Its position beneath the collided terrane is a result of convergence and later subduction of former spreading zone. It is hardly expectable that lithospheric displacement above this thermal source could locate it to the opposite ("northern") side of subduction slab. The position of thermal axis results also from the reconstruction of the Western Carpathian Permian sedimentary basin and magmatic trends in this time period (cf. Vozárová a Vozár, 1987).

The increased thermal flow caused, besides other things, the thermal erosion of lithospheric slab beneath Gelnica Group as well as the higher-grade metamorphism of the rock sequences of the Gelnica Group. These were in previous evolution protected against the income of heat (from the time of their primary sedimentaion they were localized "southward" of the spreading zone, that is besides the axis of convectional heat). We suppose, that thermal processes in collisional orogene in this internal part of the Western Carpathians were sufficient for increase of thermal gradient and served enough heat for higher-temperature metamorphism, origin of Gemeric granites and metallogenic processes.

During later Permian evolution of the terrane of Inner Western Carpathians the trend of former convergence was probably preserved and the northward relative movement of lithospheric plate continued. This is the reason, why the continual shifting of the convectional heat axis to innermost zones of Gemericum (southward) is supposed. In the Gemeric region it was confirmed by younging of Gemeric granite from the north southwards *[Hnilec - 290 Ma (Kovach et al., 1986) and 282 Ma (Cambel et al., 1989); Betliar 272 Ma; Humel 270 and*

Fig. 3. Interpretation of the geodynamics of Inner Western Carpathians. GE - Gelnica Group, RA - Rakovec Group, KL - Klátov Group, C - Carboniferous rocks, P - Permian rocks. White arrows - direction of convergence, resp. divergence, black undulating arrows - axis of convective heat, black straight arrows - relative migration of collided terrane with respect of axis of convective heat. 1 - black phyllites of Betliar Fm., 2 - green phyllites of Smolník Fm., 3 - flysch - lower bed - in Smolník Fm., upper bed - the supreme parts of Hnilec Fm., 4 - intermediate and acid volcanoclastics of Hnilec Fm., 5 - effusive and extrusive products of basalt volcanism, locally with accompanying rocks, 6 - clastics of Rudňany Fm. and further Carboniferous and Permian clastics, 7 - effusive and extrusive products of basalt volcanism of Mesozoic evolution, locally with accompanying rocks.

246 Ma; Zlatá Idka 251 and 223 Ma (Kovach et al., 1986)]. The similar effect is indicated also by the presence of best developed siderite-sulphidic veins directly in the North-Gemeric zone. These veins penetrate the suture zone often through the bondary zone of Gelnica Group, Rakovec Group, Carboniferous formations and Permian). Towards the south the vein parameters became worst. *Conductive overheating of the Lower Paleozoic rocks of Gemericum (Gelnica Group) was the most intensive in its lowermost horizons built up with the Betliar Fm., Holec Beds and the Lower variegated volcanic horizon. These served as the metal source for originating fluids entering into extensional structures above (detail aspects of this metallogenic process are stated in works by Radvanec, 1987 and Grecula et al., 1991). The "cover" position of rocks of Betliar Formation on rigid crystalline basement and beneath the soft overlier of the Gelnica Group protected them against tectonization in previous process of exhumation and south-vergent thrusting of Rakovec Group. In Permian era before the generation of ore veins started, the rocks of Betliar Fm. had been in the same deposition like during the sedimentation in Ordovician-Silurian era, that is, they were not affected by Pre-Permian orogenesis. All Pre-Permian (south-vergent) tectogenesis was accommodated by overlying Smolník and Hnilec Formations (Fig. 3)*

Alpine geodynamic evolution

The effects of Permian extension in Gemeric terrane, owing to the displacement of lithosphere above the axis of convectional heat, were gradually shifted from the north southwards. This is the reason why we suppose in Triassic-Jurassic era the slowing down the sedimentation in the North-Gemeric zone, and, on the contrary, the new spreading activity is supposed to start in the zone of the South Gemericum. The extension in the southern zone caused gradual disintegration of the continental crust and origin of the elongated Meliata-Hallstatt basin. The relicts of the former basin after its clossure are represented by obducted marginal sequences of the Meliata basin, the Bôrka nappe (cf. Németh, 1996, Fig. 4 ibid.) and origin of geosuture in the Rožňava discontinuity zone, being indicated also by magnetoteluric profile of Pawliszyn (1978) in Grecula et al. (1995).

