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VARISCAN AND ALPIDIC NAPPE STRUCTURES OF THE WESTERN CARPATHIAN CRYSTALLINE BASEMENT

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Abstract: A few generations of the crystalline basement nappes have been distinguished in the Central Western Carpathians. The closure of a proto-Variscan (500 - 415 Ma) ocean caused the formation of the subduction (415 - 380 Ma) and collision (380 - 280 Ma) related highly metamorphosed nappes of the Lower Variscan structural level. The subduction and collision processes of the basement led to an extension (415 - 380 Ma) and formation of the new volcano-sedimentary complexes, which were metamorphosed incorporated (380 - 280 Ma) into the nappes of the upper Variscan structural level. The southern zones of the Western Carpathians underwent the Early Alpidic extension or transtension (280 - 190 Ma) and the Late Cimmerian (190 - 90 Ma) subduction(190 - 130 Ma), nappe thrusting (130 - 110 Ma) and collisional transpression (110 - 90 Ma). The Jurassic - Crecateous extension (190 - 110 Ma) of the northern zones was followed by the Penninic-Vahic oceanic crust subduction (110 - 90 Ma), the Paleo-Alpidic nappe formation (90 - 70 Ma) and transpressional sinistral strike slips (70 - 20 Ma). The Meso-Alpidic basement nappes (70 - 20 Ma) are evident in the peri-Vahic (peri Klippen Belt-, Infratatric-) zone.

Key words: Variscan, Alpidic, nappes, crystalline basement, Western Carpathians.

Introduction

The nappe structure of the crystalline basement is one of the characteristic feature of the Alpidic Western Carpathian orogeny.

There is undoubted existence of Alpidic nappe units comprising the crystalline basement (Kettner 1938; Koutek 1959; Jaroš 1965, 1971; Klinec 1966, 1976; Kahan 1969; Grecula 1974, 1982; Jacko 1975, 1979; Putiš 1981, 1983, 1987 a, b, 1989, 1991 a, b; Krist et al. 1992).

A possible Variscan age of thrust tectonics in the Western High Tatra Mts. was considered by Kahan (1969). Recent petrological data from this area (Janák et al. 1988; Janák 1991, 1992) support this ideea. Grecula (1982) considered Variscan nappes in the Gemeric unit.

An evolutionary model of the Late Variscan - Alpidic structure of the Central Western Carpathian basement was published by Putiš (1991 a). The same author suggested distinguishing Variscan and Alpidic nappe structures on the basis of lithology, metamorphism, tectonics and available palynologic and radiometric data (Putiš 1987 a, b, 1989, 1991 a, b, c). The criteria which have been used are described in this paper with the aim of emphasizing the existence of Early Variscan, Late Variscan and Early Alpidic nappes, which have been incorporated into the mainly mid-Cretaceous structure of the Central Western Carpathians.

Variscan - Alpidic structure of the crystalline basement

A few generations of the crystalline basement nappes of different age, kinematics and P-T conditions have been distinguished in the Western Carpathians:

Early Variscan nappes in the Alpidic structure of the Tatric crystalline basement

The Variscan nappe structure, which incorporates an Early Variscan or even Caledonian structural horizon, is especially characteristic for the Tatric basement (Figs. 1, 2) built of the pair of nappes exposed on the surface.

The Tatra Nappe, commposed of paragneisses, amphibolites, less banded amphibolites, migmatites, anatectic migmatites and Early to Late Variscan mainly S-types of granitoids, is thrust over the Hron Nappe, composed of micaschists to gneisses, huge amounts of amphibolites, banded amphibolites, less banded amphibolites, locally metagabbros, metaperidotites and serpentinites.

The overthrust plane is exposed in the West High Tatra Mts. (Kahan 1969), Považský Inovec Mts. (Kamenický in Maheľ et al. 1967; Putiš 1981, 1983), Tríbeč Mts. (Putiš 1991 a, b) and Low Tatra Mts. (Putiš 1987 a, 1989, 1991 b). The overthrust plane was reactivated during the Late Variscan and especially during the Alpidic deformation.

The West High Tatra Mts.

The negligible increment of superposed Alpidic deformation (directly along the Variscan thrust plane) is supposed in the West High Tatra Mts., although common north-vergent recumbent folds of the upper Tatra Nappe crystalline complex with the Mesozoic cover unit are known (Gorek 1959).

Detailed petrological data obtained by Janák et al. (1988) and Janák (1991, 1992) prove different metamorphic evolution in the upper and lower nappes with an inverted metamorphic zoning (sillimanite zone above the staurolite-kyanite-sillimanite one) in the lower nappe due to overheating by the thrust of the upper nappe in deep-crustal conditions.

The retrograde mineral assemblage (chloritoid, margarite, chlorite, muscovite, albite, cf. Janák 1991), the ductile behaviour of quartz and the brittle-ductile of feldspars in both metamorphic and granitoid rocks indicate the lowest overthrust temperatures about 450 - 400 °C and a long term formation of the pair of nappes practically up to the end of the Variscan orogenesis. Such conditions have not been attained during the Alpidic metamorphism of the Tatric cover units, which are unmetamorphosed or locally anchimetamorphosed.

All the rock Rb-Sr radiometric dating of paragneisses (420 Ma, Burchart 1968) and the U-Pb dating of zircons of migmatite leucosome (450 Ma, Bibikova in Janák 1991) support the previous interpretation concerning the age of nappe formation.

The stretching lineations are oriented mostly in a WNW - ESE direction. The most asymmetric textures of low-temperature (less than 300 °C) mylonites are the result of the locally strong effect of the Alpidic sinistral transpressional shear movement. The top moved to the W along the C-planes. Preliminary study of oriented thin sections indicates scarcely preserved SE vergency of the upper nappe (Fig. 3). The maxima of diagrams indicate middle-temperature combined basal **a** and prisma **a** glide in a plane strain to pure shear regime.

The Považský Inovec Mts.

The thrust plane between the Tatra and Hron Nappes was affected here by a poly-stage Alpidic deformation (Putiš 1980, 1981, 1983, 1986 a, 1991 b; Leško et al. 1988). The mountain is not far from the Klippen Belt and the NW part of the Mts. was overprinted by steep klippen-like tectonic style which comprises crystalline, Upper Paleozoic and Mesozoic cover-rocks including Upper Cretaceous sediments. The mentioned overthrust plane (in the W part) includes Upper Carboniferous, Permian and Mesozoic cover-rocks, but the pebbles of diaphtoritic and mylonitic rocks, especially from the lower nappe, are present in the only anchimetamorphosed Upper Paleozoic metaconglomerates (Kamenický 1958; Putiš 1981, 1986 a; Korikovsky & Putiš 1986). These data prove the splitting of the pair of crystalline nappes already during the Late Variscan period.

Crystalline schists of the lower Hron Nappe appear to have similar lithology and metamorphic evolution to those of the West High Tatra Mts. But here, the metamorphites contain all three alumosilicates - kyanite, andalusite and sillimanite coexisting with staurolite (Putiš l.c.; Korikovsky & Putiš l.c.). The mutual relationship of alumosilicates is the following: kyanite, kyanite + andalusite (andalusite replacing kyanite), andalusite + sillimanite (fibrolitic sillimaanite replacing andalusite), but kyanite + sillimanite has not been found. Andalusite encloses relic staurolite together with biotite and muscovite oriented in metamorphic foliation. A change of middle-pressure kyanite (-sillimanite) type of regional metamorphism to low-pressure andalusite-sillimanite type is supposed (Putiš 1982, 1983).

The metamorphism of the Tatra Nappe-segment (paragneisses, amphibolites, migmatites, granitoids) belongs to a low-pressure andalusite-sillimanite type in the Považský Inovec Mts. (Putiš l.c.). Metamorphic planar and linear structures are oriented in a WNW - ESE direction.

