New K/Ar and Ar/Ar ages on the Veporic crystalline basement in Northern Hungary

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The Veporic crystalline basement in Northern Hungary is composed of mainly garnet- bearing gneisses and associated micaschists, and subordinately ”greenschists” which comprise generally strongly retrogressed garnet-amphibolites, actinolite-chlorite-biotite schists and chlorite schists. (For a more detailed petrographical and petrological description see Koroknai and Horváth, this vol.). New geochronological investigations were carried out on the following borehole samples.

Borehole Hont-1 114±6 Ma K/Ar age was reported on white mica from the micaschist (Lelkes et al., 1996, Balogh, 1984). On the same white mica, an Ar/Ar plateau age of 113.9±0.8 Ma was obtained in the 782-1140 °C temperature range where 70% of the ^{39}Ar was released. This plateau age is interpreted as cooling (uplift) age. The youngest age (41.4±3.1 Ma) was measured at the lowest temperature step (at 497 °C), this rejuvenation might have been caused either by the Eocene-Oligocene tectonism or the Miocene volcanism of the Börzsöny Mts. Determination of closure temperature has been attempted by using the Arrhenius diagram. The points fit fairly well to a straight line in the 606-1140 °C temperature range, but the activation energy and the closure temperature are too low (E=26.6±4.4 kcal/mol, 125 °C). A tentative explanation could be a stimulated argon release under vacuum conditions, but in this case a scattered arrangement of the points could be expected in the Arrhenius diagram (Evernden et al., 1960).

Borehole Szécsény-7 Biotite K/Ar age of 96±7 was published earlier (Lelkes-Felvári et al, 1996). This is confirmed here by a new K/Ar age of 88.2±3.3 Ma on a fresher biotite separate from this borehole.

Borehole Sóshartyán-3 A K/Ar age of 108±5 Ma was measured earlier on white mica (Lelkes-Felvári et al., 1996). Ar/Ar spectrum on the same mineral separate defines a plateau age of 87.4±1.0 Ma in the 740-1061 °C temperature range where 84.0 % of the ^{39}Ar was released. Older ages were obtained at lower temperature steps (112.9±7.9 Ma at 527 °C). This phenomenon is caused by incorporation of excess argon during the closure of white mica. An attempt to measure closure temperature resulted in E=32.8±1.8 kcal/mol activation energy and the too low (176 °C) formal closure temperature, which is explained similarly as for the white mica from borehole Hont-1. It was observed also in other cases that white micas formed during retrograde metamorphism result in irrealistic low closure temperatures when they are degassed in vacuo.

A new K/Ar age on amphibole of 93.5±5.6 Ma from the same rock agrees very well with the white mica plateau age and shows that excess argon appeared only after the closure of amphibole. Excess argon was transported probably by hydrothermal fluids.

These new age determinations on biotite, white mica and amphibole from both the gneissic and amphibolitic lithologies clearly show that Eoalpine metamophism completely reset previous metamorphic event(s). These data indicate that Alpine metamorphism reached at least temperature of ca. 500 °C. The older K/Ar ages from the Hont-1 borehole may indicate an earlier uplift in that area, however, this explanation requires further data from the borehole and its surroundings. Fast uplift is suggested by the small time difference between the mica and amphibole ages in the case of Sóshartyán borehole.

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Structure and development of the Western Carpathian’s Hercynian orogen

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In the Western Carpathians ve can distinguish the following main Hercynian lithotectonic units: in the Hercynian internal domain (Tatro-Veporic) the low-grade metamorphics in the upper most position, the upper gneiss unit, the middle unit, the lower (subautochtonous) unit, and in the Hercynian external (Gemeric) domain Klátov, Rakovec and Gelnica units. These lithotectonic units have been formed during the Hercynian continental collision, which advanced from the internal to the external zones.

The reconstruction of the Hercynian development summarizes the latest results of basement studies in the Western Carpathians based on structural, metamorphic and radiometric data. From this point of view, three evolutional stages have been distinguished in the Western Carpathians:

Paleohercynian (430-380 m.y.), with subduction processes accompanied by a high-pressure metamorphism,

Mesohercynian (380-340 m.y.), with collision processes, middle crustal thrusting of the main lithotectonic units, medium pressure metamorphism of the Barrowian type and extensive intrusions of the S-type granite,

Neohercynian (340-260 m.y.), with predominating low-temperature tectono - metamorphic processes, occurring in a transpressional and finally in an extensional regime. Granitoid magmatism of the I- and/or A-type is characteristic of this stage.

Neoalpine sub-greenschist to greenschist metamorphism of the Eastern Slovakian core complex

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Geology

Pre-Neogene basement of the Eastern Slovakia is formed mainly by the Iňačovce-Krichevo Unit. This subsurface unit comprises mostly of metasedimentary formations with distinct similarities to the Penninic Zone. At the base of the complexes there are variegated phyllites, phyllitic marbles and marbles which can be correlated with the red-bed formations, in Alpine region known as „Quartenschiefer“. Their Upper Triassic age has been determined biostratigraphically. Above them a thick „Bündnerschiefer“-like formations follow containing green or dark phyllites, metasandstones and metasiltstones. Oceanic lithology of these metasediments has been proved by the presence of metaultramafic rocks, metabasalts and metatuffites. In the upper part, „Bündnerschiefer“ formations pass into the more arenaceous sequences. The Upper Cretaceous sediments are probably represented by turbiditic sequences of dark schists and metasandstones. The youngest sediments (Middle Eocene) are formed of black phyllitic schists intercalated by Nummulites-bearing metasandstones. Considering that, the latest phase of syntectonic low-temperature metamorphism, were taking place probably after Middle Eocene.

Metamorphism

Low-temperature metamorphism of the metasediments has been studied on approx. 100 core samples. The estimation of the physical conditions of metamorphism is based on the illite and chlorite „crystallinity“ data, coal rank data, as well as study of mineral assemblages.

Illite and chlorite „crystallinity“. The lowest degree of metamorphism has been determined in the youngest metasediments of the Iňačovce-Krichevo Unit, represented by the Middle Eocene rock complexes. They are composed of black phyllites and metasandstones which show signs of flysch lithofacies. The phyllites are lacking in diagnostic metamorphic assemblages, since they are composed of illite/muscovite, quartz, chlorite, albite, organic matter, dolomite, pyrite and organic matter. Therefore, the metamorphic conditions for these rocks have been estimated on the basis of phyllosilicate „crystallinity“ data and coal rank data. For the „crystallinity“ measurements, a total of 50 phyllite samples were collected from the Middle Eocene rocks of the Zbudza-1 borehole. Experimental results were converted to the original Kubler's scale by the calibration against set of CIS standards (Warr & Rice, 1994), thus, the anchizone boundary values are 0.42 and 0.25°$\Delta 2\Theta$. The samples show a large interval of „crystallinity“ values, ranging from 0.23 to 0.39°$\Delta 2\Theta$. However, the average value is 0.31 and mode is 0.34°$\Delta 2\Theta$. In general, these data correspond to the middle or upper part of anchizone. Similar results have been observed using second (7Å) basal reflections of chlorite. Considering a limiting values of anchizone proposed by Árkai et al. (1995; 0.307 - 0.244°$\Delta 2\Theta$), an average value of ChC(002) = 0.258°$\Delta 2\Theta$ indicates metamorphic conditions of the higher anchizone.

Coal rank data. Coal rank was determined through vitrinite reflectivity measurements. In Middle Eocene metasediments, an organic matter occurs finely dispersed in the rock matrix or concentrated along cleavage planes. Three types of organic matter with following mean characteristics have been recognized:

	Ro max	Ro min	Ro max - Ro min
1. inertinite (n=58)	5.22 ± 0.54%	3.56 ± 0.52%	1.66%
2. vitrinite (n=36)	5.75 ± 0.72%	3.37 ± 0.67%	2.38%
3. graphite (n=5)	12.30 ± 1.80%	0.41 ± 0.07%	11.89%

When plotted to the diagram of the maximal against the minimal reflectance values of Teichmüller et al. (1979), a data are concentrated within the meta-antracite field. This stage of coalification can be correlated with metamorphic conditions ranging from higher temperature part of anchizone to lower epizone (Kisch, 1987).

Peak metamorphic conditions. Diagnostic metamorphic minerals have been observed in high alumina metasedimentary rocks. The peak metamorphic conditions are documented by assemblages: muscovite + quartz + pyrophyllite + paragonite + intermediate Na-K micas ± chlorite ± chloritoid. Based on these assemblages the following mineral reaction can be assumed: pyrophyllite+chlorite → chloritoid+quartz+H_2O; equilibrium temperature: 300 - 350°C (Theye et al., 1992)

The formation of chloritoid according this reaction requires temperatures under the breakdown point of pyrophyllite at the low to mid pressure conditions. Therefore, peak metamorphic temperatures were between the upper stability limit of kaolinite + quartz and the upper stability limit of pyrophyllite + quartz pairs, presumably between 350 and 400°C.

Metamorphic mineral assemblages of metabasic rocks can be summarized as follows: calcite + chlorite + biotite + phengite + stilpnomelane + titanite + quartz (ophicalcites), epidote + chlorite + biotite + phengite + titanite + albite + quartz (metabasalts), and magnesioriebeckite + winchite + actinolite + quartz, occurring exclusively in folded quartz bands within basic metatuffites, while rock matrix consists of chlorite, biotite, phengite, titanite, albite, quartz and hematite. Co-existence of Na and Ca amphibols is considered here as a relic of earlier, higher pressure metamorphic event (greenschist to blueschist transition zone, $p \approx 7\text{-}8$ kbar). During younger phase of metamorphism normal greenschist assemblages occurred (chloritoid in metaplelites and biotite in metabasalts) at a pressures <5 kbar (phengite geobarometry).

Postmetamorphic cooling and retrograde alteration. Postmetamorphic cooling of the Iňačovce-Krichevo Unit is recorded by zircon fission track data. This unit passed through a zircon fission track blocking temperature in Early Miocene (20 ± 0.9 Ma). The structural unroofing and uplift have been accompanied by distinctive processes of retrograde alteration, which occurred on the regional basis. Retrograde processes gave rise to formation of clay minerals incompatible with host mineral assemblages of prograde origin (e.g. chloritoid + kaolinite, biotite + smectite). The most remarkable there is replacement of muscovite, chlorite and chloritoid by kaolinite. Direct precipitation of kaolinite as well as tosudite within microfissures has been also recorded. The appearance of these hydrated minerals can be explained by the reaction of the fluids and prograde minerals (rehydration) at a temperature lower than peak of metamorphism.