Later Alpine evolution after Upper Jurassic? convergence has been divided into four deformation phases:

Deformation phase AD_1 is tightly related to the closure of Meliata-Hallstatt basin with following succession of events: Closure of the basin and transport of the Bôrka nappe on Gemericum. Ongoing convergence caused not only the north-vergent imbrication of Lower Paleozoic rocks of former Variscan collisional terrane, but the Lower Cretaceous displacement of several kilometers thick rock pile of Gemericum northward on Veporicum. This process of detachment was allowed by the rheologically contrast horizon of the black schists of Betliar Fm. (Németh et al., 2001a), dividing rigid crystalline basement from the rocks of Gelnica Group.

We suppose that a part of former Betliar Formation (incl. Holec Beds) remained cut in its homeland. The north-vergent imbrication in low-temperature brittle-ductile and brittle regime caused multiple repeating the Early Paleozoic lithology of Gemericum. Next consequence of north-vergent overthrust setting (indicated by white arrows in Fig. 1) was also the recent picture of distribution of zonality of Variscan metamorphism in Gemericum (cf. Radvanec, 1989, 1992; Faryad, 1991a, b, c). The overthrust setting destructed also the courses of Late-Variscan/Early-Alpine ore veins (cf. numerous examples in Grecula et al., 1990b, 1995; Grecula, 1982).

The Alpine Lower Cretaceous nappe displacement on Veporicum during AD_1 (Fig. 1) caused:

1. Truncation of northern depth continuation of Rakovec geosuture, and "retraction" of its lower parts below Gemericum. This "bended" course of depth continuation of flat body of heavy material was indicated also by the complex geological-geophysical profiles of the Project SGR-geophysics (Grecula and Kuchařič, eds., 1992).

2. Thrusting of North-Gemeric zone on "Veporic ramp" caused elevation uplift ("vent") of this area in frontal parts of the nappe, its disintegration and later erosive removal of cover carbonates of the Stratená Group.

The Alpine nappe-overthrust piling of crustal material (the basement nappe) caused thickening of continental crust in the Western Carpatians and in Middle Cretaceous the unroofing of Veporic basement during phase AD_2 (Fig. 1 upper left and right).

Deformation phase AD_3 with the origin of conjugate systems of brittle-ductile and brittle shear zones of NW-SE and NE-SW trends (cf. Grecula et al., 1990a; Németh et al., 1997) caused arc bending of Gemericum, as well as the Lubeník-Margecany line, and *sensu lato* also of the whole Western Carpathians (Németh et al., 2001b).

Deformation phase AD_4 is a gradual continuation of AD_3. It reflects an orogen parallel extension in east-west direction. The crustal indentor for the whole Western Carpathians was directed northward to the South-Gemeric zone. The brittle deformation during AD_4 takes place in shallow crustal levels and prevailing structures are those of pure-shear (faults, joints).

Conclusions

Defining of Variscan geosuture in the North-Gemeric zone and microstructural proof of kinematics of representative rock types in the Gelnica and Rakovec Groups led to suggestion of modified model of Variscan tectonic evolution of Gemericum together with new interpretation of ore-veins generation.

We suppose, that thermal processes in collisional orogen in this internal part of Western Carpathians were sufficient for increase of temperature gradient, and served sufficient heat for higher-temperature metamorphism, origin of Gemeric granites as well as metallogenic processes in Permian era.