The tectonic contact of the higher - Tatra and lower - Hron

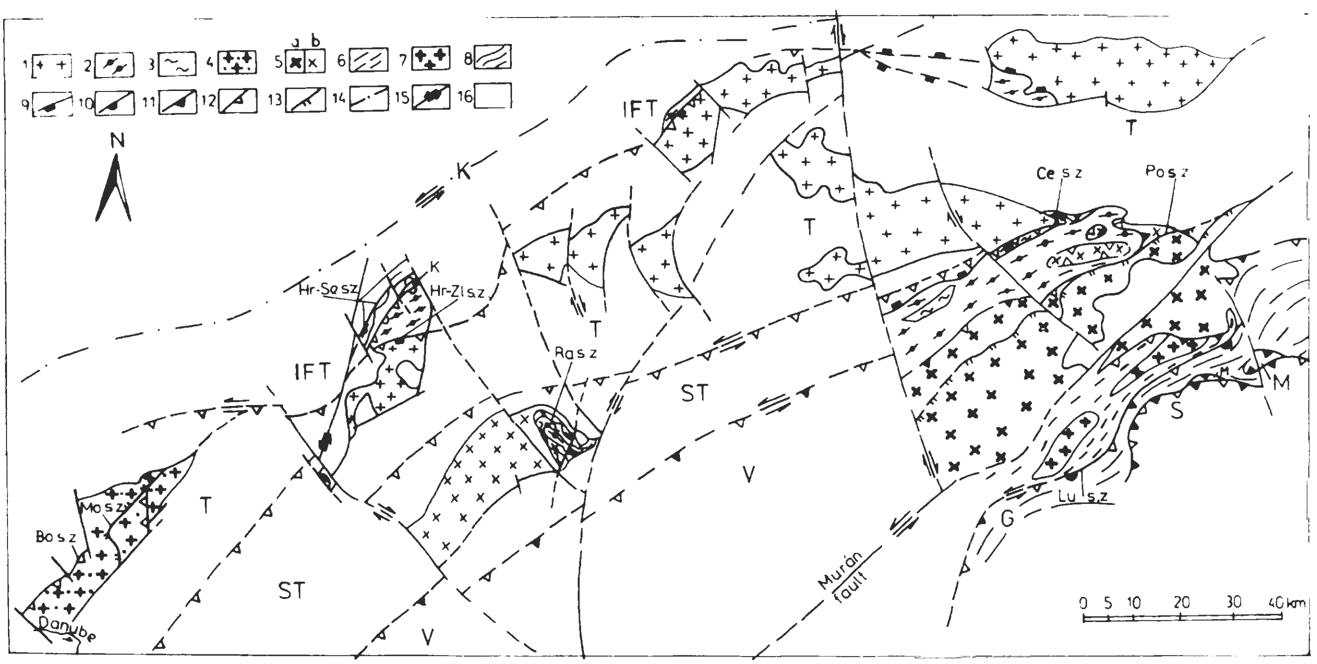

Fig. 1. Tectonic sketch-map of the Central Western Carpathian crystalline basement.
Legend: 1 - Tatra Nappe; 2 - Hron Nappe; 3 - Ľubietová subordinate Nappe (the Tatra Nappe); 4 - crystalline of the Malé Karpaty Mts.; 5 - north-Veporic crystalline basement: a - as a part of the Veporic tectonic zone, b - thrust over the Supra-Tatricum; 6, 7 - south-Veporic crystalline basement; 8 - Gemeric crystalline basement; 9 - Early Variscan thrust; 10 - Late Variscan thrust; 11 - Early Alpidic (Late Cimmerian) thrust; 12 - mid-Cretaceous thrust; 13 - reverse fault; 14 - Klippen Belt axis; 15 - strike slip, 16 - higher units.
Abbreviations: K - Klippen Belt; IFT - Infra-Tatric tectonic zone; T - Tatric t. z.; ST - Supra-Tatric t. z.; V - Veporic t. z.; G - Gemeric t. z.; M - Meliata tectonic unit; S - Silica t. u.; Hr-Se s. z. - Hrádok-Selec shear zone in the Považský Inovec Mts. (compare the High Tatra Mts. in the upper right corner of the Fig.); Ra s. z. - Razdiel shear zone in the Tribeč Mts.; Ce s. z. - Čertovica shear zone in the Low Tatra Mts.; Po s. z. - Pohorelá shear zone in the Low Tatra and Slovenské rudohorie Mts. - West Lu s. z. - Ľubeník shear zone in the Slovenské rudohorie Mts.

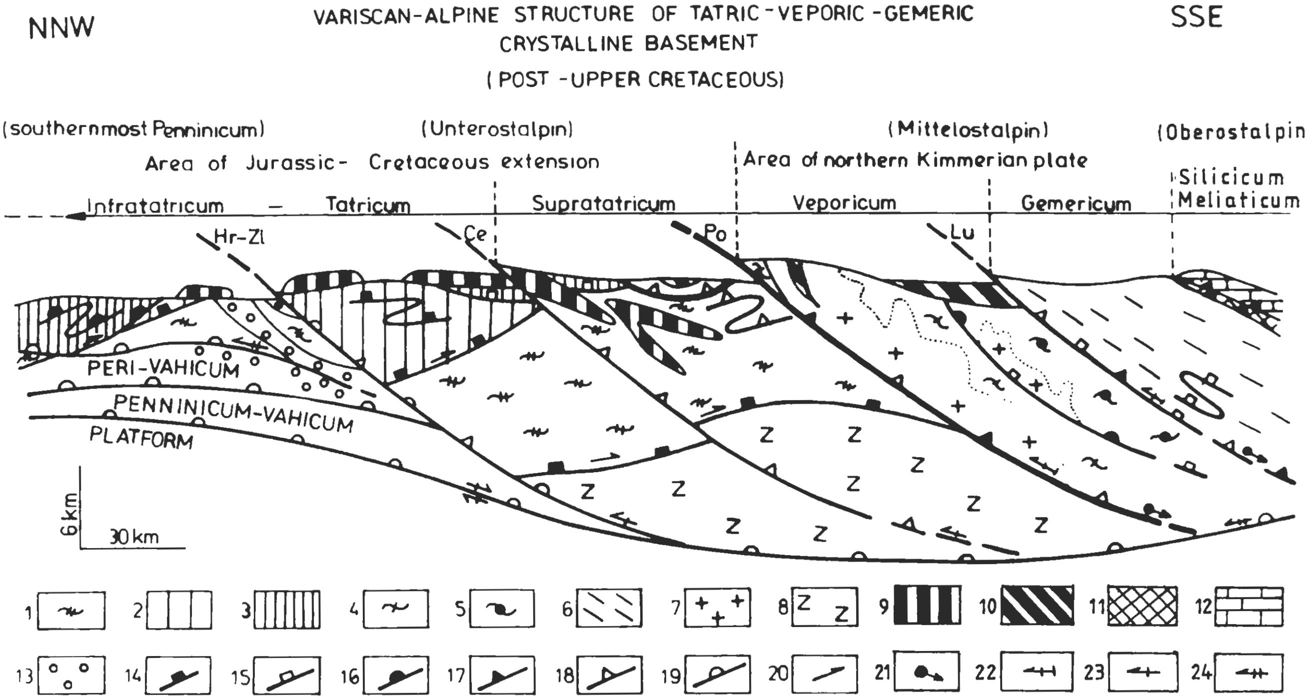

Fig. 2. Variscan - Alpidic structure of the Western Carpathian crystalline basement.
Legend: 1 - Hron Nappe; 2 - Tatra Nappe; 1, 2 - Early Variscan nappes of the lower Variscan structural horizon; 3 - Late Variscan nappes of the Tatric zone - a part of the upper Variscan structural horizon; 4 - north-Veporic Čierny Balog complex; 5 - south-Veporic Kohút, Hladomorná dolina Valley and Predná hoľa complexes; 6 - Gemeric crystalline basement - Klátov, Rakovec, Gelnica and other complexes; 7 - Late Variscan granitoid Vepor pluton; 8 - Zemplín type of the crystalline basement (pre-Cambrian ?); 9 - Krížna Nappe; 10 - Foederata (Struženík) Group; 11 - Meliata unit; 12 - Silica unit; 13 - Middle-Upper Cretaceous sediments; 14 , 20 - Early Variscan thrust; 15, 16 - Late Variscan thrust; 21 - extensional fault; 17, 22 - Early Alpidic (Late Cimmerian) thrust; 18, 23 - mid-Cretaceous thrust; 19, 24 - Laramian and younger thrust.