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Dispersed organic matter as an indicator of the metamorphic processes - the example of graphites from western tatra crystalline basement

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Introduction

Carbonaceous matter, found in many rocks, represents different stages of graphitisation and differ in physical-chemical properties depending on the temperature of metamorphism as well as on the nature of organic precursors. The temperature is the most important factor of graphitisation, but the pressure – especially stress – needn't to be excluded as the factor controlling the anisotropy of metamorphosed carbon matter. Consequently, the aim of the presented paper is to show the possibility of reconstruction of the metamorphic regime in natural coal-bearing rocks using. Oxyreactive thermal analysis was proved as a good way of identification of the transformation stages of organic matter starting from diagenesis through catagenesis and metagenesis to deep metamorphism (Cebulak et al., 1999). The results obtained by this method are in agreement with data from routine geological investigations. The preliminary results showed the differences between graphites with different organic precursors what should be kept in mind for concluding remarks.

Sampling & Methods

Two generations of graphites from the Western Tatra Mountains: primary graphite (metamorphosed bituminous matter) near the contact with granite intrusion and hydrothermal graphite, coexisting with postmagmatic minerals were the base materials for investigations. We also used standard graphites from the collections of prof. Barbara Kwiecińska and dr John Winchester as well as anthracites and cokes showing different degrees of thermal metamorphism from Upper Silesian Coal Basin, Ukraine and Ireland and synthetic graphites produced in the graphite industry. Samples of cokes and anthracites were taken at different distances from magma intrusions. For all investigated samples we carried out the standard petrographical observations, R_o measurements, Oxyreactive Thermal Analyses (OTA) and for selected samples: scanning microscope images and microprobe analyses of minerals coexisting with graphites.

Results

The microscope and scanning observations of W-Tatra graphites revealed the differences in morphology between primary (G_1) and hydrothermal (G_2) graphites. The first one was dynamically transformed after graphitisation to form case-like structures (in case of ductile deformations) and fine-grained pulp (in case of younger brittle deformations). The hydrothermal graphite flakes were almost not deformed, and are mainly enclosed in the postmagmatic muscovite grains, syngenetic with graphite G_2. The OTA investigations of G_1 graphites showed the peak temperatures in the range of 650-780^{o}C with the maximum of results between 700 and 780^{0}C, what is in agreement with the calculation of metamorphic temperatures in the W-Tatra crystalline basement (Gawęda & Kozłowski, 1998). The hydrothermal G_2 graphites precipitated together with muscovite and albite from the post-magmatic fluid in the temperature range of 700-450^{0}C (Gawęda et al., 1998) what is supported by the peak temperatures in OTA analyses (700-450^{o}C, with exceptional results at 730^{o}C).

Reflectance measurements of G_1 and G_2 graphites showed the linear positive correlation between Rmin and Rmax (correlation coefficient C_c= 0.681) what is an unusual feature in graphitisation process. Such a correlation in typical of coalification process and during graphitisation the negative slope of Rmin versus Rmax is observed. The G_1 graphites are characterised by more linear trend, with weak difference between Rmin and Rmax what suggests that temperature was the predominant factor during graphitisation. G_2 graphites showed higher bireflectance ΔR values and the separate trend. The correlation between Rmin and ΔR is negative with C_c = -0.755. To support the results for W-Tatra graphites we carried out the series of measurements for graphites crystallised in T-dominated regime and we have obtained the same positive trend of Rmax *versus* Rmin (C_c=0.829), as well as the negative trend for ΔR *versus* Rmin (C_c = -0.722).

For natural cokes and anthracites the correlation shows the same trend (Rmax *versus* Rmin C_c = 0.762), but there was no significant correlation between ΔR and Rmin. For the whole population the positive linear trend of Rmax *versus* Rmin is confirmed by C_c=0.911. That is in contradiction with previous studies, but suggests that graphitisation process proceeds in different way in regionally metamorphosed terrains and in near-intrusion circumstances. OTA results of natural cokes and anthracites correlate well with their reflectance measurements and support our suggestion.

The previously published papers suggested that with increasing degree of metamorphism DTA/OTA peaks of graphites shifted to higher temperatures (Diessel & Offler 1975, Kwiecińska & Parachoniak 1975, Kwiecińska 1980). For coals and semianthracites there is a linear function between R_o and temperature of coalification. We checked the possibility of correlation between Rmax and peak temperature during OTA analysis. There is a linear positive correlation again, supported by C_c=0.911, suggesting the T-dependence of both values.

Conclusions

1. In graphite-bearing rocks we could distinguish two populations of graphites, distinguishable by every methods.
2. The graphitisation of the predominant G_1 graphite took place in T-dominated regime, what caused the graphitisation trend was the continuation of coalification. Dynamic metamorphism occurred much later after graphitisation, what is supported by morphology of graphite crystals and high scatter of ΔR in relation to both Rmin and Rmax (irregular distribution of temperature gradient).
3. The hydrothermal graphites precipitated from postmagmatic fluid phase in high temperatures but in P-dominated regime (shearing).
4. There is a linear relationship between Rmax and OTA peak temperature of graphites what suggests that both methods (or one of them) can be used as the indicators of metamorphic conditions. Comparative OTA and reflectance measurements give a background for recognition of coalification and graphitisation processes.

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An overviev on metamorphism of the Western Carpathians

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The Western Carpathians are transversally subdivided into External, Central (Tatra, Vepor and Gemer Belts) and Inner Western Carpathians (Meliata unit, Turna and Silica nappes). Basement units are exposed in the central Western Carpathians and they consists of early Paleozoic volcanosedimentary complexes (mostly paragenesis, micaschists, phyllites and amphibolites) and several suites of Variscan granitoids. The Pre-Alpine basement rocks, exposed in the Tatra Belt, form 9 isolated units: Malé Karpaty, Považský Inovec, Tribeč, Stražovské Vrchy, Žiar, Malá Fatra, Veľká Fatra, Nízke Tatry and in Vysoké Tatry. P-T conditions of Variscan metamorphism correspond mostly to amphibolite facies, however some indications of eclogite facies conditions are also present. Metamorphic P-T conditions of amphibolite to greenschist facies are characterized also for the Vepor Belt. Pre-Alpine metamorphism in the Gemer Belt occurred in greenschist facies conditions, only small amount of amphibolite facies rocks, forming tectonic slices, are present.

Based on metamorphic mineral assemblages in late Paleozoic-Mesozoic sedimentary covers complexes and in granitoid rocks that formed at end of Variscan metamorphic event in the Western Carpathians, Alpine metamorphism in the Tatra Belt reached mostly very low- to low-grade conditions (maximum 300 ^{o}C). Alpine metamorphism in the Vepor belt depend on erosion level, but generally a southeastwards grading to Gemericum is significant. Metamorphic mineral assemblages in the Permian-Mesozoic cover rocks (phengite, chlorite, albite, microcline) indicate temperature of 310-350 °C for the northern part and 400-450 °C and 0.7-0.9 GPa for the southern parts. High-pressure metamorphism for the south Vepor area is assumed by the presence of chloritoid and kyanite in late Paleozoic metasediments as well as by Sps-Grs-Alm garnet in metagranites. ^{40}Ar-^{39}Ar data indicated 105-115 Ma ages for amphibole and 82-89 Ma for white mica. The first age is assumed to represent regional metamorphism and the later is interpreted as a result of uplift and unroofing of the Vepor Belt.

Because of low-grade metamorphism in the Gemer basement during both Pre-Alpine and Alpine events, it is hardly to distinguish mineral assemblages formed by these two events. P-T conditions of Alpine metamorphism can be estimated only from metamorphic minerals in late Paleozoic to Mesozoic cover sequences and in Permian granites that contain metamorphic phengite, chlorite K-feldspar, albite and garnet (1/3 Alm + for 1/3 Sps + 1/3 Grs). P-T conditions estimated using phengite barometry with K-feldspar and garnet indicates pressure of 0.7 GPa at 330 oC. The upper Carboniferous cover rocks at Ochtina in the vicinity of Vepricum are characterized by the presence of phengite, K-feldspar, chlorite, chloritoid for that high-pressure greenschist facies condition is assumed. Ar-Ar data obtained for white mica from the late Paleozoic metasediments gave 86-101 Ma age.

The presence of blueschists, occurring as pebbles in the conglomerates from the Klippen belt or forming slices and blocks in the Meliata units (are evidence of subductions of the Pieniny and Meliata-Hallstatt oceanic crusts and adjacent continental wedge. The Meliata rocks show steeply dipping, generally fan-wise imbricate structure. The most common rock of the Meliata unit are ophiolites associated with deep-see sediments that show very low-grade metamorphic conditions. Protoliths of the blueschists were oceanic, but mainly continental rocks, including basement rocks. ^{40}Ar-^{39}Ar dating both for metabasites and phyllites gave Middle Jurassic age of 151.9 - 155 Ma, but some high-pressure white mica gave also 172 and 222 Ma ages .

The most younger metamorphic event of low-grade conditions (350-400 °C and 0.5-0.7 GPa) occured in pre-Neogene sequences of the the Inačovce-Krichovo Unit. Metamorphic mineral assemblages are phengite, chlorite, albite, paragonite, chloritoid, biotite and actinolite. Postmetamorphic cooling of the Inačovce-Krichevo Unit, recorded by zircon fission track data, was dated of early Miocene time.

(For references see excursion guide)

Thermal aureole at the contact with alaskite intrusion (W. Tatra Mountains, W. Carpathians)

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Geology

The metamorphic basement of the Western Tatra Mountains is composed of two units:

a) Metapelitic Lower Structural Complex (LSC) metamorphosed in greenschist to lower amphibolite facies conditions (P = 5-6 kbar; T = 446-550 ^oC);

b) Upper Structural Complex (USC) composed of metapelites and metabasalts, metamorphosed in upper amphibolite facies conditions (P = 7.5-11 kbar; T = 700-780 ^oC);

Both complexes are divided by a shear zone, filled by leucogranite flat intrusion (Gawęda et al. 1998). The white, equigranular leucogranit is called popularly alaskite (Kreutz 1930, Jaroszewski 1965, Burchart 1970) and is composed of equal proportions of K-feldspars, albite-oligoclase and quartz. Muscovite (2-6 vol.%) is a subordianate mineral, present mainly in border zones Alaskite intrusion is peraluminous in composition and shows the geochemical characteristics of anorogenic/postorogenic granites.

Metapelites within the contact zone are characterised by the ductile S-C fabric and show two generations of foliation: a) S_1 dipping to NW-WNW; b) S_2 dipping to SE-ESE and deforming the older S_1 foliation near the shear zone plane.

Petrography Of Thermal Aureole

A) Progressive metamorphic reactions.

The zone of thermal changes are several meters thick. The main feature observed here is the growth of garnets porphyroclasts and abundant sillimanite mats, as well as the retrogressive muscovites enclosing sillimanite.

Biotite represents a Fe-rich variety (*fm* = 0.608-0.615), with high Ti content (2.56-3.02%wt.), with significant amount of Al in octahedral positions. Oligoclase has typically the An content of 14-20%.

