Mitt. Österr. Geol. Ges.	ISSN 0251-7493	**86** (1993)	S. 83–99	Wien, August 1994

Key words
Slovakia
Western Carpathians
Crystalline
Nappes
Thick-skinnned tectonics
Extensional tectonics
Quartz fabric

South Tatric-Veporic Basement Geology: Variscan Nappe Structures; Alpine Thick-Skinned and Extensional Tectonics in the Western Carpathians (Eastern Low Tatra Mountains, Northwestern Slovak Ore Mountains)

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15 Text-Figures

Contents

Grundgebirgsgeologie des Südtatrikums und Veporikums: Variszische Deckenstrukturen; Alpidische "thick-skinned" Tektonik und Zerrungstektonik in den Westkarpaten (Östliche Niedere Tatra, nordwestliches Slowakisches Erzgebirge)

Zusammenfassung

Duktile Deformationen mylonitischer Orthogneise, gebänderte Amphibolite, sowie höher temperierte Quarzgefüge weisen auf die Reste variszischer Decken (höhere Tatra-Decke und tiefere Hron-Decke) im tatrischen und supratatrischen Untergrund. Die gegenwärtige Dekkenstruktur des supratatrisch-veporischen Untergrundes inclusive der Hüllgesteine ist im wesentlichen das Resultat einer „thick-skinned" Tektonik. Sie wird mit einer kontinentalen Verkürzungphase in dem Gebiet verknüpft, das den geschlossenen triadisch-jurassischen Bekken wie z.B. dem ozeanischen Meliata Becken südlich der veporischen und gemerischen Zone benachbart ist.

Auf die transpressive Hebung der Vepor- und Gemer-Einheit folgt eine extensive Überschiebung nach E–ESE und die Exhumierung tiefer und metamorphosierter (Granat-Biotit- oder Chloritoid-Disthen-Biotit-Zone) Niveaus der veporischen und supratatrischen Einheit. Ausgedehnte Mylonit- und Phyllonit-Zonen begleiten die tiefen Partien bedeutender Brüche wie die des Pohorela- und Lubenik-Bruches mit einer komplizierten tektonischen Entwicklung.

Abstract

Ductile deformations of mylonitic orthogneisses and layered amphibolites, as well as higher-temperature quartz c-axis fabrics, indicate remnants of Variscan (higher Tatra- and lower Hron-) nappes in the Tatric and Supratatric basement. The present-day nappe structure of the Supratatric-Veporic basement including, the cover rocks are mainly the result of the Alpine thick-skinned tectonics. We connect it with the continental shortening phase that occurred in the area adjacent to closed Triassic-Jurassic basins such as the Meliata oceanic basin situated S of the Veporic and Gemeric zones.

Transpressional uplift of the Veporic (and Gemeric) unit was followed by top-to-E(ESE) extensional thrusting and exhumation of deeply buried and metamorphosed (in garnet-biotite, or chloritoid-kyanite-biotite zone) levels of the Veporic and Supratatric tectonic units. Large mylonite and phyllonite zones accompany deep parts of significant faults like the Pohorela and Lubenik faults with the complex tectonic history.