Nappe is accompanied by a few tens of meter thick fine-grained and banded mylonites, coming from the leucocratic granitoids of the upper nappe and phyllonites of mica schists and mica schist gneisses of the lower nappe with typical intrafolial isoclinal mesofolds and cleavage defined by white mica, chlorite, albite, quartz and less by minerals of epidote-zoisite group (cf. Putiš 1981, 1983).

The boundary between nappes was firstly incorporated into a mid-Cretaceous sinistral shear zone with approximately E - W (to ENE - WNW) direction of stretching lineation, and later into a post Upper Cretaceous sinistral transpression zone in a NNE - SSW direction (Putiš 1991 b).

The Low Tatra Mts.

The Ďumbier Massif crystalline complex (granitoids, anatectic migmatites, gneisses, amphibolites, tiny bodies of metaultramafic rocks) represents the upper - Tatra Nappe.

Most of the metamorphites belong to the sillimanite zone of regional metamorphism (Krist et al. 1988; Spišiak & Pitoňák 1990). In the late Variscan granitoid rocks, especially the Ďumbier type granodiorite, marks of synkinematic formation of the plutonic body emphasized by distinct mesoscopic oriented structures, in places with foliation appear (e.g. the road cut Nižná Boca - Čertovica).

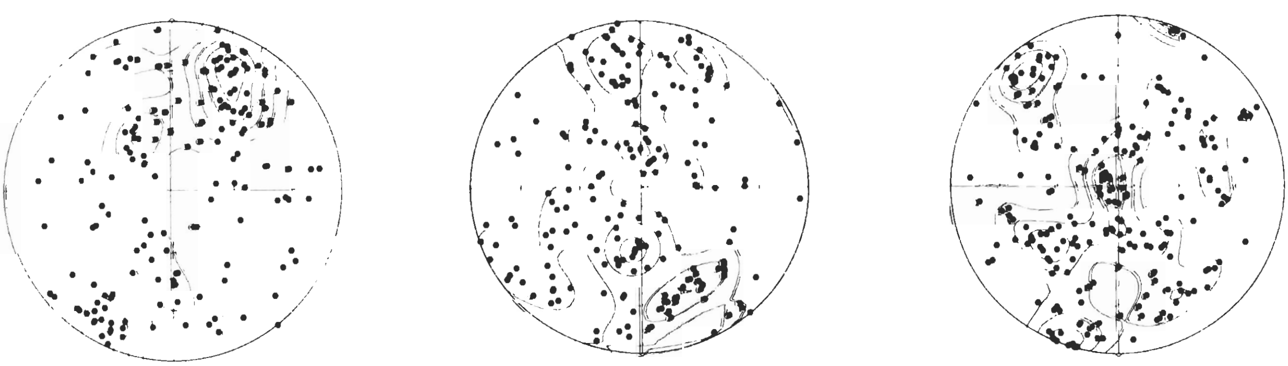

Fig. 3 a - c. Quartz c-axes fabrics from the mylonites along the Variscan thrust of the Tatra Nappe over the Hron Nappe in the West High Tatra Mts. indicate ESE vergency of the nappe thrusting (top to the ESE).

The metamorphic rocks situated S of the Čertovica line mostly belong to the lower - Hron Nappe (micaschists to gneisses, amphibolites and banded amphibolites, locally metagabbros, metaperidotites, serpentinites). Protholite of banded amphibolites could be subduction related basic to intermediate magmatic-volcanic rocks (the light layers do not contain K-feldspars) of an active continental margin or ensialic island arc. These rocks resemble the leptinite-amphibolite complexes of the European Variscides. The regional metamorphic conditions (mostly garnet to staurolite zone) and mineral composition of light bands (quartz, plagioclase, amphibole, epidote, biotite) exclude a possible anatectic origin of the light layers of the banded amphibolites here. In addition, no marks of anatectic differentiation appear in the host rocks-mica schists to gneisses. The regional metamorphism of the Hron Nappe achieved staurolite zone conditions here (Putiš 1981, 1987 a, 1989) with the occasional presence of andalusite and fibrolitic sillimanite (Krist et al. 1992).

Mylonites of micaschist gneisses with new-formed white mica and chloritoid replacing staurolite have been found (Putiš l.c.) in generation of tight folds with E - W B-axes. Transitions into fine-grained phyllonites are quite common. Some orthogneiss bodies are present in the form of layers a few meter thick (Veľký potok Valley region, S of the Hron river and Beňuš village) in micaschists. The orthogneiss contains ductile deformations of eyed feldspars (K-feldspar and plagioclase) and distinct foliation defined by coarse-grained white mica and garnet. The upper part of the Hron Nappe is built mainly of amphibolites and banded amphibolites again with marks of higher temperature ductile deformation, with stretching lineation defined by hornblendes and biotites in a WNW - ESE direction.

The contact of the pair of nappes is strongly reactivated and the Hron Nappe crystalline is thrust over the Tatra (upper) Nappe and its Permian - Mesozoic cover along the mid-Cretaceous Čertovica line.

The whole region of the Hron Nappe outcropping on the surface between the Čertovica and Pohorelá line belongs to the root zone of the Mesozoic Krížna Nappe thrust over the Tatricum to the NW during the mid-Cretaceous deformation. This is further evidence of the splitting of the pair of Variscan basement nappes in this case during the Jurassic - Cretaceous extension and origin of the Krížna Basin. Comparable Permian and Mesozoic cover sequences, of the upper nappe, in the neighbouring area of the Ďumbier Massif, north of the Čertovica line, indicate only a short-distance displacement between the Tatra and Hron Nappes during the Alpidic tectogenesis.

The area between the Čertovica and Pohorelá lines was subjected to a strong generally S - N compression during the formation of the NW-vergent mid-Cretaceous Krížna Nappe followed by sinistral transpression in an ENE - WSW direction. Both deformation events are recorded in quartz c-axis fabrics (Fig. 4; Putiš 1991 b).

The Tribeč Mts.

The northern part of the Mts. includes a tectonic window into the lower - Hron Nappe, which is covered by an Alpidic granodiorite-granite nappe and its Permian - Mesozoic cover rocks (Putiš 1991 a, b).