Almandine garnets (1 to 6 mm) growing at the expense of biotite and plagioclase show the significant admixture of Mn, gradually increasing to the margins($Alm_{0.65}Spess_{0.23-24}Py_{0.1}Gros_{0.02}$). The Ca-exchange between garnet and plagioclase did not play any important role, in contradiction to Fe⇔Mg exchange in biotite-garnet pairs. The mineral reactions leading to garnet crystallisation can be written as:

$1.7Bt + 2Pl_1 + 1.35Mn^{+2} + 0.24Na^{+} \Leftrightarrow 2Grt + 2Pl_2 + 1Ms_p + Fe_{1.49}Ti_{0.51}O_3 + 0.58Fe^{+2} + 2.4Mg^{+2} + 0.22\ Ca^{+2} + 1.33K^{+}$ and $Ann + Py \Leftrightarrow Alm + Phl$.

Sillimanite is represented by two generations: a) prismatic sillimanite, growing at the expense of kyanite, found sporadically as the remnants in the centres of the sillimanitic aggregates;

b) fibrolite – as the mats or rock-cork - consuming biotite. In the thin zone (approx. 1cm) from the contact the fibrolite content increased to 6.2 %vol. Two mineral reactions are possible to explain two sillimanite generations: $Ky \Rightarrow Sill_{(p)}$ and $1.3Bt \Rightarrow Sill_{(f)} + 2.9SiO_2 + 0.2TiO_2 + 2Fe^{+2} + 0.45Mg^{+2} + 1.3K^{+}$. The fibrolite mats could be interpreted as the products of metastable reaction with no Al external supply.

The P-T conditions of peak-metamorphism, calculated according to calibration of Hoisch (1990) and Indares and Martignole (1985) are: T = 741(±4)^oC and P = 8.3-8.8 kbar dropping to T = 735(±2)^oC and 7.0-7.4 kbar.

B) Retrogressive metamorphic reactions

Retrogressive reactions had began relatively early (late magmatic stage), at 5-6 kbars of pressure and 680-700^oC (calculation according to Massone and Schreyer 1987), as the result of reaction of progressive minerals with the exsolved fluid phase. The fluid was probably rich in CO_2 and CH_4 (Gawęda & Cebulak 1998) what promote the fluid phase exsolution (Hort 1998). The most widespread reaction was the consumption of sillimanite and K-feldspar and formation of muscovite:

$Sill + Kfs + V_{(H2O + C + Na)} \Rightarrow Ms_s + Q + Gph + Ab$. The remnants of kyanite reacted in a similar way giving rise to abundant muscovite.

Up to 2 kbars the reaction continued along the muscovite stability curve. The muscovite crystals are fringed by the Ms+Q intergrowths, what could be the result of the shift to lower temperatures (Ms+Q stability field).

Hornblende in amphibolites and biotite + plagioclase are replaced by low-Fe epidotes and albite below 500^oC at low pressures (1-2 kbar). The low Fe content in epidotes are typical of low oxygen fugacity conditions, supported by graphite presence.

Conclusions

1. Thermal aureole was restricted to narrow zone (some metres) of metastable reactions leading to enrichment in garnets and sillimanite.
2. Sillimanite $Sill_{(p)}$ crystallisation was controlled by Ky ⇒ Sill transformation.
3. The heating by the alaskite intrusion caused the crystallisation of garnet and fibrolitic sillimanite $Sill_{(f)}$. The rapid loss of volatiles from the alaskite melt resulted in shift of granitic liquidus to higher temperatures and sudden crystallisation of the fine grained alaskite. The released crystallisation heat caused the increase of residual melt temperature to anomalous high values (up to 800°C) and possibly the local disequilibrium mineral reactions.
4. Retrogression, influenced by the exsolved fluid phase, started at the late magmatic phase, at 5.5-6 kbar and 700°C and continued to about 450-500°C at 1-2 kbars of pressure.

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Petrography and metamorphic evolution of the Bódva Valley Ophiolite Complex, NE Hungary

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The dismembered Bódva Valley Ophiolite Complex (BVOC) forms part of the Meliata Unit of the Inner Western Carpathians (Kovács et al., 1996-97). The oceanic slivers of the BVOC represent slices and small (from dm to 100 m in scale) fragments embedded in the ductile Upper Permian Perkupa Evaporite found in the basal part of the non-metamorphic Silica Nappe, which forms the uppermost nappe in the area studied. The Silica Nappe is underlain by the intermediate-high pressure/low temperature metamorphic Torna Nappe and the Paleozoic rocks of the Gemericum (Árkai & Kovács, 1986). The metamafic rocks of the BVOC do not form a single tectonic unit, as they are imbricated with the unmetamorphosed sedimentary sequences of the Silica Nappe. On the basis of sporadic biostratigraphic data from radiolarites synchronous with MORB-type pillow basalts the age of the magmatic crystallization in the BVOC is thought to be Middle Triassic (Dosztály & Józsa, 1992).

The dominant rock type of the studied boreholes is coarse-grained (>5 mm) metagabbro. Its variants exhibit ophitic to subophitic texture, and sometimes grade into medium-grained (1-3 mm) metamicrogabbro or dolerite. Metagabbros and metamicrogabbros consist of clinopyroxene, blue amphibole, actinolite, hornblende, epidote, biotite, albite, chlorite, quartz, titanite, apatite, zircon and Fe-Ti-oxides. In these rocks the association actinolite-hornblende, epidote, chlorite, albite and quartz is the dominant mineral assemblage. Metabasalts show intergranular or intersertal texture, with matrix consisting of chlorite, albite, epidote and opaque minerals. Replacing phenocrysts and filling amygdules we can find abundant chlorite, calcite, minor albite, epidote and biotite. The metabasalts are cut by numerous veins filled by usually actinolite-calcite, and rarely we found calcite-epidote-chlorite assemblage as well. The metabasalt complex sometimes grade into metamicrogabbros or cut them. In the albitite veins additionally to albite and chlorite; phengite, K-feldspar and chloritoid were also found with apatite as an accessory phase. Aggregates of chloritoid and matrix phengite seem to be in equilibrium with each other, while chlorite and K-feldspar were found in the albite-rich matrix. Albitites are present only in the Komjáti-11 borehole.

Relic Na-amphiboles (crossite and Mg-riebeckite) and Ca-Na-amphiboles (winchite) were found in the Komjáti gabbros (Horváth, 1997). The metamorphic Ca-amphiboles from the Szögliget gabbros are edenitic hornblende or magnesio-hornblende, while the Komjáti amphiboles fall into the actinolite or magnesio-hornblende field. The amphibole analyses from the Tornakápolna basalts plot into the actinolite field (Leake, 1978).

The first recognizable, blueschist facies event (min. 7-8 kbar, 350-500 ^{O}C) was followed by nearly isothermal decompression to 4-6 kbar in the greenschist facies (Horváth, 1997). The following metamorphic event was characterized by temperature increase up to 500-600 ^{O}C in isobaric conditions to the albite-epidote-amphibolite facies (Evans, 1990). The P-T path is described by subduction, which was followed by uplift without any significant change in the temperature conditions. The late temperature increase was caused by isothermal relaxation following subduction.

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Normal versus inverted tectono-metamorphic zonation, in pre-Alpine metamophic terranes; a cas study, South Carpathians, Romania

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The metamorphosed rock assemblages of Paleozoic and Proterozoic age in the basement units of the South Carpathians crop out in two different alpine nappe systems: Danubian and Getic-Supragetic.

- The main types of metamorphosed protoliths are: Paleozoic prograde metamorphosed lithological rock sequences (preserved in both, Danubian and Getic-Supragetic realms); Proterozoic polymetamorphic medium-grade rock-assemblages (documented in the Danubian basement); Paleozoic-Proterozoic (undated, unseparated) polymetamorphic medium to high-grade rock-assemblages (gneissic terranes, in the Getic-Supragetic basement).

- Other general separation can be realised having in wiew: general features of the metamorphic evolution, physical conditions and timing of the metamorphic history, using the relative and known absolute ages of the tectono-metamorphic events.

A first cartographical image of the pre-Alpine metamorphism distribution include:

1.Prograde, anchizone to green schist facies (low grade) metamorphism in Paleozoic formations, partly preserving their sedimentary or magmatic protolith mineralogy and structures; the age of metamorphism is Variscan; sometimes pre-metamorphic unconformities are preserved.

2.Prograde-retrograde, polystage metamorphism in green schists to epidot-amphibolite facies conditions of Lower (?) Paleozoic rock complexes; some documented ages of the last tectono-metamorphic events correspond to Variscan history.

3.Polymetamorphic (poly-stage / poly-orogenic) metamorphism of the Proterozoic and/or Paleozoic rock-complexes, whose metamorphic histories can be attributed to two tectono-metamorphic and orogenic cycles: pan-African, for the main litho-tectonic units of the Danubian basement (Dragsan and Lainici-Paius); (Berza, 1978; Liegeois et al., 1996); pan-African+Paleozoic reactivation, for the upper Danubian basement; Cadomian+Variscan for the main litho-tectonic units of the Getic-Supragetic basement (Cumpana, Sebes, Lotru, Fagaras, Ursu), (Iancu et al., 1998).

The aim of this paper is to present the petrological criteria in descyfering the effects of the tectonical processes in case of an apparent metamorphic zonation in metamorphic terranes, for which a “tectono-metamorphic zonation” is proposed as discriminant therminology in respect with classical prograde metamorphic zonation in metamorphic facies series.

The apparent metamorphic zonation is, in some areas of the South Carpathians, an effect of tectonical relationships; a downgrade or a upgrade change in the physical parameters of the peak metamorphic conditions is observed acros the limits of different litho-tectonic units, generally separated by blastomylonitic rocks (simple shear zones), giving a false metamorphic zonality. Some isolated areas preserve true metamorphic zonation (Hartopanu, 1986) in the getic basement.

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HP/LT metamorphosed basic rocks of the Bôrka Nappe (inner Western Carpathians): their protolith, geodynamic setting and metamorphic evolution

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The Bôrka Nappe, a newly defined tectonic unit in the inner Western Carpathians (Mello et al., 1996), represents a HP/LT metamorphosed part of an ancient accretionary prism formed by closing of the Meliata-Hallstatt ocean to the end of the Jurassic period. The Bôrka Nappe is recently lithostratigraphically divided into three formations. The (1)Jasov and (2)Bučina Formations, probably Permian in age, are composed of metamorphosed clastic sediments and volcaniclastic rocks. The (3) Dúbrava Formation, supposed to be Mesozoic in age, contains metamorphosed sedimentary and basic magmatic rocks.

The basic rocks of the Bôrka Nappe do not represent a homogeneous group. Our study of relic primary textures as well as geochemical and petrological characteristics indicate that following five groups of HP/LT metamorphosed basic rocks with the differences in protolith, geochemical signature and metamorphic evolution can be recognized in the Dúbrava Formation:

(1) Basalts, dolerites and gabbros with BABB (back-arc basin basalt) to N-MORB (normal oceanic-ridge basalt) affinity transformed into epidote-glaucophane rocks with variable amounts of Na-pyroxene (acmite), clinozoisite, albite, white mica and garnet. Basalts originally formed lava flows with glassy or lava breccia rinds as follows from preserved relic variolitic, intersertal or ophitic textures as well as findings of former autoclastic and hyaloclastic breccia. Some basalts erupted in carbonatic environment, the others seem to be spatially connected with pelitic sedimentation. Basalts experienced progressive metamorphic evolution from prehnite-pumpellyite through greenschist to epidote blueschist facies conditions. Vestiges of an ocean-ridge type metamorphism strong overprinted by HP/LT metamorphic event were found in the dolerites and gabbros.