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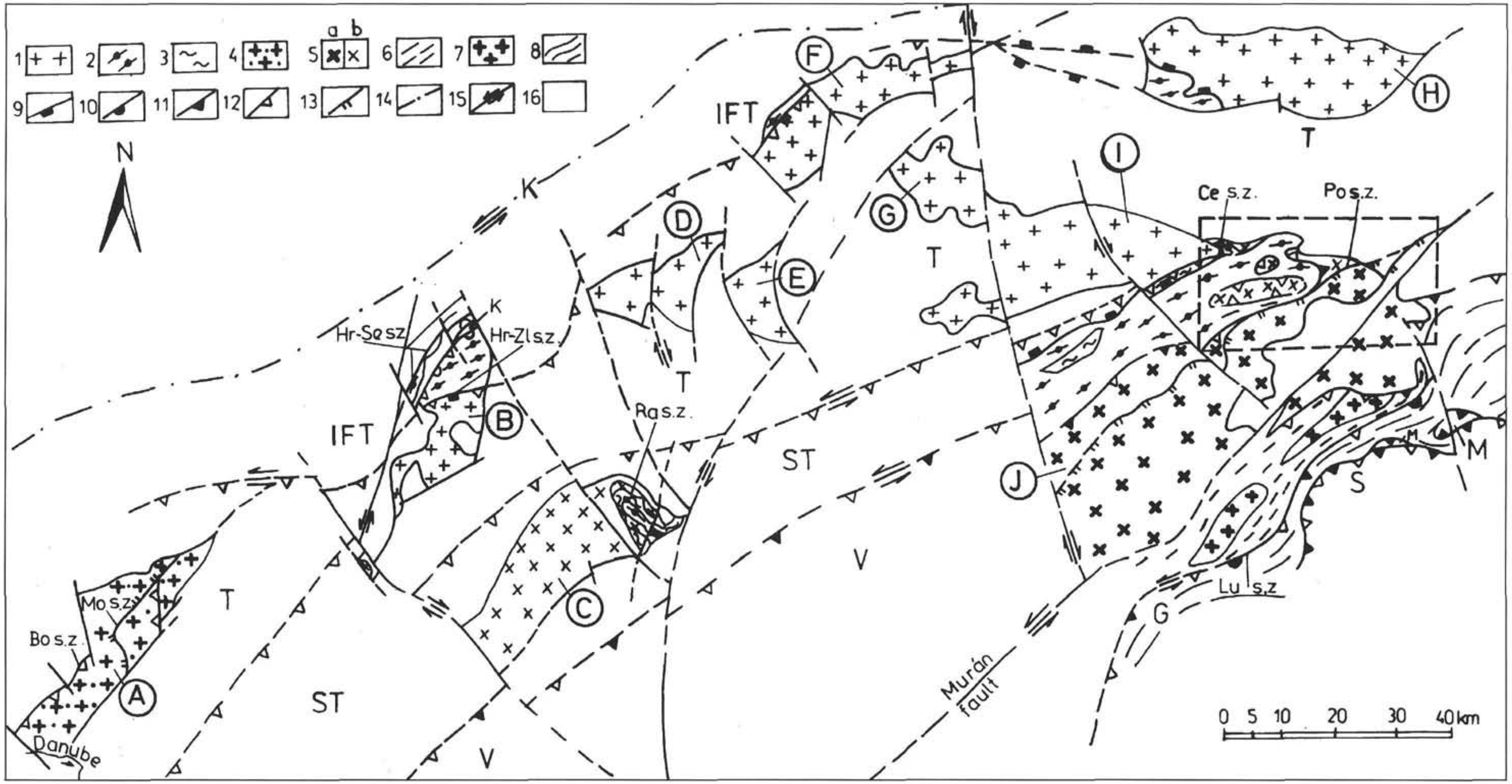


Text-Fig. 1.
Tectonic sketch-map of the Tatric and Veporic zones crystalline basement complexes (PUTIŠ, 1992).
Tatric basement (1–4): 1 = Tatra (lithostratigraphical) complex in the Tatra Nappe (for explanation see tex); 2 = Hron complex in the Hron Nappe; 3 = Lubietova succession as a part of the Tatra complex and Nappe; 4 = Male Karpaty Mts. (Little Carpathian Mts.) crystalline complexes.
Veporic basement (5–7): 5 = the Cierny Balog complex (5a = a part of the Veporic zone, 5b = thrust over the Supratatric zone); 6+7 = the south Veporic crystalline complexes.
Gemeric crystalline basement (8).
Structural elements (9–15): 9 = Early Variscan (appr. Early Devonian) thrust; 10 = Late Variscan (Early Carboniferous) thrust; 11 = Early Alpine (Late Jurassic-Early Cretaceous) thrust; 12 = mid-Cretaceous thrust; 13 = reverse fault; 14 = Klippen Belt axis; 15 = strike-slip fault; 16 = post-Early Carboniferous complexes.
Abbreviations of the Alpine tectonic zones: K = Klippen Belt unit; IFT = Infratatric zone; T = Tatric zone; ST = Supratatric zone; V = Veporic zone; G = Gemeric zone; M = Meliata unit; S = Silica unit.
Abbreviations of the shear zone names: Bo s.z. = Borinka shear zone (further s.z.); Mo s.z. = Modra s.z.; Hr-Se s.z. = Hradok-Selec s.z.; Hr-Zl s.z. = Hradok-Zlatniky s.z.; Ra s.z. = Razdiel s.z.; Ce s.z. = Certovica s.z.; Po s.z. = Pohorela s.z.; Lu s.z. = Lubenik s.z. A–J in circle = the mountains with crystalline basement: A = Male Karpaty Mts. (Little Carpathian Mts.); B = Povazsky Inovec Mts.; C = Tribec Mts.; D = Strazovske vrchy Mts.; E = Ziar Mts.; F = Mala Fatra Mts.; G = Velka Fatra Mts.; H = Vysoke Tatry Mts. (High Tatra Mts.); I = Nizke Tatry Mts. (Low Tatra Mts.); J = Slovak Ore Mts.
The investigated area is framed on the right side of the figure.

1. Introduction

The Dumbier massif crystalline and cover rocks belong to the Alpine (mid-Cretataceous) Tatric zone of the Central Western Carpathians (Text-Figs. 1,3).

Concepts accepted to this date in the Western Carpathians (MAHEL' et al., 1968; MAHEL', 1986) assign the area between the Certovica and Pohorela lines (Text-Figs. 1,3) to the Northern Veporicum (Supratatricum, sensu PUTIŠ, 1992). How can we use the terms Tatricum, Supratatricum, Veporicum, designating the main Alpine (mid-Cretaceous) zones of the Central Western Carpathians?