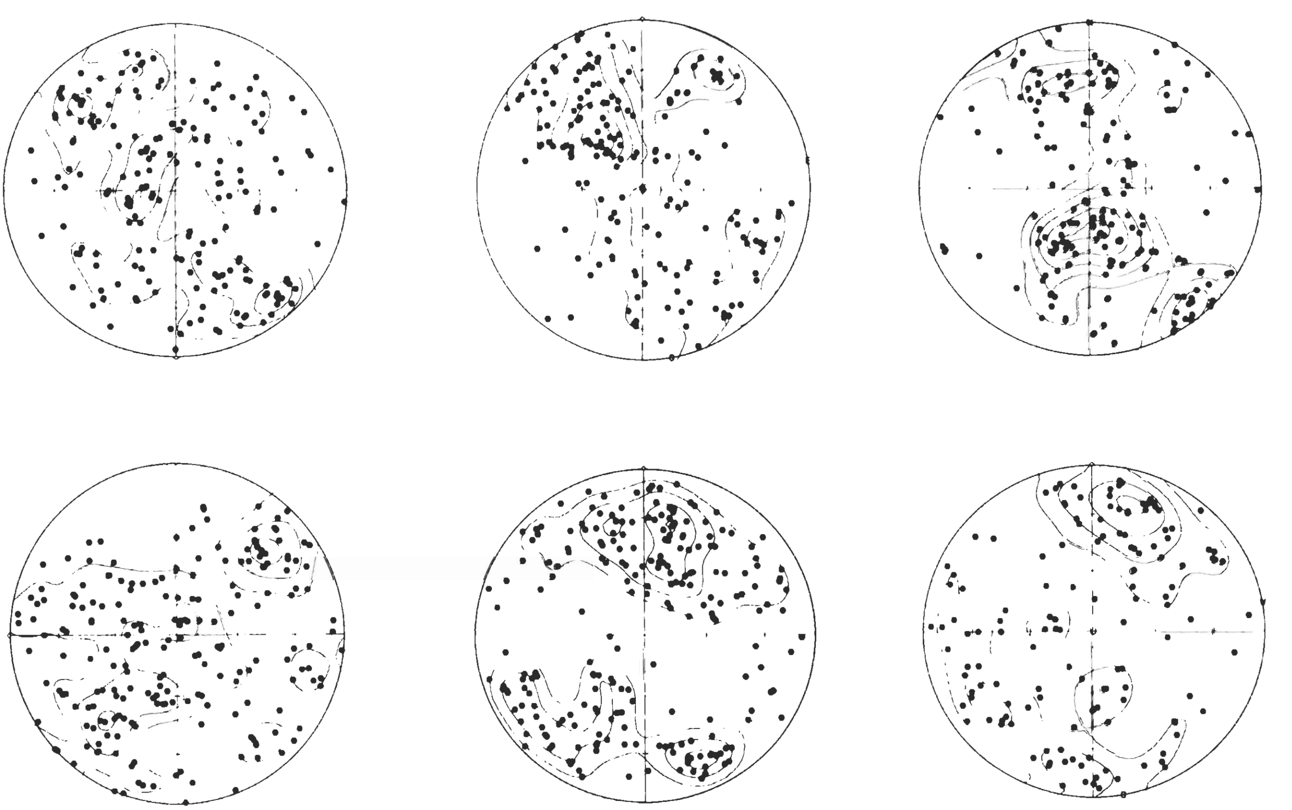

Fig. 4 a - f. Quartz c-axes fabrics indicate mid-Cretaceous NW thrusting (4 a - c) of the Veporic unit over the Supra-Tatric one (4 a & b) and Supra-Tatric over the Tatric one (4 b & c), as well as Late Cretaceous - Paleogene sinistral transpression zone between the Čertovica and Pohorelá lines (4 d - f). S-plane, as the reference horizontal line in both Figs. 3 & 4.

Origin of the Early Variscan nappes

The paleotectonic position of both the Tatra and Hron Nappe complexes (Fig. 5) is depicted in an original scheme according to Frisch & Neubauer (1989), completed by the Western Carpathian crystalline complexes (Putiš in Putiš et al. 1991).

We interpret the formation of the pair of nappes due to a large-scale, deep-crustal shortening and thrusting of a thickened continental edge crust slab, which comprised the upper - Tatra Nappe dominated by low-pressure andalusite-sillimanite type of metamorphism, over a thinned edge crust slab, which incorporated the lower - Hron Nappe, with a middle-pressure kyanite-sillimanite type of metamorphism overprinted in some places by the andalusite-sillimanite type. The higher-pressure character of the metamorphic rocks near the contact of the Tatra and Hron Nappes have also been found according to relics of Mg-rich garnet-cores and clinopyroxenes in amphibolites to eclogitic (?) amphibolites (Korikovsky et al. 1987; Hovorka & Méres 1989, 1990; Spišiak & Pitoňák 1990; Janák 1991). Eclogitic types of amphibolites, found in both nappes, could indicate the relics of former, probably Silurian - Early Devonian, HP-LT tectonometamorphic event connected with subduction processes, followed by a Late Devonian - Early Carboniferous collision, melt-enhanced deformation and extensional uplift.

Banded amphibolites, which are also known in the West High Tatra Mts., Low Tatra Mts., Low Fatra Mts. and Tríbeč Mts., have a specific position in relation to the Tatra and Hron Nappes. They appear to be the base of the Tatra Nappe - in the West High Tatra Mts. and Low Fatra Mts., or the top of the Hron Nappe - in the Low Tatra Mts. and Tríbeč Mts. In some places they have a character of dark granulites or eclogitic aphibolites (cf. Korikovsky et al. 1987; Hovorka & Méres 1989, 1990; Spišiak & Pitoňák 1990; Janák 1991), even with a metamorphic gap to the adjacent rocks. Banded amphibolites thus can be interpreted as the mid-crustal base of the Tatra Nappe (e.g. the situation in the W. H. Tatra Mts., according to Janák 1991; Fritz et al. 1992), or obducted thin basal continental tectonic slices, as a part of the Hron Nappe. These types of amphibolites represent a special tectonic unit situated between the Tatra and Hron Nappes.

Both the Tatra and Hron Nappes probably come from the same - upper plate, although the base of the Tatra Nappe and the Hron Nappe are influenced by the underthrusting lower plate (presence of metaultramafites, higher-pressure metamorphism).

Both nappes represent a relatively older and lower Variscan structural level. The Pohorelá fault-thrust zone definitively cuts the Tatric Early Variscan basement emerging to the S (in mid-Cretaceous structure) under the Veporic unit with ambiguous basement equivalents.

The Early Variscan basement appears analogous to the marginal units of the South Variscan ocean (sensu Matte 1991) i.e. with Pannonic (the Tatra Nappe) and partially with the Koriden (the Hron Nappe) terranes (cf. Frisch & Neubauer 1989).

Generally, the Tatra Nappe unit, Pannonic terrane and Moldanubic unit, have a lot of common features.

Late Variscan nappes

The Early Variscan tectonometamorphic events started the development of the Upper Ordovician - Devonian extensional basins. Volcano-sedimentary complexes were formed (Fig. 5) and metamorphosed, mostly in low-grade conditions. These units belong to a relatively younger and higher Variscan structural level, outcropping at the surface especially in the (Cretaceous) Veporic and Gemeric zones, scarcely in the Tatric one.

Gemeric crystalline basement

The Lower Paleozoic Gelnica (or porphyroid series, Ordovician - Devonian) and the Rakovec (or diabase series, Devonian - Early Carboniferous) volcano-sedimentary complexes (Matějka & Andrusov 1931) of the Gemeric basement are dominated by greenschist facies metamorphic rocks (320 - 380 °*C*, 280 - 380 *MPa*, cf. Faryad 1990, 1991). On the basis of new detailed geological maps, lithological profiles, geochemical and geophysical investigations of the whole territory of the Slovenské rudohorie Mts. - east, Grecula (1982) concluded that both the Gelnica and Rakovec complexes had a common facies history. He identified them as the Volovec Group, subdivided into the Betliar Formation (dominated by black phyllites with intercalations of metalydites, marmors and metapsammites), the Smolník Formation (dominated by greenish phyllites with volcanic clastic and acid, less basic and intermediary rocks) and the Hnilec Formation (dominated by volcanic rocks of the spilite-keratophyre-diabase formation, according to Bajaník 1976) subdivided into the Gelnica porphyroid complex, the Rakovec diabase complex, Helcmanovce rhyolites and Klátov amphibolites.

Paleotectonic reconstruction of the Early Paleozoic volcano-sedimentary basin stated, that the Gemeric basement is a part of an extensive rift zone in the first stage bound to a continental crust (the Gelnica unit) and in the later one bound to an oceanic crust (the Rakovec and Klátov units) with deep-water sediments and ophiolites (Grecula 1982).

Dianiška & Grecula (1979) considered the basalts of the Rakovec Nappe a part of an obducted incomplete ophiolite suite with scarcely preserved pillow lavas (Bajaník 1976) and some ultrabasic rocks (Hovorka & Zlocha 1974).

The presence of blue amphibole, barroisite and stilpnomelane in the Rakovec metabasalts indicates a middle-pressure and low-middle temperature character of metamorphism (Hovorka et al. 1988). Amphibolite facies (500 - 620 °*C*, 450 - 600 *MPa*) of regional metamorphism (amphibolites, gneisses, metagabbros, serpentinites, erlans, marbles) appears only in the rocks of the Klátov Nappe (Dianiška & Grecula 1979; Hovorka et al. 1984; Faryad 1988) thrust over the Rakovec unit. Protholites of gneisses were mainly basic to intermediary volcanic and volcanoclastic rocks of andesite composition with a detrital admixture.

The lithological-geochemical and metamorphic evolution of the Rakovec and Klátov units, dominated by basic and ultrabasic magmatic rocks mostly of tholeitic trend (pillow lavas, gabbros, peridotites), is connected with the oceanic crust evolution on which both units have been formed situated north of the Gelnica unit dominated by calc-alkaline acid to intermediary volcanic, volcanoclastic and thick flyschoid rocks.