(2) Dolerites and basalts with BABB signature originally metamorphosed to the epidote blueschists and latter retrogressed to greenschist facies conditions. Riebeckite, Na-bearing actinolite epidote, chlorite, albite, leucoxene and small octaeders of magnetite are typical mineral assemblage. Relics of doleritic, ophitic or intersertal textures are still preserved. Some basalts are accompanied by red metamorphosed cherts or radiolarites. The basalts of this group seem to be also spatially connected with metacarbonates and pelitic metasediments.

(3) Basalts, rarely gabbrodolerites with CAB (calc-alkaline basalt) affinity experienced at least two stage metamorphism, where older metamorphic stage in epidote-amphibolite facies conditions was overprinted by HP/LT event producing blueschists with variable amounts of pale-colored glaucophane replacing bluish-green amphibole (edenite) and also containing epidote/clinozoisite, garnet, white mica, chlorite and rutile concentrically rimmed by ilmentite and titanite. Relics of porphyric, ophititic or gabbrodoleritic textures are poorly preserved in some samples. Metavolcanic rocks of this group are a part of volcano-sedimentary sequence included also black pelitic sediments and volcaniclastics transformed by multi-stage metamorphism into variable types of phyllites.

(4) Banded basaltic volcaniclastics with calc-alkaline signature retrogressed from high- or medium-pressure metamorphic conditions to the low-pressure greenschists of actinolite-chlorite-epidote-albite composition with small magnetite octaeders. Greenschists occure in association with white banded marbles.

(5) Amphibolites, mostly phyllonitized, geochemically close to N-MORB with HP/LT metamorphic overprint and usually retrogressed by hydrothermal activity again to greenschist facies conditions. The best preserved samples of amphibolites are composed of plagioclase and brown to green-brown hornblende rimmed by sodic amphibole. Beside amphibolites also garnet-hornblende gneisses as protolith of this group of rocks has been found (Faryad, 1988).

All above-mentioned different groups of basic rocks associated with specific types of metamorphosed sedimentary rocks occure in the separate areas of the Bôrka Nappe. This implies that the Dúbrava Formation is, in fact, composed of several individual lithostratigraphic formations in the form of slices with mutual tectonic contacts and the Bôrka Nappe as a whole does not represent uniform tectonic unit but a nappe pile with complicated tectonic history. Based on the lithology, geodynamic setting and tectonometamorphic evolution these formations could be divided into two essential types: (1) material of the subducted slab of the Meliata-Hallstatt ocean and (2) material of the overriding lithospheric plate immediately above subducting oceanic slab. Former type is represented by metamorphosed basaltic rocks with BABB to N-MORB affinity (Groups 1 and 2). Their association with carbonates, pelitic schists and only rare radiolarites indicates an immature back arc basin as a setting of origin of the subducted oceanic crust. All rocks in these groups are probably Mesozoic in age. The latter type includes basaltic rocks and associated sediments, both Paleozoic in age, where HP/LT metamorphic event was preceded by epidote-amphibolite or amphibolite facies of metamorphism (Groups 3, 4 and 5). They indicate that the Meliata-Hallstatt ocean was subducted beneath terrain composed of a crust of the magmatic arc origin with evolved deeper crustal metamorphic basement. It follows from the calc-alkaline signature of metavolcanic rocks and from the presence of high-grade metamorphic rocks - amphibolites and gneisses.

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Some consequences of the Branisko and Čierna hora structure to evolution of adjoining units of the Western Carpathians

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Branisko and Čierna hora Mts. (B-Čh) are the most eastern morphostructures of the Central Western Carpathians (CWC) containing representative lithostructural units of both Variscan and Alpine orogenic cycles. Their pre-Alpine edifice consists of two structural levels. The Early – Carboniferous one comprises two basement nappe sheets of the CWC namely: the Upper lithotectonic unit (ULU) and the Middle lithotectonic unit (MLU). Molasse formations of the Late-Variscan level (i.e. Late Carboniferous and Permian sequences) are completely developed in the Čierna Mts. only. The paleo-Alpine (i.e. pre-gossau) structural level consists of Early-Triassic to Malmian formations. Post-orogenic Paleogene sequences transgressively overlay the all mentioned structural units. Cover and/or basement units of the B-Čh are overridden by the Choč nappe formations. Southwesterly dipping the Margcany shear zone (MSZ) forms an expressive tectonic boundary towards adjoining Gemericum unit.

In comparison to other morphostructural domains of the CWC both the Variscan and Alpine units of the region reveal some peculiarities which caused difficulties even in such principal questions as to which the Alpine paleogeographic realm -–i. e. Tatric and/or Veporic one belong the morphostructures. The next problem arising through researches of the region is: - how many essential paleo-Alpine units of the CWC participate on the structure of the region - four (i.e. Tatricum, Veporicum, Fatricum, Hronicum and or Gemericum in the last case),- three (i.e. Tatricum, Veporicum and Hronicum) – or only two (i.e. Veporicum and Hronicum). The last up to now unsolved question is a cause and time specification of paleo-Alpine structures rotation in this and adjoining Gemeric region into NW-SE direction. These problems and relationships of the region to other CWC domains could by perhaps explained by a reevaluation of basic features of its Variscan and Alpine structure.

Indicative evidences of the Variscan structure of the Branisko and Čierna hora Mts.

Similarly like in others morphostructures of the CWC (e.g. Tatra Mts., Považský Inovec Mts., Vepor Mts.) the Early – Carboniferous structure of the region consist of two representative basement nappe sheets of the CWC, i.e. the ULU and MLU. That means the discussed Variscan edifice of the B-Čh realm is the same as in the decisive part of the Tatra-Fatra belt. The final nappe emplacement of the ULU over MLU (exactly dated from this region only) have been completed during Early-Carboniferous (330 – 312 Ma).

The same time interval and southern vergency as well, results for overriding of Klatov nappe sheet over Rakovec group in the adjoining Gemericum unit (geological data). Because Carboniferous conglomerates of Gemericum cover formation contain pebbles of both Gemericum and Tatra-Fatra basement rocks both the units had to be proximately connected already in this time. If a protolith of the Klatov nappe amphibolite facies rocks shows a clearly different geodynamic setting than ULU metabasites of the Tatra-Fatra belt, it is probably to suppose a hereditary impact of the Klatov nappe suture for a later location of Jaklovce branch of the Meliata trough.

Both a presence of cover Late-Carboniferous sequence at the NE flank of the Čierna hora basement complexes (by the way the only occurrence of the sequence in the northern Veporic zone) and a common. Permian acidic volcanizm throughout the northern Veporic zone clearly indicate a generally accepted possibility of Fatric sedimentary trough creation within the main Late – Variscan extensional structures. Examples of such relationships are also well known from southern parts of the Western Carpathians.

On exclusive rock presence of both the ULU a MLU in the pebbles of Late – Carboniferous cover sequence of the Čierna hora area also indicate a rapid Late – Carboniferous uplift and structuralization of the basement and confirm geologically the pre-Late-Carboniferous stacking of the basement nappe piles as well. Both frequent secretional quartz veins in diaphtorites of the MLU, (folded into paleo-Alpine recumbent folds) and their common pebbles in Late-Carboniferous conglomerates clarify a source question of the rocks and confirm geologically a presence of strong the Late Variscan diaphtoresis of the MLU.

Selected problems of the Alpine structure of the Branisko and Čierna hora Mts.

Despite very strong influence of the region by Alpine tectonometamorphic events it is-at least lithostratigraphically, possible to compare all its units with corresponding ones in the CWC realm. From this point of view it is without doubt that the upper basement sheet in B-Čh Mts. is formed by the ULU. This reality however at least doubts the dividing of the area into Tatric and Veporic paleogeographical realms. Variscan basement nature seems not to be a reliable criterion for dividing of Alpine paleogeographical realms within the Fatra – Tatra belt.

If we take into consideration above mentioned hereditary influence of Late – Paleozoic basinal structures on to homeland areas of the Tatric and Veporic units than – in B – Čh region, is necessary to drown their boundary (and the Križná nappe root zone as well) at least at the NE edge of the Late-Paleozoic formations of the Čierna hora Mts. However, Mesozoic Early-Triassic to Malmian formations on both i.e. northern and southern side from the mentioned bounder are in clear subautochtonous position and they have the same lithostratigraphy. The next possibility for emplacement of Križná nappe root zone is northern part of the Branisko Mts. The Križná nappe root zone (i.e. the eastern pendant of Čertovica „line“) is probably covered by the Choč nappe pile which build up the northern edge of the Branisko Mts. The foregoing discussion results to conclusion that also from Alpine structure point of view both morphostructures i.e. Branisko and Čierna hora Mts. mast probably belong to the Veporic zone of the CWC.

The only remaining question is to which-northern or southern, Veporic zone belong the Late Paleozoic and Mesozoic cover formations of both discussed mountains. As it has been mentioned above throughout the whole northern Veporic zone the Late-Carboniferous sequences is present only at SE flank of Čierna hora Mts. basement. Furthermore, Permian sequences continually, without lithological changes overlap the basement units of the Čierna hora Mts. – they evidently belong to the same formation. Mesozoic cover formations (except of northern part of the Branisko Mts. where only Early-Triassic cover is probably present) have in the whole SE-SW cross-section nearly the same lithostratigraphy. Furthermore their Triassic sequences contain typical Carpathian-keuper formation and even Lunz beds. The mentioned problem arises from generally accepted idea that Carpathian-keuper formation is characteristic for Mesozoic cover of the northern Veporic zone only. If we accept this idea than it is necessary to take into consideration an oblique cut-off of the central and southern Veporic units at the distance at least of 70 km (at present coordinates).

The last essential problem of this region and adjoining Gemeric unit is diagonal (i.e. NW-SE) orientation of the paleo-Alpine structures in comparison with analogous ones in other domains of the CWC. Presently it is necessary to point out that this orientation has been finished before the Intra Carpathian Paleogene sedimentation. Its flysh formations transgressively overlap the structures. Because paleo-Alpine nappe stacking and directional shear zones in this region have been completed during the Early Cretaceous it is most probable that their present NW-SE orientation connects with the Late-Cretaceous unroofing of the Veporic metamorphic dome. It is also possible that these processes contributed to opening of spatially extensive Eastern Slovakian Intra-Carpathian Paleogene basin having in this territory maximal thickness of its formations.

Comparison of LT/HP metamorphic rock sequences from the Mesozoic units of the Eastern Alps

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In the Mesozoic rocks of the Penninic zone of the Eastern Alps remnants of a LT/HP metamorphic event are widespread and were investigated by various research groups since a long time. A similar LT/HP event was reported from the “Tarntal Mountains” in the Lower Austroalpine nappe more recently by Dingeldey et al.