Conductive overheating of Lower Paleozoic rocks of Gemericum (Gelnica Group) was the most intensive in its lowermost horizons, built up by the Betliar Fm., Holec Beds and the Lower variegated volcanic horizon. Their position on rigid crystalline basement and beneath the cover of overlying rocks of Gelnica Group protected them against tectonization during exhumation and south-vergent overthrusting of rocks of Rakovec Group. The rocks of Betliar Fm., Holec Beds and Lower variegated volcanic horizon served as the metal sources for generating of fluids (cf. Radvanec, 1987; Grecula et al., 1991). Fluids entered into originating extensional structures in overlying rock sequences.

The Cretaceous Alpine tectonics destructed former Variscan structures.

Geodynamics of Inner Western Carpathians from the beginning of Ordovician riftogenesis till Mesozoic is interpreted as the product of the thermal flow of the same convective heat. The divergence, resp. the changes of kinematics of crustal segments were caused by changes of mutual position of overlying crustal segments regarding the convective heat.

References

Cambel, B., Bagdasaryan, G. P., Gukasyan, R. C. & Veselský, J., 1989: Rb-Sr geochronology of leucocratic granitoid rocks from the Spišsko-gemerské rudohorie Mts. and Veporicum. Geol. Zbor. Geol. carpath., 40, 323-332.

Cambel, B., Kráľ, J. & Burchart, J., 1990: Isotope geochronology of crystalline basement of Western Carpathians. Veda, Bratislava, 183. (in Slovak)

Faryad, S. W., 1991a: Metamorphism of mafic rocks in the Gemericum. Mineralia slov., 23, 109-122. (in Slovak)

Faryad, S. W., 1991b: Metamorpism of Lower Paleozoic acid to intermediate volcanites of Gemericum. Mineralia Slov., 23, 325-332. (in Slovak)

Faryad, S. W., 1991c: Metamorphism of Lower Paleozoic sediments of Gemericum. Mineralia Slov., 23, 315-324. (in Slovak)

Fusán, O., Máška, M. & Zoubek, V., 1955: Some problems of stratigraphy of the Spiš-Gemer Ore Mts. Geol. Práce, Zpr., 2, 3-15. (in Slovak)

Grecula, M., 1998: Carboniferous of Črmelicum terrane, Western Carpathians: relict of a fore-arc basin within Alpide Variscides. Mineralia Slov., 30, 109-136.

Grecula, P., 1970: Gelnica series as the only Early Paleozoic representant of the Spiš-Gemer Ore Mts. Mineralia slov., 2, 181-190. (in Slovak)

Grecula, P., 1982: Gemericum - segment of the Paleotethyan riftogeneous basin. Mineralia Slov.-Monogr. Alfa, Bratislava, 263. (in Slovak with extended English resume)

Grecula, P., Návesňák, D., Bartalský, B., Gazdačko, Ľ., Németh, Z., Ištván, J. & Vrbatovič, P., 1990a: Shear zones and arc structure of Gemericum, the Western Carpathians. Mineralia Slov., 22, 97-110.

Grecula, P., Návesňák, D. & Bartalský, B., 1990b: Shear zones and types of deformation of ore veins in Gemericum, Western Carpathians. Mineralia Slov., 22, 111-122.

Grecula, P., Radvanec, M. & Bartalský, B., 1991: Critical thermic isograde in metamorphic-hydrothermal model of vein mineralization on the background of the Variscan events, Gemeric unit, Western Carpathians. Mineralia Slov., 23, 403-411.

Grecula, P. & Kucharič, Ľ., eds., 1992: Partial Final report from complex geological-geophysical interpretation of northern part of SGR. Manuscript, archives of GSSR, Bratislava, 199. (in Slovak)

Grecula, P. et al., 1995: Mineral deposits of the Slovak Ore Mts. Vol 1. Geocomplex, Bratislava, 1-829.

Hovorka, D., Ivan, P., Jilemnická, L. & Spišiak, J., 1988: Petrology and geochemistry of metabasalts from Rakovec (Paleozoic of Gemeric unit, inner Western Carpathians). Geol. Zbor., Geol. Carpath., 39, 395-425.