The distribution of REE of metabasalts has been studied (Ivan et al. 1992) in the Gemeric Paleozoic units. Metabasalts are rare in the Gelnica Group, they are close to E-MORB/OIT to CT-types (in the N). The metabasalts of the Rakovec Group are close to typical E-MORB/OIT with some trends to calc-alkaline features. The Gelnica and Rakovec Groups probably represent the relics of a rifted island arc. Metaultrabasites and metabasites of the Klátov Group are close to N-MORB. The

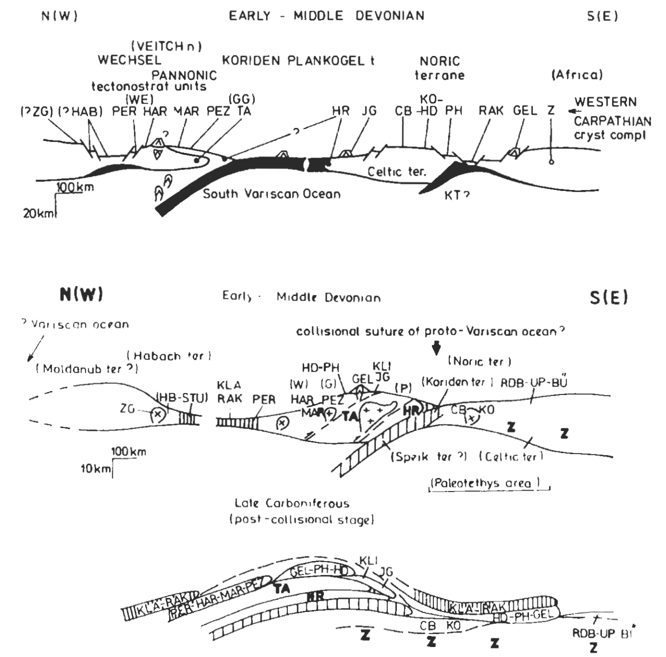

Fig. 5. Supposed (alternative) paleotectonic position of the Western Carpathian crystalline (pre-Carboniferous) complexes in relationship to the Eastern Alpine ones (cf. Fig. 3 in Frisch & Neubauer 1989).
The Early Variscan units: TA - Tatra complex; HR - Hron complex, Z - Zemplín complex.
The Early Variscan ? units: CB - Čierny Balog complex; KO - Kohút complex.
The Late Variscan (accretionary) units: KLA (KT) - Klátov complex; RAK - Rakovec complex; GEL - Gelnica complex; HD - Hladomorná dolina Valley complex; PH - Predná hoľa complex; KLI - Klinisko complex; JG - Jánov grúň complex; PER, HAR, MAR, PEZ - Pernek, Harmónia, Marianka and Pezinok complexes.
The Late Variscan Noric terrane units: RDB-UP-BÜ - Rudabánya, Upony, Bükk complexes, incl. (?) KLA, RAK, GEL c.
Abbreviations: of the Eastern Alpine units: (P) - Pannonic terrane; (HB-STU) - Habach and Stubach units; (ZG) - Zentralgneis unit; (W) - Wechsel unit; (G) - Grobgneis unit. For detailed explanations, see Frisch & Neubauer (1989).
Variscan (future) granitoids: + - mostly S-types, x - mostly I, I-S-types.

evolution of the terrane with the Gemeric Paleozoic units proceeded in a destructive plate margin setting probably in ensialic island-arc with back-arc basins (Ivan et al. 1992), cf. Fig. 5 - the lower part.

Acid to intermediary volcanics are most widespread in the Gelnica Group. Their chemical composition, especially the REE trend, corresponds to the type of island-arc volcanics (Bajaník 1981). Grecula (1982) related their origin to the rift zone, assuming its axial part to had been situated in the present Rakovec Group (cf. Fig. 5 - the upper part). A high percentage of crystaloclasts, or porphyroclasts in these rocks indicates that they belong to island-arc or continental margin volcanics (Faryad & Grecula 1984).

Taking these presumptions into account, the Gemeric basement units appear as a thick accretionary complex, which may have been thrust over the Tatric and Veporic basement, during the Early Carboniferous. The remnants of these partial nappes (Fig. 5) overlie the lower structural level in the Tatric tectonic zone (the Pernek, Harmónia, Marianka and Pezinok units in the Malé Karpaty Mts., the Klinisko and Jánov grúň units in the Low Tatra Mts.), and the Veporic zone (at least Predná hoľa and Hladomorná dolina Valley units).

All the above mentioned Gemeric units comprise a variety of tectonic settings representing oceanic (back-arc ? - the Rakovec-Klátov units) to ensialic (island-arc ? - the Gelnica unit) domains.

The S (SE) vergent nappes formed during the N-ward subduction (?) of the Rakovec-Klátov basin oceanic crust, followed by an obduction during the collisional stage of a Variscan ocean.

The units situated S of the thrust Gemeric basement comprise shallow-water platformal lithological successions (Rudabánya, Upony and Bükk Mts. in northern Hungary) with carbonates, only slightly metamorphosed. They represent a passive continental margin (Noric terrane) situated on the lower plate south of the proto-Variscan ocean suture zone (Fig. 5).

Despite new geochemical data, the geotectonic setting of the Gemeric Early Paleozoic complexes has not been resolved definitively. It is not clear whether these Variscan complexes, are Early Variscan subduction related complexes originating on the upper plate (cf. Fig. 5 - the lower part), or represent different rifting stages of the lower plate (cf. Fig. 5 - the upper part).

Veporic crystalline basement

The present-day Alpidic tectonic structure of the Veporic unit (the region between the Pohorelá and Ľubeník line, Fig. 2) comprises different crystalline complexes.

The northern and central part of the Veporic unit is formed by the Čierny Balog complex (Krist 1976, 1977), composed of gneisses, leptites, amphibolites, intruded by the Late Variscan Hrončok granite body and the large Vepor granitoid pluton (granite to tonalite) 303 - 279 Ma in age according to U-Pb method on zircons (Bibikova et al. 1990, and Bibikova written information).

The Čierny Balog complex underwent the middle-pressure kyanite-sillimanite type of metamorphism according to the mineral assemblage present in some gneisses and leptites (garnet, kyanite, muscovite, biotite, microcline, amphibole, cf. Krist l.c., Krist et al. 1986).

The low pressure andalusite-sillimanite type of metamorphism is apparent in paragneiss enclavas in granitoid rocks (e.g. Kráľova hoľa Massif - Putiš 1981, 1987 a, 1989, or further to the S - Bezák 1991).

The Muráň gneiss complex (orthogneisses, paragneisses to micaschist gneisses, amphibolites) represents a distinctive tectonic element of the south-Veporic Kohút zone (cf. Hovorka et al. 1987), dragged and uplifted along the Murán fault zone.

The Kohút unit (Máška & Zoubek in Buday et al. 1961) is dominated by garnet micaschists intercalated with graphitic and micaceous metaquartzites, lydites as well as metacarbonates and with exceptional, but characteristic tiny bodies of amphibolites, albite-epidote amphibolites and serpentinites. The unit tectonically borders the Čierny Balog complex (or Alpidic Kráľova hoľa tectonic unit) along a reverse-fault plane steeply dipping to the S. Foliation of both neighbouring units is commonly steeply fan-shaped (Gregor 1964). The Variscan regional metamorphism of the Kohút unit reached staurolite-chloritoid zone conditions (Korikovsky et al. 1989).

The southern part of the Kohút unit is dominated by low-grade metamorphic rocks of the so called Hladomorná dolina Valley and Predná hoľa complexes (phyllites to garnet micaschists, greenschists to albite-epidote amphibolites, porphyroids-metakerathophyres, metarhyolites, metagabbros, chloritoid schists, metapsammites, marbles).

The whole region of the Kohút unit is intruded by the Variscan (Bibikova et al. 1988) Rimavica leucocratic granites. The superposed contact metamorphism (andalusite- cordierite hornfelses) on the edge of the Rochovce granite (Permian ?) was recently studied by Vozárová & Krištín (1985).

The Čierny Balog and Muráň complexes, without any proofs of their age, with higher-grade metamorphic rocks could represent a part of Early Variscan units (cf. the Tatric basement), or together with the Kohút unit belong to the Late Variscan basement (cf. the Gemeric basement), that could be comparable with the Noric terrane-units in the Eastern Alps (Fig. 5).