(1997). A comparison of both high pressure units, the Penninic windows and the Mesozoic rocks of the Lower Austroalpine nappe, show significant differences in their lithology.

The Penninic realm, widely distributed in the Western and Central Alps can be followed along a series of windows across the whole range of the Eastern Alps. These are, from the W to the E the Lower Engadin Window (LEW), the Tauern Window (TW) and a group of small windows at the eastern margin of the Alps called the Rechnitz Window Group (RWG) (Höck & Koller, 1989; Koller & Höck, 1990). The Rhenodanubian Flyschzone is also ascribed to the Penninic realm (e.g. Oberhauser, 1995) but not considered here further in terms of metamorphism.

Stratigraphically, the metamorphics in the Penninic Mesozoic units range from the Trias (?) to the Paleogene. They contain Triassic quarzites, marbles and dolomites as well as Jurassic and Cretaceous phyllites, micaschists, calcmicaschists and other metasediments, several well developed MORB-type ophiolites and non-ophiolitic volcanics throughout all Penninic windows. The upper stratigraphic boundary of the Mesozoic to Cenozoic sequences is still under discussion. Late Cretaceous and Paleogene sediments are proven from the LEW (Oberhauser, 1995), Early Cretaceous from the TW (Reitz et al., 1990) and the RWG (Pahr, 1980). The occurrence of Late Cretaceous and Tertiary sediments in the more easterly windows are questionable.

Two metamorphic events are recognizable in all Pennic windows where the older is regarded as the HP/LT metamorphism and the younger of Barrovian type, an earlier eclogite facies event is only reported from the Tauern window. The PT conditions of the formation of eclogite are fairly well established within the analytical error and the errors of the different geobarometers used. The eclogitized metabasics and metasediments passed through a mantle/crust segment in a depth of 70 km (possibly 85 km according to Stöckhert et al., 1997). With Tmax around 600 °C they formed in an array of a very low geothermal gradient of 7 – 9 °C/km typical for subduction zones. It should be noted here that only the structurally lowest part of the Mesozoic sediments and volcanics underwent the eclogite metamorphism.

Whereas the PT conditions are well constraint no dating of the eclogites is available yet. If the $^{40}Ar/^{39}Ar$ data of Zimmermann et al. (1994) are valid for the blueschist event the eclogite formation has to be earlier than the Eocene/Oligocene boundary. It was believed to have taken place in the Cretaceous but any positive proof for that is missing. On the other hand U/Pb zircon dating of eclogites in the Central Alps (Gebauer et al., 1992) indicates at least for some eclogites a formation close to the Eocene/Oligocene boundary. Whether this applies also to the Tauern eclogites remains a problem to be solved in the future.

The blueschist event is neither well constraint in respect to the PT path, nor with age dating. Only for the TW the data by Zimmermann et al. (1994) suggest an age of late Eocene - early Oligocene of the formation of the blueschist assemblages. For the eclogitic rocks the HP/LT event is a stage of cooling and uplift from 70 - 85 km to 35 - 40 km. This corresponds to the subduction of other sediments and metavolcanics structurally above the eclogite zone to the same depth and an according heating to 400 - 450C. Again the low thermal gradient of 10 – 13 °C/km suggests a subduction zone bringing down most of the ophiolites and metasediments of their structural position below the ophiolites.

The HP/LT remnants in the LEW and RWG record somewhat lower pressure and lower temperature compared with the TW but indicate also an subduction zone along the same low thermal gradient around 10 – 12 °C/km. In the LEW mostly the deeper parts (North Penninic metasediments) are metamorphosed in blueschist facies, for the ophiolites a proof of a HP/LT metamorphism is missing. In the RWG the ophiolites indicate clearly the blueschist event, the metasediments below and above the ophiolites are not investigated. Therefore, the question Whether the blueschist event is synchronous throughout the Pennninic realm in the Eastern Alps and its range is an unsolved problem.

The Lower Austroalpine Nappe at the rim of the Tauern Window covers it the NW ("Tarntal" mountains) and NE Radstädter Tauern) the Penninic rocks of the Tauern Window. The tectonic succession consists according to Tollmann (1977) in the NW of the Tauern window of three individual nappes. From the base to the top they are the Paleozoic Innsbrucker quartzphyllite nappe, the Mesozoic Hippold and Reckner nappe. The Hippold and Reckner nappe are built up by a huge variety of partly fossil bearing Mesozoic sediment sequences from Skyth to Malm ages (Enzenberg, 1967; Enzenberg-Prähauser, 1976). The top of the Reckner nappe is formed by the serpentinites representing a not depleted mantle fragment and thin blueschist horizons defined as Reckner complex by Dingeldey et al. (1997). For both, Reckner and Hippold nappe a Tertiary HP/LT event in the range of ~350 C and ~10 kbar has been reported by Dingeldey et al. (1997). Typical minerals of this event are alkalipyroxens (<$Jd_{37}Ac_{50}$), Mg rich pumpellyite [$Fe_{tot}/(Fe_{tot}+Mg) = 0.05$], stilpnomelane, high Si phengite (<3.65). The to the Hippold nappe adjoined Penninic metasediments exhibit only intermediate pressure conditions (6 - 7 kbar).

The equivalences and differences in the typical profiles of the two tectonic units and the contrasting style of LT/HP rocks of the Penninic zone and of the Lower Austroalpine unit will be discussed in detail.

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New petrological data on the metamorphic evolution of the Veporic crystalline basement, Northern Hungary

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In the late '60-ies and early 70-ies hydrocarbon-prospecting boreholes exposed crystalline basement rocks below the Tertiary sedimentary cover north of the Börzsöny and Cserhát Mts., very close to the Slovakian border. Later, these rocks were investigated by Ivancsics and Kisházi (1982) from a petrographic point of view and also some X-ray diffraction analyses were performed but no other detailed petrological data have been available since that time.

The aim of this study is to present the first results of our new detailed mineralogical and petrological investigations from these boreholes. Essentially, the crystalline rocks can be divided in two main lithological groups:

1. Garnet-bearing gneisses and associated micaschists. This group represents the predominant mass of the exposed crystalline basement both in the investigated boreholes and in other ones in their surroundings. Mineral assemblage of this group includes garnet, biotite, plagioclase, quartz, white mica, chlorite, opaque minerals, rutile, tourmaline, zircone and apatite.

2. "Greenschists", which comprise generally strongly retrogressed amphibolites, actinolite-chlorite-biotite schists and chlorite schists. These rocks form relatively thin layers or lenses in the gneisses. Garnet is much less abundant here than in the first group. These lithologies are characterized by garnet, amphibole, plagioclase (albite-oligoclase), quartz, chlorite, epidote, (clino)zoisite, biotite, white mica, carbonate, titanite and Fe-Ti oxides. Due to strong retrograde overprint chloritization of earlier formed metamorphic minerals is very widespread in the investigated rocks.

Microfabrics indicate intense ductile deformation in both groups: quartz shows crystallplastic deformation with well-developed lattice preferred orientation in the gneisses, whereas feldspar displays essentially brittle, cataclastic behaviour, suggesting a temperature range between c. 300-450°C during ductile deformation. On the contrary, feldspar is often dinamically recrystallized in the "greenschists" that indicates deformation temperature over c. 450°C. Ductile fabrics are overprinted in both groups by (semi-)brittle structures, generally in the form of steep faults and fractures that are accompanied by well-developed cataclasites in many cases.

According to the microprobe investigations, garnets display complex chemical zoning in both lithological groups. They show two-stage growth that is reflected in the appearance of a thin, chemically different rim around the core regions. This zoned character does not appear in all cases: both small, idiomorphic garnets with "rim-composition" and larger grains without rim-overgrowth are present. Similar, zoned garnets were reported by Kováèik et al. (1997) from the southern Veporic basement. The discontinous character of the garnet-zoning displays a complex metamorphic history of these rocks: the garnet cores most probably represent relicts of a previous metamorphic event (probably Variscan).

Detailed microprobe measurements were carried out on the garnet-amphibolites. Garnet cores are dominated by almandine, but considerable amount of grossular is also present (X-Alm: 57-65%, X-Pyr: 7-10%, X-Gros: 20-30%, X-Spes: 4-5%). The most distinctive feature of the rim is the relatively high spessartine content (X-Spes>10%), whereas that of almandine and pyrope is somewhat lower, grossular does not show significant change. Amphiboles have a very uniform tschermakitic-hornblende composition according to the nomenclature of Leake (1987). Plagioclase displays a rather variable An content (X-An: 0 to 30%) that is most probably due to the strong retrogression. The more basic compositions might refer to the higher-temperature conditions of the metamorphism.

Garnet-amphibole thermometry (Graham and Powell, 1984) yields temperatures between 430-480ºC very consistently (with garnet rims), indicating greenschist facies metamorphic conditions that may represent slightly resetted temperatures after the peak of metamorphism. Considering the more basic plagioclase compositions (oligoclase) an approx. range of c. 500-530ºC and 7-8 kbar can be estimated for peak metamorphic conditions using the method of Plyusnina (1982). Based on the new geochronological data from these rocks (see Balogh et al., this vol.), we argue for the Alpine age of this Barrovian-type metamorphic event that must have reached about 500ºC, that is also pointed out by the geochronological data (Alpine age of amphiboles).

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Low-grade metamorphism of mesozoic cover rocks from the veporic unit, Western Carpathians: phyllosilicates study and new illite-chlorite crystallinity data

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The Veporic superunit is the middle of three thick-skinned basement thrust sheets of the Central Western Carpathians (CWC). The imbricated crustal structure of the CWC originated during the Cretaceous continental collision after the Late Jurassic closure of the Meliata ocean. As a consequence of collisional thickening, the Veporic basement and its Permian-Mesozoic cover suffered regional Alpine metamorphism.

Metamorphic conditions of Mesozoic metasedimentary cover rocks (metaquartzites, metapelites, and metacarbonates) were evaluated by Kübller index (crystallinity) of white mica and chlorite. X-ray diffractograms were made from < 2µm clay fraction of illite-muscovite ± chlorite concentrates as oriented slides (diffractometer Siemens D-5000, Univ.Basel). Illite and chlorite crystallinity data (IC, ChC) were calculated from more than 30 samples using the EVA MFC Application, DIFRACPlus evaluation program and Profile plus v. 1.06, DIFRACPlus software.

Diffraction maximum for first basal reflex of white mica is well developed with narrow width, documenting high crystallization degree of mica crystals. Correlation between white mica full width at half maximum of diffraction maximum 001 (FWHM) and chlorite 002 FWHM, in samples containing both phases, points to epizonal (subgreenschist to greenschist facies) metamorphic conditions.