Chemenda, A.I., Mattauer, M. & Bokun, A.N., 1996: Continental subduction and a mechanism for exhumation of high-presure metamorphic rocks: new modeling and field data from Oman. Earth Planet. Sci. Lett., 143, 173-182.

Chemenda, A.I., Matte, Ph., & Sokolov, V., 1997: A model of Paleozoic obduction and exhumation of high-pressure/low-temperature rocks in southern Urals. Tectonophysics, 276, 217-227.

Kovách, A., Svingor, E. & Grecula, P., 1986: Rb-Sr isotopic ages of granitoid rocks from the Spišsko-gemerské rudohorie Mts., Western Carpathians, Eastern Slovakia. Mineralia Slov., 18, 1-14.

Németh, Z., 1996: First discovery of the Bôrka nappe in the eastern part of the Spiš-Gemer Ore Mts. Mineralia Slov., 28, 175-184. (in Slovak with English resume)

Németh, Z., 1999: Explanations to geological maps in the scale 1 :25 000, sheets M-34-113-B-d, M-34-114-A-c, M-34-114-A-d, M-34-114-B-c, M-34-114-B-d. Stadial report. Manuscript - archives GSSR, Bratislava.

Németh, Z., 2001: Petrotectonics of the ductile shear zones of Gemericum. Ph.D. thesis. Comenius Univ., Bratislava, 1-98.

Németh, Z., Grecula, P. & Putiš, M., 2001a: Lithotectonic relations in boundary zone of Gelnica and Rakovec Groups in the North-Gemeric zone. Geol. práce, Správy 105, 67-70. (in Slovak)

Németh, Z., Putiš, M. & Grecula, P., 2001b: Origin of the arc-bended boundary zone between Gemericum and Veporicum from the viewpoint of kinematics of Alpine extensional unroofing. Geol. práce, Správy 105, 65-66. (in Slovak)

Mello, J., ed., 2000: Explanations to geological map of Slovak Paradise, Galmus and Hornád basin. Dionýz Štúr Publishers, Bratislava, 298. (in Slovak with English summary)

Radvanec, M., 1989: Metamorphism of Early Paleozoic Gemeric rocks - middle part - Partial Final report of the project SGR-geophysics. Manuscript - archives GSSR.

Radvanec, M., 1992: Zonality of low-pressure and polyphase metamorphism in open system for fluid phase in the gneiss-amphibolite complex of Gemericum. Mineralia Slov., 24, 175-196. (in Slovak with English resume)

Radvanec, M., 1998: High-pressure metamorphism of Upper Carboniferous conglomerate from the locality Rudňany-Svinský hrb on the north of Gemericum. Mineralia Slov., 30, 95-108. (In Slovak with English resume)

Radvanec, M., 1999: Eclogitized clinopyroxenic gabbro with retrograde metamorphism in pumpellyite-actinolite facies on the hills Babiná and Ostrá (Gemerikum). Mineralia Slov., 31, 467-484. (in Slovak with English resume)

Rowe, K. J. & Rutter, E. H., 1990: Paleostress estimation using calcite twinning: experimental calibration and application to nature. J. Struct. Geol., 12, 1-17.

Vozár, J., Szalaiová, V. & Šantavý, J., 1998: Interpretation of the Western Carpathian deep structures on the basis of gravimetric and seismic sections. In: M. Rakús, ed.: Geodynamic development of the Western Carpathians. Dionýz Štúr Publishers, Bratislava, 241-257.

Vozárová, A. & Vozár, J., 1987: West Carpathians Late Paleozoic and its paleotectonic development. In: H. W. Flügel, F. P. Sassi & P. Grecula (red.): Pre-Variscan and Variscan events in the Alpine-Mediterranean mountain belts. Mineralia Slov. - Monograph, Alfa, Bratislava, 469-487.

Vozárová, A. & Vozár, J., 1988: Late Paleozoic in West Carpathians. GÚDŠ, Bratislava, 1-314.