The Noric terrane has undergone intensive extension since the Late Carboniferous, connected with the formation of Paleo-Tethys. This event is also consistent with the Early Alpine history of the Veporic, Gemeric and Meliata units (cf. Kozur & Mock 1987; Kozur 1991; Putiš 1991 a).

Tatric crystalline basement

The Malé Karpaty Mts.

The Paleoalpidic Bratislava Nappe (Mahel' 1980; Plašienka & Putiš 1987) has an internal Variscan structure (Putiš 1987 b, Putiš in Putiš et al. 1991) comprising two principal late Variscan units (Figs. 6, 7):

1 - the higher Pernek-Harmónia unit (PER-HAR u.),

2 - the lower Marianka-Pezinok unit (MAR-PEZ u.).

The PER-HAR u. represents the metamorphic mantle of the Modra granitoid body (320 Ma, U-Pb, Shcherbak et al. 1988).

The MAR-PEZ u. represents the metamorphic mantle of the Bratislava granitoid body (347 Ma, Rb-Sr, Bagdasaryan et al. 1982).

The PER-HAR u. consists of the Pernek and Harmónia lithostratigraphical successions and MAR-PEZ u. consists of the Marianka and Pezinok successions (Putiš l.c.).

Variscan nappe slices comprise different volcano- sedimentary successions although they are the same in age - Upper Silurian - Middle Devonian, according to palynology (Planderová & Pahr 1983; Cambel & Planderová 1985; Planderová & Putiš, unpublished data). The successions generally consist of two formations - the lower A and the upper B, but with distinct lateral differences between the successions, which represent different parts of the Early Paleozoic basin.

The PER and HAR successions have almost identical lower formation A defined by flyschoid alternations of pelites and psammites. Their upper (B) formations differ, with carbonatic lensoidal bodies (boudinaged beds ?, olistholites ?) only in the black shales of the HAR succession, while the PER succession has huge amounts of basaltic tuffs, basalts and locally gabroic rocks.

Both PER and HAR successions were regionally metamorphosed only in the biotite-garnet zone and they must have been tectonically approached before they were intruded and contact metamorphosed by Modra granodiorite. Contact hornfelses, present in both the PER and HAR units, are missing in the PEZ unit with an entirely different lithology, metamorphic zoning, and no relationship to the Modra (allanite-type) granodiorite. However the PEZ unit has a very close relationship to the slightly older Bratislava granitoids (monazite-type, Vilinovič in Putiš et al. 1991) around which so called regional-periplutonic metamorphic zoning (biotite, garnet, staurolite-chlorite and staurolite-sillimanite zones, cf. Korikovsky et al. 1984) without any contact hornfelses occurs.

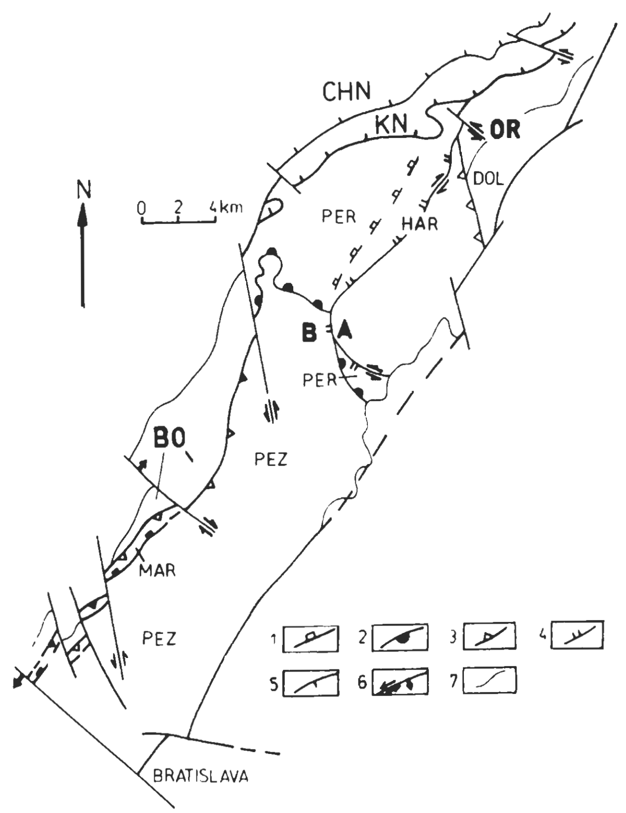

Fig. 6. Distribution of the Variscan and Eoalpidic units in the Malé Karpaty Mts.
Legend: 1 - Late Variscan thrust; 2 - Late Variscan thrust with superimposed transversal Late Variscan compressional fan-like structure; 3 - Cretaceous thrust of the Bratislava Nappe; 4 - Late Cretaceous and younger thrust; 5 - overthrust plane of Krížna (KN) and Choč (CHN) Nappes; 6 - normal and strike slip fault; 7 - primary geological boundary. Other abbreviations according to Figs. 5 & 7.

The MAR succession at the western edge of the Bratislava Massif resembles the PER, HAR (and DOL) successions, because of an increased content of sandy shales in formation A, and marly shales with thin beds of limestones (inside of the greenschists) in formation B. The PEZ succession is dominated by pelites of formation A. The thinned formation B is composed of black shales to quartzites, basalts and tuffs. The regionally metamorphosed MAR unit was thrusted, probably over a hot PEZ unit intruded by the Bratislava granitoid body, because the phyllites of the MAR u. appear to be a late metamorphic temperature overprint connected with growth of porphyroblastic $biotite_2$ mostly in axial-plane schistosity S_2.

The following mutual paleotectonic position of the Variscan units or successions appears (Figs. 5, 8):

The PER u. formed on a thinned continental crust (a back-arc basin ?). Volcanic rocks of both PER and HAR successions (ss.) correspond to slightly differentiated tholeiitic basalts (Hovorka in Grecula & Hovorka 1987) with low contents of the rare elements and distinct negative Europium anomaly.

The presence of limestones in both HAR and MAR ss. speaks for their neighbouring position (Fig. 8).

The distinct flyschoid pelitic-psammitic horizons (A) of the PER, HAR, MAR (and DOL) ss. indicate highly dynamic conditions for their sedimentation. The relief of the basin was later dissected by extensional faults, the basin became generally