Our results suggest that Mesozoic cover rocks in the Veporic unit have been metamorphosed at upper anchizonal and epizonal (greenschist facies) metamorphic conditions. Alpine metamorphism caused total recrystallization of former clay minerals and the growth of newly formed white mica and chlorite. These data point to Alpine regional metamorphism increasing from the Mesozoic cover to underlying Upper Paleozoic and basement rocks in the Veporic unit (Lupták et al., 1998; Janák et al., 1999; Plašienka et al., 1999).

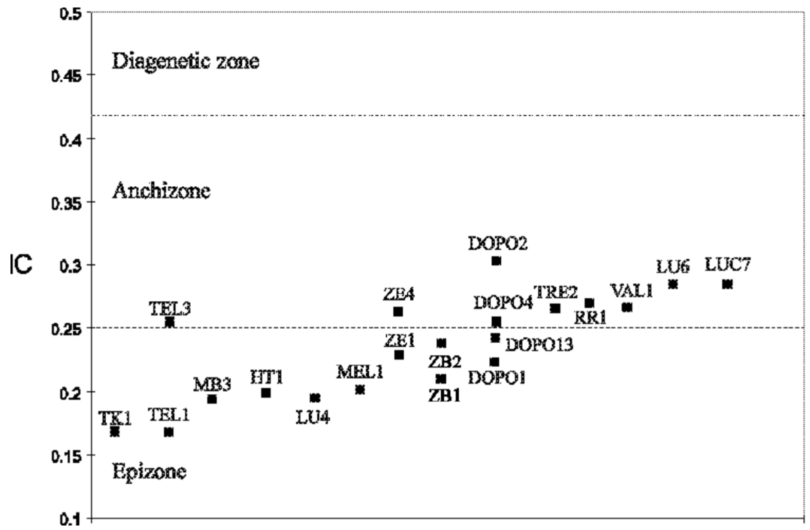

Fig.1: Illite crystallinity data from the Mesozoic cover rocks of the Veporic unit.

Chemical compositions of phyllosilicates were investigated by electron microprobe JEOL 8600 (Univ.Basel). Authigenic white mica in metaquartzites and metapelites is mostly phengitic. In the metacarbonates of dolomitic origin, phyllosilicates are represented mainly by chlorite.

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Microfabrics, kinematics and differential stresses at the eastern contact zone of Gemericum with Veporicum (the Košice-Diana locality, Western Carpathians)

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Introduction

Contribution presents the results of microtectonic studies of three marble and three quartzite samples from the Diana locality, 8 km to NW of Košice. The samples representing the cover of Veporicum, come from tectonic contact with overlying Gemericum (Lubeník line). Oriented samples were studied in cuts parallel with XZ plane using Siemens D500 reflection X-ray texture goniometer (Putiš et al., in print), U-stage microscope (Németh and Putiš, in print) and there was, for the first time in the Western Carpathians, made an attempt to define differential stresses by the application of paleopiezometry (l.c.).

The quartzite samples are assigned to Lower Triassic cover of Veporicum (Lúžna Fm., Polák and Jacko, eds., 1996); whereas the age and position of studied marble is interpreted manifoldly (Late Paleozoic?-Triassic? of Gemericum, Grecula, 1994; Upper Jurassic of Veporic cover, Polák and Jacko, eds., 1996). Field observations led authors of this contribution to affiliate the marbles on Diana locality to Triassic, and together with Lower Triassic quartzites they remember the Foederata cover of the Veporic basement. This idea supports the recent view about analogy of a part of Ružín sequence with Foederata (Struženík) succession (Jacko et al. in Polák, ed., 1996).

The microfabrics and results of the X-ray texture goniometry and U-stage measurements

The quartzites contain dynamically recrystallized flattened grains, often obliquelly oriented to metamorphic/mylonitic foliation. Low viscosity contrast between quartz-clasts and quartzose matrix is observable according to stretched and strongly dynamically recrystallized clasts without any sharp boundaries to matrix. Few present clasts of feldspars behaved as a brittle phase. Textural patterns (Putis et al., in press) document dislocation creep on basal <a> and less prism <a> and a rhomb glide systems at temperatures 400 - 500 °C. Asymmetry of patterns and the newly-formed (dynamically recrystallized) grains to S-foliation indicate a top-to-the E transport of the upper segment, dipping to the S.

The calcite marbles show alternation of layers: with dynamic recrystallization predominant (medium to fine-grained) and those with flattened, elongated (originally metamorphic) grains with e-twinning predominant over dynamic recrystallization along the grain boundaries (core-mantle structures). The textural patterns (l.c.) reflect both combined dislocation creep and mechanical e-twinning as the plastic deformation mechanisms. Sinistral traspression regime was predominant during the final microfabric development, like in quartzites.

The results of the paleopiezometry

In quartzites there was measured the size of dynamically recrystallized homogeneous quartz grains, within believing a steady-state microstructural domains (the layers parallel to C-planes). The thin sections were oriented parallel to the XZ fabric planes. To mitigate an effect of over- or underestimation of the grain sizes, we used the average of the length and width measurements as the apparent grain size. The differential stress was determined using diagram after Michibayashi (1993), where three calibrated lines Koch (1983), Twiss (1977) and Mercier et al. (1977) were taken into account. With respect to other microtectonic findings we suppose geologically most meaningful the results obtained by Koch (1983) callibration: di9-qtz 151.3 MPa, di10-qtz 195.0 MPa and di12-qtz 169.8 Mpa. These values are the most consistent with the following ones from the marbles.

Differential stresses in the marbles were determined using methodics of twinning incidence and twin density by Rowe and Rutter (1990). When calculating twin density, data were corrected using coefficient of variation below 0.25 (Ranalli, 1984). The results of differential stress in individual samples, obtained with calculating both twinning incidence and twin density were: di1-cc 255.3 MPa and 247,1 MPa, di2-cc 223.2 MPa and 232.4 MPa as well as di3-cc 222.8 MPa and 228.3 MPa.

Conclusion

The development of the western contact zone of Veporicum with Gemericum of the normal-fault character (Hók et al., 1993) appears to be contemporary with sinistral transpression/transtension at the eastern part of this boundary zone. In general, southeastern sliding of the Gemeric Nappe Complex from the Veporic One is the result of Mid- to Late Cretaceous updoming of the Veporic core complex in the NW.

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Fluids in Quartz from Central Bosnia, Indicators of Alpine Retrogressive Metamorphism

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Basic geological data

The Middle Bosnian Schist Mountains (MBSM) are a part of the Central Dinarides. The most widespread rocks of the MBSM are pre-Devonian metamorphic rocks (Hrvatovič,1996). Crystallization age of these rocks obtained by K-Ar dating is 343 ± 13 Ma (Palinkaš et al., 1996). Majer et al. (1991) proved that they were formed by low grade metamorphism at 350^o-400^oC and pressure of 3-5 kbars. Fossiliferous Devonian carbonate rocks overlie this metamorphic complex. Only in some parts of the MBSM, Lower Carboniferous marine facies is developed. The uplift of this area started in connection with the Hercynian orogeny and related extrusions and subvolcanic intrusions of rhyolites (Jurkovič & Majer, 1954). Upper Permian continental and lagoonal deposits which overlie unconformably on older Palaeozoic rocks, grade into Lower and Middle Triassic sediments. The main phase of Tethyan rifting was recorded during the Ladinian (Pamič, 1984). The plutonic/hypabissal rocks occur as minor intrusions and stocks of diorite, minor gabbro, syenite, albite granite (Radovan Mt.). Volcanic rocks are represented by basalt, spilite, andesite, keratophyre, dacite and pyroclastics. The opening of the Tethyan ocean took place during Upper Triassic and most of Jurassic, the subduction at the very end of the Jurassic and the uplift of the Dinarides during the Pyrenean phase (Pamič and Jurkovič, 1997).

Object of the study

The metamorphic terrains of MBSM are cut by numerous quartz veins of diverse origin. The objects of the study were: **A**. typical Alpine-q-veins with quartz, hyalophane, siderite, albite, rutile and sporadic pyrite, anatase, hematite and apatite ; **B.** Q-veins related to hydrothermal mineralization in the Čemernica ore deposit, consisting of quartz (50-95 % of ore mass), antimonite, sphalerite and cinnabar. Subordinate are chalcedony, siderite, ferberite, jamesonite, berthierite, boulangerite and arsenopyrite.

Microthermometry

A. Microthermometry of the Alpine-quartz veins recognized following inclusions in quartz:

1. (L_{H2O}+L_{CO2}+V), 2. (L_{H2O}+L_{CO2}), 3. (L_{H2O}+L_{CO2}+V+S_1), 4. (L_{H2O}+L_{CO2}+V+S_1+S_2), 5. Solid inclusions. In hyalophane: 1. (L_{H2O}+L_{CO2}+V), 2. (L_{H2O}+L_{CO2}), 3. (L_{H2O}+L_{CO2}+V+S_1+S_2), 4. Solid inclusions. Thermometry and

cryometry give following data: $T_{FM}CO_2$ = -60.0° to -57.2°C; $T_{LM}CO_2$ = -58.1° to -56.5°C, T_{LM}ICE = -11.7° to -4.0°C, T_{LM}CLATHRATE = +2.5° to +6.2°C. CO_2 phase homogenizes into liquid phase, T_HCO_2 = +14.6° to +29.2°C, T_HTOT = +300° to +322°C. Salinity (determined by clathrate melting temperature), 6.6 to 13.5 wt% NaCl equ.

B. In the ore bearing quartz veins, from Čemernica ore deposit, fluid inclusions can be classified as:

1. NaCl - KCl - H_2O (L+V), Te = -25°C, T_{LM}ICE = -16.6°C, salinity 14.9 - 20.2 wt% NaCl equ., T_H = 150°C to 230°C, with maximum at 190°C. 2. NaCl - H_2O (L+V); with presence of divalent cations, Te = - 31.2°C, salinity, average 16.9 wt% NaCl equ., average T_H = 330°C. 3. H_2O - NaCl - CO_2 (L_{H2O}+L_{CO2}+V), $T_{FM}CO_2$ = -80°C (majority, however melted between -61°C and -64°C; presence of CH_4, N_2), T_{LM}ICE = -7°C to -13°C, T_{LM}CLATHRATE = +3.9°C to +5.5°C, salinity 9.4 to 10.7 wt% NaCl equ., T_HCO_2 = +26°C to +28°C, density CO_2 = 0.76 to 0.33 gcm^{-3}. Homogenization proceeds L+V $\rightarrow$ V and L+V $\rightarrow$ L.

K/Ar dating

K/Ar dating of chloritoid schists, the host rocks of q-hyalophane veins gives the values 37.7 $\pm$ 1.5 , 38.6 $\pm$ 1.5 and 36.9 $\pm$ 1.8 Ma. Hyalophane from the same veins, formed by retrograde metamorphogenic fluids is dated 25.3 $\pm$ 1.0, 23.2 $\pm$ 0.9, 16.7 $\pm$ 0.9, and muscovite 38.7 $\pm$ 1.6. It is a time of the Dinaride uplift (Pyrenean orogenic phase).