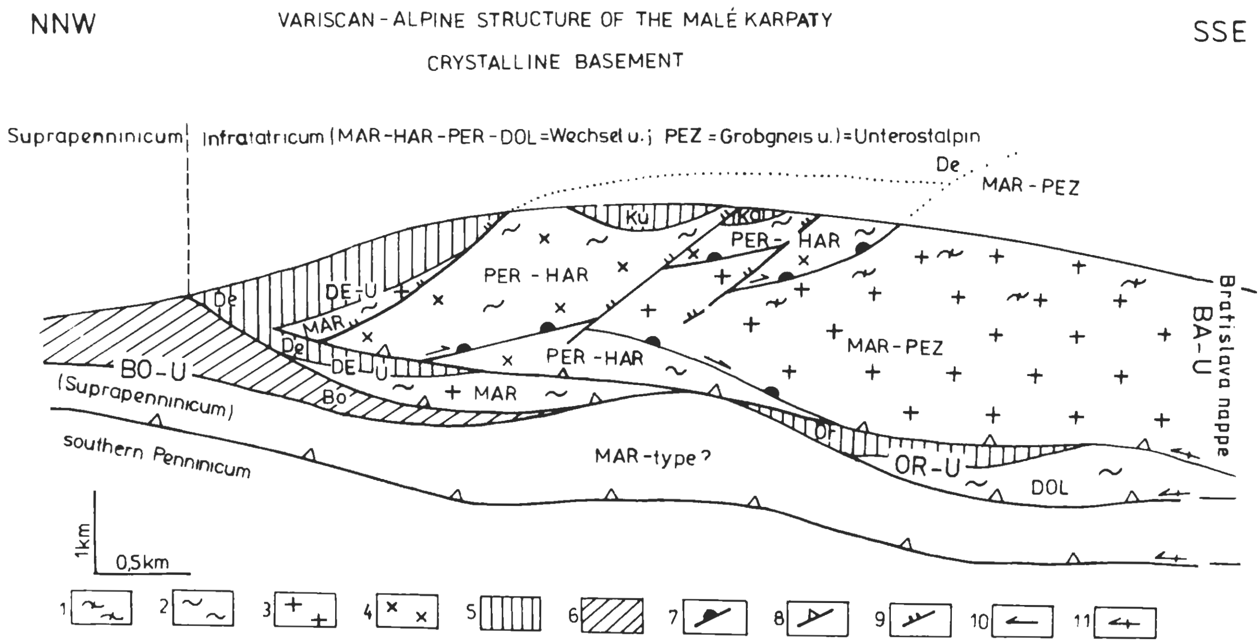

Fig. 7. Relationship of the Variscan and Alpidic basement units in the Malé Karpaty Mts.
Alpidic units: BA-U - Bratislava Nappe; OR-U - Orešany Nappe; BO-U - Borinka subautochthon unit; DE-U - Devín unit (a part of the Bratislava Nappe): De - Devín type of Permian - Mesozoic cover, with Marianka (MAR) type of the crystalline basement; Ku, Ka - Kuchyňa and Kadlubek type of the Mesozoic cover.
Variscan units: PER-HAR, MAR-PEZ - Late Variscan Pernek-Harmónia and Marianka-Pezinok units of the Alpidic Bratislava Nappe, DOL - Doľany crystalline unit of the Alpidic Orešany Nappe.
1 - metamorphic rocks of the MAR-PEZ unit intruded by Bratislava granitoids (3); 2 - metamorphic rocks of the PER-HAR unit intruded by Modra granodiorite (4); 5 - cover units of the Bratislava Nappe (De, Ku, Ka) and Orešany Nappe (Or); 6 - the Borinka (Bo) Mesozoic succession; 7 - Late Variscan thrust (10); 8 - mid-Cretaceous thrust (11); 9 - back thrust.

deeper with subsequent development of formation B comprising black shales, often carbonates and basic magmatites.

The PEZ ss. is likely to have been formed on a continental slope, (Figs. 5, 8). It is dominated by the thick pelitic formation A and with the thin formation B.

The MAR-PEZ u. with the Bratislava granitoids dips down under the PER-HAR u. with the Modra granitoids. The boundary of these two Late Variscan units has the character of a steep fan-like structure that represents probably only the last - transpressional stage of the SE-vergent thrusting of the upper unit over the lower one (Figs. 5, 8).

The west-ward thrusting of the Alpidic Bratislava Nappe (along the Borinka shear zone), under brittle-ductile conditions was accompanied by back-folds, and thrusts along the central Modra shear zone in the upper part of the nappe. The flat-lying Modra shear zone, marked by Permian - Mesozoic rocks, cuts the steep late Variscan fan-like structure. The Paleoalpidic thrust planes, of the Modra shear zone, were later refolded and steepened, during collisional and transpressional Paleogene - Lower Miocene deformation stages comprising strike-slip movements. A steep fold-thrust tectonic style has originated.

Concerning tectonic position, lithology, age, and grade of metamorphism, the Malé Karpaty Mts. crystalline complex could be comparable with the lower Austroalpine - Wechsel unit (especially the PER, HAR, MAR and DOL u.). The PEZ u. appears to be analogous to the Grobgneis unit (Fig. 5).

The Low Tatra Mts.

The nappe structure of the central Low Tatra Mts. (S of the Čertovica line) was based during Variscan orogenesis. Three dis-

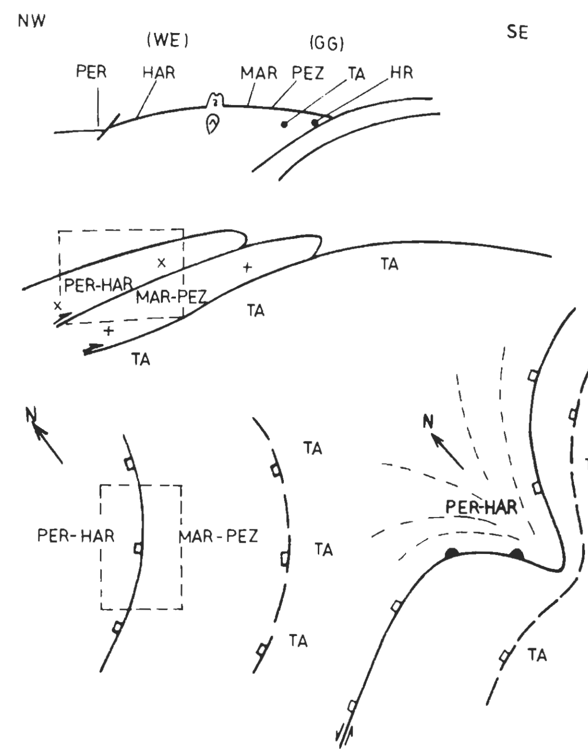

Fig. 8. Paleotectonics and Late Variscan evolution of the Malé Karpaty Mts. crystalline basement units. For abbreviations see text to Figs. 7 & 5.

tinct nappe sheets (the Hron Nappe system, sensu Putiš 1989) built of different lithological and metamorphosed complexes are included into the common Alpine recumbent folds with the same type of Permian - Mesozoic cover.

The Ľubietová Nappe sheet (Putiš 1989) is a part of the Tatra Nappe and belongs together with the Hron Nappe to the Early Variscan tectonic horizon.

The Jánov grúň complex (Miko 1981) Devonian - Early Carboniferous in age (370 Ma, U-Pb method on zircons of porphyroids) already belongs (as a nappe body) to the relatively younger and upper - Late Variscan horizon. It consists of low-grade metamorphic rocks: phyllites, green schists, porphyroids, metapsammites, metadacites. The original magma (cf. Miko l.c.) was calc-alkaline and the crust was a transient (ensialic island arc ?) type (Fig. 5).

Early Alpidic nappes in the Late Cretaceous structure

There is a possibility of dividing the Early Alpidic - Late Cimmerian, Jurassic - Early Cretaceous nappes (190 - 91 Ma) in the southern zones of the Central Western Carpathians.

The first reason for dividing this event is the lithological and age difference between the Tatric-type Mesozoic cover (N of the Pohorelá line) on one side, and the Mesozoic cover of the more southerly zones (the Veporic, Gemeric, Meliata, Silica units) on the other side. The Tatric zone, including the Supra-Tatric area (that is the root zone of the Krížna Nappe), belongs to the area of a general Jurassic - Cretaceous extension, with thick shallow- and deep-water Jurassic - Cretaceous successions and continental-lagoonal Carpathian Keuper in the Upper Triassic. On the contrary, the southern - Veporic, Gemeric, Meliata and Silica zones, belong to the area of a general Triassic extension, with threshold-basin facies in the Veporic unit up to the trough deep-water facies in the Meliata unit with ophiolites in the Middle - Upper Triassic, only with restricted occurrence of the flyschoid Jurassic sediments (Mahel' et al. 1967; Reichwalder 1970; Mahel' 1986; Kozur & Mock 1987; Kozur 1991; Putiš 1991 a).

The second reason of dividing the Early Alpidic event is the various grades of Alpidic metamorphism in the Central Western Carpathians (Plašienka et al. 1989; Korikovsky et al. 1992). The Tatric, including the Supra-Tatric zone is metamorphosed only in very low grade conditions (T - maximum of about 300 °*C* at the depth of 6 - 8 *km*).

The roots of the Krížna Nappe in the Supra-Tatricum are overlain by the Veporic basement nappes, metamorphosed in real low-grade conditions including its Permian - Triassic cover (Struženík or Foederata Group).

The Late Variscan granitoids of the Vepor pluton (303 Ma - tonalites, 279 Ma - porphyric granites, according to U-Pb method, Bibikova et al. 1990) were thrust over the Supra-Tatric zone (sensu Putiš 1991 a, b), or over the Northern Veporicum (sensu Klinec 1966; Putiš 1987 a, 1989). Very strong mylonitic structures and textures defined by new-formed fine-grained low-Ti biotite$_2$, scarcely garnet (with high content of grossularite), muscovite$_2$, minerals of epidote-zoisite group, albite, chlorite, calcite appear in them. A mineral lineation of biotite$_2$ and feldspars in the WNW - ESE direction can be seen on the S-planes (flow structures with superimposed surfaces of ductile mylonitization) of the granitoid mylonites. The mylonites reflects deformation conditions of about 350 - 400 °*C* at depths of 10 - 13 *km*. Such types of Alpidic mylonites (closely related to the deformation and metamorphism of the cover rocks) are unknown in the deeper Tatric unit overriden by the Veporic one. The Veporic mylonites appear to be older, pre-Eoalpidic (pre-Middle Cretaceous), probably Late Cimmerian, according to model depicted in the Fig. 9 (Putiš 1991 a, b).

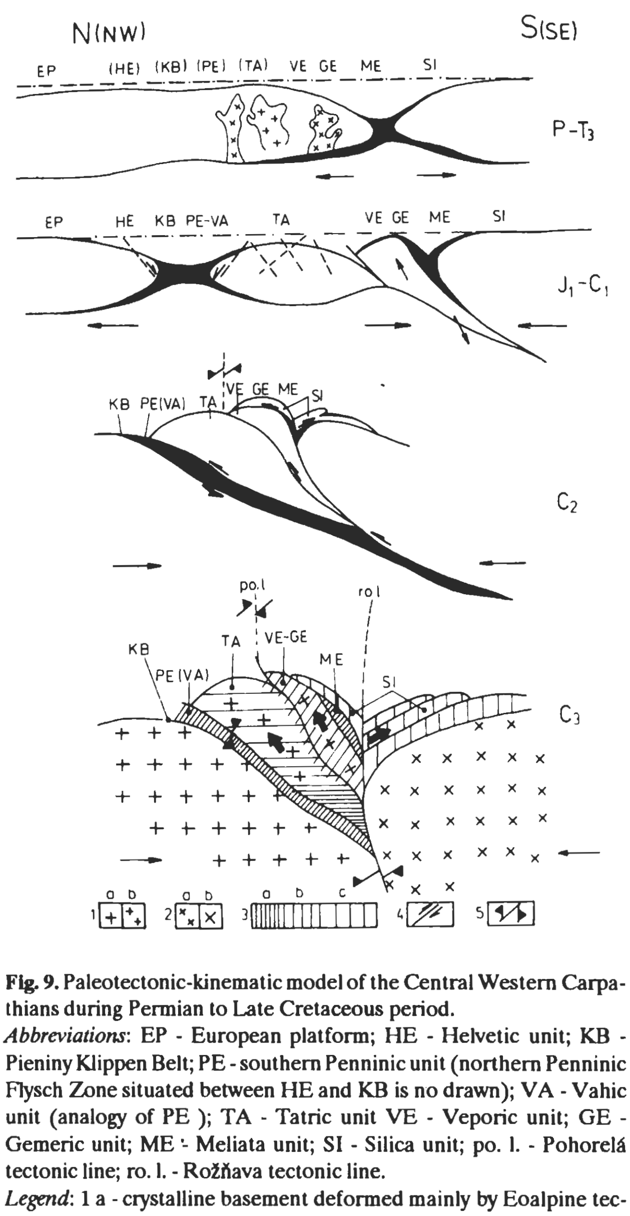

Fig. 9. Paleotectonic-kinematic model of the Central Western Carpathians during Permian to Late Cretaceous period.

Abbreviations: EP - European platform; HE - Helvetic unit; KB - Pieniny Klippen Belt; PE - southern Penninic unit (northern Penninic Flysch Zone situated between HE and KB is no drawn); VA - Vahic unit (analogy of PE); TA - Tatric unit VE - Veporic unit; GE - Gemeric unit; ME - Meliata unit; SI - Silica unit; po. l. - Pohorelá tectonic line; ro. l. - Rožňava tectonic line.

Legend: 1 a - crystalline basement deformed mainly by Eoalpine tectonic events, 1 b - Variscan S-type granitoids; 2 a - Variscan I, I-S type granitoids, 2 b - crystalline basement deformed by Cimmerian and Eoalpidic tectonic events; 3 - grade of the Cimmerian - Eoalpidic metamorphism: a - low-grade, b - low- to very low-grade, c - very low-grade to diagenesis; 4 - vertical Eoalpidic movement direction; - strike slip.

The closure of the Triassic Meliata oceanic trough and subduction of its oceanic crust have left glaucophanites and serpentinites in the Meliata unit. Chloritoid and kyanite (?) are known along the boundary between the Veporic and Gemeric units (Vrána 1964, 1966). Two-interval ages for the Alpine- type fissure veins from the south Veporic zone (Hurai 1983; Hurai et al. 1991; Burchart et al. 1987) are consistent with the previous results. The first generation of the fissure veins formed at the temperature 495 - 420 °*C* in the time interval 143 - 98 Ma, the second one at T = 420 - 320 °*C* in time interval 127 - 92 Ma, according to U-fission track ages of the rock forming minerals.

An uplift of the buried Veporic, Gemeric and Meliata units to the level of the Tatric one before the mid-Cretaceous deformation, that is during the Jurassic to Early Cretaceous (at that time extension was occurring in the Tatric zone), was the result of the collisional event after the closure of the Triassic Meliata oceanic trough and Triassic basins. The stretching lineation (WNW - ESE) is defined by fine-grained mylonitic biotite$_2$ (83 - 103 Ma, Rb-Sr method, Bibikova et al. 1990).

The Eoalpidic (mid-Cretaceous) NW-vergent nappe transport continued due to the Penninic-Vahic oceanic crust subduction that lasted up to the Late Eoalpidic collisional or transpressional sinistral strike slip movements along the Hrádok-Zlatníky, Čertovica, Pohorelá and Ľubeník shear zone (cf. Hók & Hraško 1990; Putiš 1989, 1991 b).

Conclusions

A nappe structure of the crystalline basement is one of the characteristic features of the Alpidic Western Carpathian orogeny. A few generations of the crystalline basement nappes of the different age, kinematics and P-T conditions of their formation have been distinguished in the Western Carpathian basement.

The closure of a proto-Variscan (500 - 415 Ma) ocean caused the formation of the subduction (415 - 380 Ma) and collision (380 - 280 Ma) related highly matamorphosed nappes of the lower Variscan structural level. They are represented by the large-scale, deep-crustal ESE-vergent thrust of the Tatra Nappe over the Hron one due to the closure of a proto-Variscan ocean and subsequent collisional events.

The subduction and collision processes of the basement led to an extension (415 - 380 Ma) and formation of the new volcano-sedimentary complexes, which are metamorphosed incorporated (380 - 280 Ma) into the nappes of the upper Variscan structural level. The south-vergent nappes formed during the northward subduction of the Rakovec (-Klátov) basin oceanic crust and perhaps the related Pernek one.

The Late Variscan collisional stage is roughly consistent with the origin of the granitoid rocks in the time interval 350 - 320 Ma in the Tatric basement (in the N) and 300 - 280 Ma in the Veporic basement (in the S). These data support a model of the southward directed Variscan shortening in the Central Western Carpathian basement.

The southern zones of the Central Western Carpathians (the Veporic, Gemeric, Meliata, Silica units) underwent the Early Alpidic extension or transtension (280 - 190 Ma). The Late Cimmerian (190 - 90 Ma) subduction (190 - 130 Ma), nappe thrusting (130 - 110 Ma) and collisional transpression (110 - 90 Ma) are related to the closure of the Triassic Meliata oceanic trough, Triassic basins and subsequent collisional events. Glaucophane bearing schists, serpentinites, chlorite-bearing and chloritoid schists, as well as biotite mylonites have originated.

The Jurassic - Cretaceous extension (190 - 110 Ma) of the northern zones of the Central Western Carpathians was followed by the Penninic-Vahic oceanic crust subduction (110 - 90 Ma), Paleo-Aplidic nappe formation (90 - 70 Ma) and transpressional sinistral strike slips (70 - 20 Ma).

The Meso-Alpidic (post-Late Cretaceous) nappe (70 - 20 Ma) are evident in the peri-Vahic (or peri-Klippen Belt-, Infratatric-) zone. The Považský Inovec Mts. crystalline basement is thrust and refolded with the Upper Cretaceous sediments of the Klippen Belt-Klape type.

Translated by E. Putišová

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