Discussion

The fluid inclusions in the quartz from the Čemernica mineralisation are aqueous and aqueous - carbonic primarily. Their P-T-X characteristics show a complex geological history of the area, which underwent poly-phase metamorphism. The P-T-t metamorphic loop, constructed on the basis of metamorphic phase analysis (MAJER et al., 1991), is characteristic of the regional metamorphism caused by collisional processes. It gives a frame for possible P-T evolution of the fluids. Isochores for the aqueous FI-s were calculated by ZHANG and FRANTZ (1987) equation of state (EOS), using FLINCOR, 1.4 Version (BROWN, 1989). Some selected H_2O-NaCl-CO_2 FI-s with Tm CO_2 close to -57°C (approaching CO_2 triple point) were elaborated by Bowers and Helgeson (1983) EOS.

They intersect the retrogressive part of the P-T loop. Similar FI-s have been already determined in quartz and hyalophane, within chloritoide schists of the Busovača area, adjacent to the Čemernica mineralisation. Their growth within the open clefts, proceeded during exumation of the hot metamorphics. FI-s within a quartz slab from Čemernica with a wide span of densities and similar salinity should be attributed to the frequent pressure drop, characteristic for brittle tectonic processes during exumation. The type 1 and 3 of FI-s contain retrogressive fluids which were flashing terrain through particular shear zones. The type 2, with the highest Th (330°C), recorded in the quartz falls outside of the described group. Their P-T-X characteristics ressemble to the FI-s of the Kreševo barite deposit, neighbouring the Čemernica mineralisation, probably, not much affected by metamorphic fluids (Palinkaš and Jurkovič, 1994).

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Structure and Paleoalpine evolution of the Central Western Carpathians

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The updated regional tectonic nomenclature of the Western Carpathians uses the inferred oceanic sutures and/or subvertical crustal-scale lineaments as principal dividing elements. This approach meets best the plate-tectonics criteria, because oceanic sutures indicate fossil plate boundaries and their identification in the orogenic edifice should be reflected by the basic tectonic nomenclature of the respective mountain belt. For the zones south of the Meliatic suture, the term **Internal Western Carpathians** is proposed (with the aim to distinguish them from the poorly defined and ambiguously used term „Inner Western Carpathians"). The southern boundary of the IWC is formed by the mid-Hungarian (Zagreb-Zemplín) tectonic line that juxtaposes IWC against the Tisia composite terrane that is mostly hidden below the thick Neogene sedimentary cover of the Pannonian basin. The **Central Western Carpathians** are the heart of the Slovakian Carpathians, they comprise zones between the Meliatic suture and the Pieniny Klippen belt. The term **External Western Carpathians** is used for the units forming zones north of the Pieniny Klippen belt. The definition of the EWC differs from the widely used term „Outer Western Carpathians“ by involvement of the Pieniny Klippen belt into the CWC zones.

Considering genetical aspects and lateral relationships of the pre-Tertiary tectonic units, the units building central zones of the Western Carpathians are undoubtedly prolongations of the Austroalpine units from the Central Eastern Alps. Taking into account principal differences in the Tertiary history of both mountain belts, the most appropriate name for the Carpathian analogues of the Austroalpine system appears to be the term **Slovakocarpathian system**. Analogously, the term **Hungarocarpathian syst**em is proposed for units occurring dominantly in the IWC, encompassing the superunits as the Bükkicum, Transdanubicum and, possibly, also Zemplinicum. The **Meliata system** between these two is a Jurassic accretionary complex comprising two superunits, the Meliaticum (oceanic) and Turnaicum (active margin). The **Pennine system** is an Upper Cretaceous – Paleogene accretionary complex that is external to the Slovakocarpathian system. It consists of the Vahic, Oravic and the Magura superunits, occurring in the transitional zone between the CWC and EWC. The **Moldavian system** (Silesian-Krosno nappes) is a Neogene accretionary prism overriding the European Platform.

Within the Slovakocarpathian tectonic system, six principal superunits can be defined. These are, from bottom to top, the Tatric, Veporic and Gemeric basement/cover crustal-scale sheets, and the Fatric, Hronic and Silicic thin-skinned cover nappe systems. The Vahic (Penninic) oceanic complexes in the north and the Meliatic suture in the south create the boundaries of the Slovakocarpathian system.

The Slovakocarpathian system (SCS), located between the Meliatic and Penninic-Vahic oceanic sutures, originated by shortening and stacking of a continental domain which was related to Europe during the Late Paleozoic and Triassic and to Adriatic microcontinent during the Cretaceous and Tertiary. The SCS basement complexes developed in the inner Variscan zones and display features of a southern polarity. The outer Variscan zones to the south of the SCS suffered Late Permian to Scythian rifting and late Anisian break-up of the Meliatic ocean, followed by its Middle to Late Triassic spreading. The northern, SCS shelf shows zoning from slope facies deposited on a transitional crust, huge reef bodies on a subsiding distal passive margin, and lagoonal to terrestrial environments landwards. The first manifestations of the southward subduction of the Meliatic ocean are coeval with rifting within the SCS domain during the earliest Jurassic. The "wide rift" mode of extension focussed in break-up of the Penninic-Vahic oceanic realm at the Early/Middle Jurassic boundary. This event separated the Austroalpine-Slovakocarpathian realm from the North European Platform. The closure of the Meliatic ocean during the Late Jurassic welded the SCS domain with the Adria-related Internal Western Carpathians located presently south of the Meliatic suture.

The Cretaceous growth of the West Carpathian orogenic wedge shows a northward progradation from the Meliatic suture and an episodic accretion of stretched crustal material from its northern foreland. The first latest Jurassic – earliest Cretaceous episode directly followed closure of the Meliatic ocean. It was associated with an exhumation of the Meliatic blueschists and a deep burial of the Veporic domain below the accretion/collision stack. The second episode was the mid-Cretaceous underplating of the Veporic wedge by the buoyant Tatric-Fatric crust that triggered the vertical extrusion of thermally softened material in the rear of the wedge. The inferred P-T-D-t path of the Veporic metamorphic core complex, which is based on detailed petrological and structural studies, indicates its exhumation from lower crustal levels (peak metamorphic conditions: T about 600°C, P in excess of 10 kbar) to the near-surface during ca 30 Ma (the time span between Ar/Ar cooling ages of amphiboles and biotites). The path remained in the stability field of kyanite, therefore heating from the mantle can be excluded. Large parts of the stiff and buoyant Tatric crust avoided substantial thickening and were overridden by only thin blankets of the Fatric and Hronic cover nappe systems. During the Late Cretaceous, the rear of the orogenic wedge cooled and contraction prograded to the zones at the northern Tatric (continental) and Penninic-Vahic (oceanic) interface. However, only indistinct crustal thickening is indicated there and the northern Tatric edge became to act as the rear buttress of the developing External Carpathian accretionary wedge during the Paleogene.

Eclogites in metamorphic complexes: three case histories in the South Carpathians

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Inclusion of eclogites in apparently lower-pressure metamorphic complexes is a topic in which frequent lack of unambiguous criteria in deciphering the pertaining mechanisms is fought by a large variety of proposed scenarios. As mafic composition and the high-pressure assemblages unequivocally pin-points eclogites as subducted oceanic crust, accompanying felsic or pelitic rocks in which no high-pressure metamorphism can be documented clearly originate from different geotectonic backgrounds. Nevertheless, subduction and exhumation of continental rocks is a phenomenon increasingly recorded in a large number of high-pressure belts, supporting at least the possibility a common subduction-exhumation history of the geochemically contrasting rocks. As direct evidence from metamorphic assemblages is frequently poor, it remains but to often a mere matter of speculation whether particular mafic-felsic assemblages containing eclogites were intermingled during or after subduction.

In the most fortunate cases, stiff porphyroblasts in felsic and pelitic rocks preserve inclusions and chemical zonalities that allow a direct comparison between the metamorphic paths of associated continental-derived and ocean-derived crustal lithologies. This is the case in the South Carpathians, where three different eclogite-containing pre-Alpine metamorphic belts, bounded by Alpine tectonic lines, point all to a foreign character of eclogitic lithologies as against their host formation, providing, as well, evidence for exhumation before subduction was arrested.

The Leaota Massif, located at the south-eastern extremity of the South Carpathians, is constituted by a flat-lying sequence defined by well-expressed lithologic markers (Gheuca, Dinica), corresponding to a pre-Alpine tectonic pile. The extent of the units involved, the details and ages of the emplacement mechanism are still poorly-understood, as proven by the diversity of current interpretations. Metamorphic assemblages range from low- to medium- grade, evidence for retrogression being extensive throughout the pile.

The eclogite-bearing unit is located in a narrow sheet-like zone exhibiting metamorphic and lithologic contrasts that define it as a suture zone. The lowermost term of the unit is the syn-collisional Albesti granite sill, Cadomian in age (540-523 Ma Rb-Sr isochron reported by Zincenco, 1995, Sabau *et al.,* 1997), inducing a low-pressure thermal overprint on highly-deformed neighbouring mica-gneisses. The Albesti granite is overlain by a variegated series (the Bughea Level) dominated by a semi-pelitic matrix, that contains lenses and pods of eclogites and amphibolites. Evidence for subduction-zone associated LILE-metasomatism is conspicuous in the paragonite - barian muscovite assemblage of the matrix.

The mafic lithologies display contrasting compositions and metamorphic conditions, that can culminate in concentric zonation given by lower-grade mica- or amphibole- rich rinds around eclogite “knockers”. Peak conditions recorded in the eclogites distinguish “normal” eclogites (up to 2.4 GPa, 620° C) from UHP varieties (3.2 GPa, 800° C). In contrast, prograde metamorphism attaining only 0.9-1.1 GPa, 550-600° C is clearly documented by the assemblages in the semipelitic matrix of the Bughea Level, as well as in the Albesti Granite and its former hornfelses. The metamorphic history documents a two-stage uplift of the eclogites: return along the active subduction zone of small fragments detached from the downgoing plate and enclosure in a melange in the acretionary prism, followed by exhumation of the suture zone including the underlying granite sill as a coherent block.

Another example of a flat-lying sequence containing litostratigraphically-controlled eclogite inclusions is in the Lotru Metamorphic Suite, that constitutes most of the medium- to high-grade basement of the Getic Realm. In this metamorphic belt, several units contrasting in their lithology and metamorphic evolution can be distinguished. The metamorphic background is dominated by a syn-foliation overprint ranging from sillimanite±staurolite to kyanite-staurolite grade at pressures around 0.6 GPa in thrust slices overriding a hotter unit, in which peak temperatures slightly exceeded 700° C. Relict assemblages in all units for document older prograde regional events with peak conditions around 600-650° C, at pressures attaining, unlike in eclogites, not more than 1.1-1.3 GPa.

Eclogites and associated rocks display, apart from contrasting chemistry, differing peak conditions and specific settings in the pile.

A first group of eclogites belongs to a complex consisting of scattered fragments with mafic to ultramafic composition. They form small outliers lacking continuity, located immediately below the uppermost unit of the pile that consists of mica gneisses and schists of the Negovanu Mare Formation, that displays a limited metamorphic, though a pervasive structural overprint during the medium-grade syn-foliation event. As the kyanite-bearing omphacite-garnet eclogitic assemblages are generally overprinted by retrogression, mineral composition usually fail to characterise extensive PT-paths. Nevertheless, a wide array of consistent equilibrium conditions can be identified from coexisting minerals combining data from individual samples. As a result, it appears that fragments with contrasting exhumation-uplift history distributed along a typical gradient ranging from 1.3 GPa, 600° C to 3 GPa, 820° C were sampled and uplifted through forced convection from an active subduction zone. Associated ultrabasic rocks, including a known occurrence of garnet lherzolite, also make evidence of extensive tectonical uplift of small fragments with original deep location, consistent with this interpretation. Garnet and kyanite-bearing amphibolites appearing also as isolated outliers and exhibiting a prograde anticlockwise metamorphic path culminating at 1.1 GPa, 720° C, stand for fragments which had a limited burial history, being exhumed from shallower depths during the terminal stage of subduction. The whole subduction assemblage was afterwards scattered along the main intra-lithospheric thrust surface associated with post-collisional flake tectonics.

The second context in which eclogites appear in the Lotru Suite is in a typical assemblage made up of eclogites, ultrabasic rocks and felsic lithologies (highly strained high-grade gneisses and calc-alkaline intrusives) which build up a coherent unit (the Valea Caprareasa Complex), which had a refractory behaviour during the sillimanite-grade syn-foliation metamorphism, contrasting with the adjacent rocks. Metamorphic contrasts exist inside the unit as well. The felsic rocks display high-grade, high pressure conditions culminating at 1.3 GPa, 850° C, while granitoids exhibit a post-consolidation phengite-garnet-kyanite overprint at 750-850° C, 1.3 GPa.

Eclogites are well preserved and form large-sized lenses and pods. They group in two differing types: cold eclogites with Na-Al-rich compositions and well-defined clockwise paths with peak temperatures of 650° C at 2.3 GPa, opposed to hot eclogites equilibrated at 2.2-2.6 GPa and *ca.* 850° C. The hot eclogites typically contain diopside-rich pyroxene and pyrope-rich garnet. Compositions and metamorphic conditions imply a subducted oceanic crust origin for the cold eclogites. The hot eclogites display spectacular zonation patterns in garnet, indicating either decompression or cooling paths prior to attainment of equilibrium shown by the pyroxene-quartz-garnet±kyanite±zoisite assemblage, thereby documenting high differential movements. The most probable origin of these rocks is from beneath an active continental margin, consistent with high-grade metamorphism and calc-alkaline plutonism in the adjacent felsic rocks. The Valea Caprareasa complex as a whole most presumably originates from deep-seated tectonic mixing among fragments scrapped off from the subducted slab, crustal material of the active margin and upper mantle inclusions. The tectonic association of these rocks gave birth to a low-strength buoyant sliver which experienced uplift through an extrusional mechanism. The high-pressure overprint undergone by metagranitoids indicate that crust thickening in a compressive setting was still active by the time of extrusion. The extruded wedge was involved during late-collisional flake tectonics in thrust sheets stacking building up the present structure of the Lotru Metamorphic Suite. Consistent age indications about this process is provided by a 575 Ma Rb-Sr whole-rock isocron in the metagranites (Zincenco, 1998).

A somewhat similar felsic-mafic eclogite-bearing complex appears in the Fagaras Massif, located north from the Leaota Massif. In contrast to the other two belts, the anisofacial high to medium grade basement rocks in this region do not display a flat-lying sequence, at least because of being strongly affected by Alpine folding, faulting and thrusting. The eclogites are located in a typical assemblage together with felsic gneisses in a regionally extended, constant-featured complex, separated as the median amphibolites of the Topolog “Formation” (Gheuca, 1988). The metamorphic conditions are so far more systematically defined for the eclogites themselves than for the neighbouring gneisses; at any rate the macroscopic features and mineral assemblages of these are strikingly similar to those of the gneisses in the Valea Caprareasa Complex, suggesting a similar exhumation process.

The eclogites display a common garnet - omphacite - kyanite - quartz ± zoisite ± amphibole assemblage indicating peak pressures of 1.8-2.6 GPa attained at 600-650° C. Several samples display an unusual feature: a significant isobaric temperature increase at peak pressures, not only documented by quartz inclusions surrounded by radiating cracks and plagioclase neoformation in voids left among coalescing garnet porphyroblasts, but also sustained by clinopyroxene-garnet geothermobarometry (Sabau & Negulescu, *in press*). Maximum temperatures reached during high-pressure isobaric heating are in the analysed samples around 780° C. This PT-path documents decoupling of portions of the subducting slab followed by residence at maximum depths, until rising geothermal gradients trigger differential uplift caused by the combined effect of buoyancy and tectonic weakening.

The features displayed by these eclogite-bearing metamorphic belts in the South Carpathians indicates that uplift and incorporation of small eclogite fragments in regionally metamorphosed terrains can in many instances be a combined effect of early small-scale counter-current movement along the subduction zone, followed by differential uplift of larger slivers and/or involvement in crustal flake tectonics.

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Apparently monometamorphic rocks in a polymetamorphic pile: probable discontinuity markers

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Polymetamorphism in several basement complexes of Alpine tectonic units in the South Carpathians is supported by an increasing volume of qualitative data, mostly consisting of microtextural relationships in disequilibrium assemblages. On the other hand, lithologic and metamorphic contrasts within apparently structurally coherent metamorphic piles casts serious doubts on the meaningfulness of attempts to generalise a metamorphic history derived from a single formation over the entire pile, or to combine individual metamorphic overprints identified in different formations into a global scenario.

The medium- to high-grade basement of the Getic Realm* in the South Carpathians was subject to a clearly polymetamorphic history, mostly referred to by an indiscriminate $M_{1-2(3)}$ general succession. At the same time, a composite structure was repeatedly invoked on account of exotic lithologies like eclogites (Hann, 1984), ultrabasic pods, or both (Iancu *et al.*, 1987) or even metamorphic contrasts among more common rock types (Iancu, Maruntiu, 1994; Sabau, 1994). A recently found rock variety calls upon another type of relevant situation in this respect, namely monometamorphic rocks sandwiched between two polymetamorphic units.

An unusual garnet quartzite appears in the right slope of the Barzava River in the Semenic Mountains. The rock has a well expressed foliation given by the orientation of white mica in the quartz groundmass. Garnet forms mostly equant, but also elongated or winged porphyroblasts which may exceed 1 cm, while subordinate grains of kyanite, staurolite and ilmenite are also present. Green Fe-rich chlorite persist as rare digested relics, especially in garnet. Garnet contains abundant quartz inclusions which concentrate in concentric domains, resulting in a spectacular zonation of the quartz inclusions in the porphyroblasts. Inclusion-poor rings concentrically alternate with layers of web garnet, grown along quartz grain boundaries or as platy pseudomorphs sometimes including chlorite relics. This microtexture documents discontinuous variations of garnet growth rate under low differential stress, that also persisted indefinitely after porphyroblasts grew.

The chemical composition of the garnet, at variance with the textural zonation, is remarkably homogenous, being at the same time the richest in almandine among all garnet compositions in LMS ($Alm_{84-92}Pyp_{\leq 8}And_{\leq 5}Cal_{\leq 3}$). Ca and Mn do not exhibit bell-shaped profiles as expected in case of normal fractionation, showing instead grouping along compositional steps, as also does Mg, suggesting that the three elements are mobile components. White micas consist of both muscovite and paragonite. The latter is the only Na-phase, as plagioclase is generally absent from the assemblage, appearing only as inclusions in garnet. Biotite is also rare and preferentially forms inclusions in garnet. Staurolite is iron-rich ($X_{Fe} > 0.94$), with Zn > Mg. Fe-Mn distribution between garnet and ilmenite yields metamorphic peak temperatures of 582-607° C. Mineral compositions and microtextures clearly indicate prograde growth of the metamorphic assemblage during a single event, when the prevailing metamorphic foliation was generated by predominantly simple-shear, as well as no later mineralogical or structural overprint.

The prograde blasthesis of a paragenitical assemblage simultaneously with a progessive deformation, well expressed in the assymetrical orriented shape of the garnet porphyroblasts and the S-C type composite foliation, suggest a mylonitic type rock.

In contrast, both overlying and underlying porphyroblastic rocks show a polymetamorphic history, most clearly expressed by garnet porphyroblasts displaying a variable overgrowth and resorbtion history involving relict cores, as well as (partly homogenised) normal fractionation patterns of Ca and Mn. Syn-foliation overprint corresponds in the neighbouring rocks to a thermal span including the temperatures derived in the garnet quartzite, displaying at the same time a regional discontinuity in both temperature and degree of overprinting that coincides with the location of the quartzite.

Either originating from sediments first metamorphosed during the event responsible for the prevailing regional foliation or, alternatively, formed by metamorphic segregation along a mobile zone during this event, the garnet quartzites in the Bîrzava Valley mark a tectonic discontinuity surface in the metamorphic pile. The behaviour of Ca, Mg, Mn and Na is indicative of an important role of mobile components in the formation of the quartzite, thereby preferentially supporting a metamorphic segregation mechanism.

Late metamorphic re-equilibration in retrograde conditions is connected with extentional processes, as quarts is recrystallised even in the extention gashes of the garnet porphyroblasts and chlorite appear at the expence of the former minerals.

*The basement of the Getic Realm (Alpine nape system) is known in the romanian literature as: undivided, Sebes-Lotru Metamorphic Series in the 1:50.000 scale maps of IGR; diveded: Sebes, Lotru, and Ursu, the main pre-Alpine units, cf. Iancu, Maruntiu, 1994; Iancu et al., 1998; Lotru Metamorphic Suite, as a whole, cf. Sabau, Gheuca, 1996).

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The contemporaneous condition P – T in the Earth’s continental crust

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The measurements in the drill holes are an important source of the information about the distribution of pressures and temperature in the lithosphere. Acquired data are not in fully agreement with some common petrological conceptions.

The stress and the lithostatic pressure seem to be important factors at the origin of mineral associations by the contact metamorphism. On the facults a reduction of the pressure (a „pressure paradox“) appears. A contrast behavior of related minerals (e.g. antigorite and lizzardita) in stress field have been estimated experimentally. The stress field is influenced by the local fluid pressures and by the fluid migration. These factors are controlling the mineral composition of the rocks (metamorphic facies). Therefore the concept of mineral facies and theoretical „facies of depth“ especially, seems to be not correct.

The temperature field of the Earth's continental crust is irregular and its variability is not connected with the rise of the energy flows from the interior only. A connection between the thickness of the crust and mainly its middle „ granitic“ layer is proved in the West Carpathians and in the Bohemian massif too. The course of geotherms after measurements in the drill holes is quite different from the theoretical presumptions.