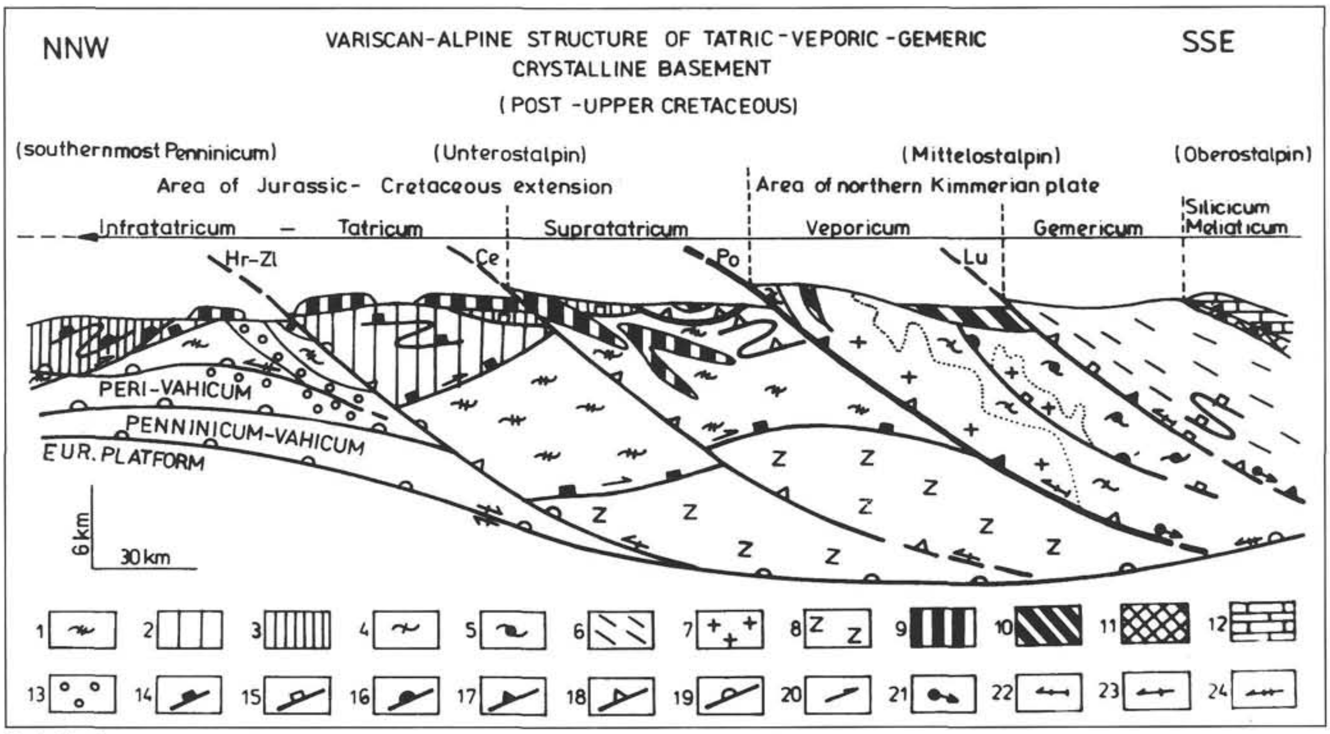
From the view point of the lithological facies of the parautochthonous Mesozoic cover, the Velky bok parautohthonous succession in the Northern Veporic (or Supratatric) zone and also as a part of the Krizna Nappe the thick Jurassic–Middle Cretaceous sediments, shallow-water as well as abyssal facies and Carpathian Keuper tends more to the Tatricum, it is a zone of a general Jurassic-Cretaceous extension (Text-Fig. 2). Both the Tatric and Supratatric zones have comparable lithological facies of the same age. It would be perhaps more precise and convenient to regard the area between the Certovica and Pohorela lines as the Supratatric, rather than the Veporic zone. Similarly, the northern margin of the Tatric zone (the Infratatricum) displays a more complex deformation history and tectonic style than the central Tatric zone (PUTIŠ, 1991a, 1991b, 1992).

On the other hand the so called Southern Veporicum (S of the Pohorela line) exhibits a different lithological facies from those of the Northern Veporicum. It comprises swell-basin facies of the unified Foederata (or Struzenik) succession indicating a general Triassic extension of the Veporic unit. At the present day this unit is roughly situated S of the Pohorela fault zone (Text-Figs. 1, 2, 3, 4). This part of the Veporic zone converges to the southern areas adjacent to the Meliata oceanic basin with Triassic-Jurassic succession, (KOZUR & MOCK, 1987; KOZUR, 1991). Due to these reasons we use the term "Veporicum" only for the area between the Pohorela and Lubenik lines (cf. PUTIŠ, 1992) with the Permian-Mesozoic cover of the Foederata (or Struzenik) succession.

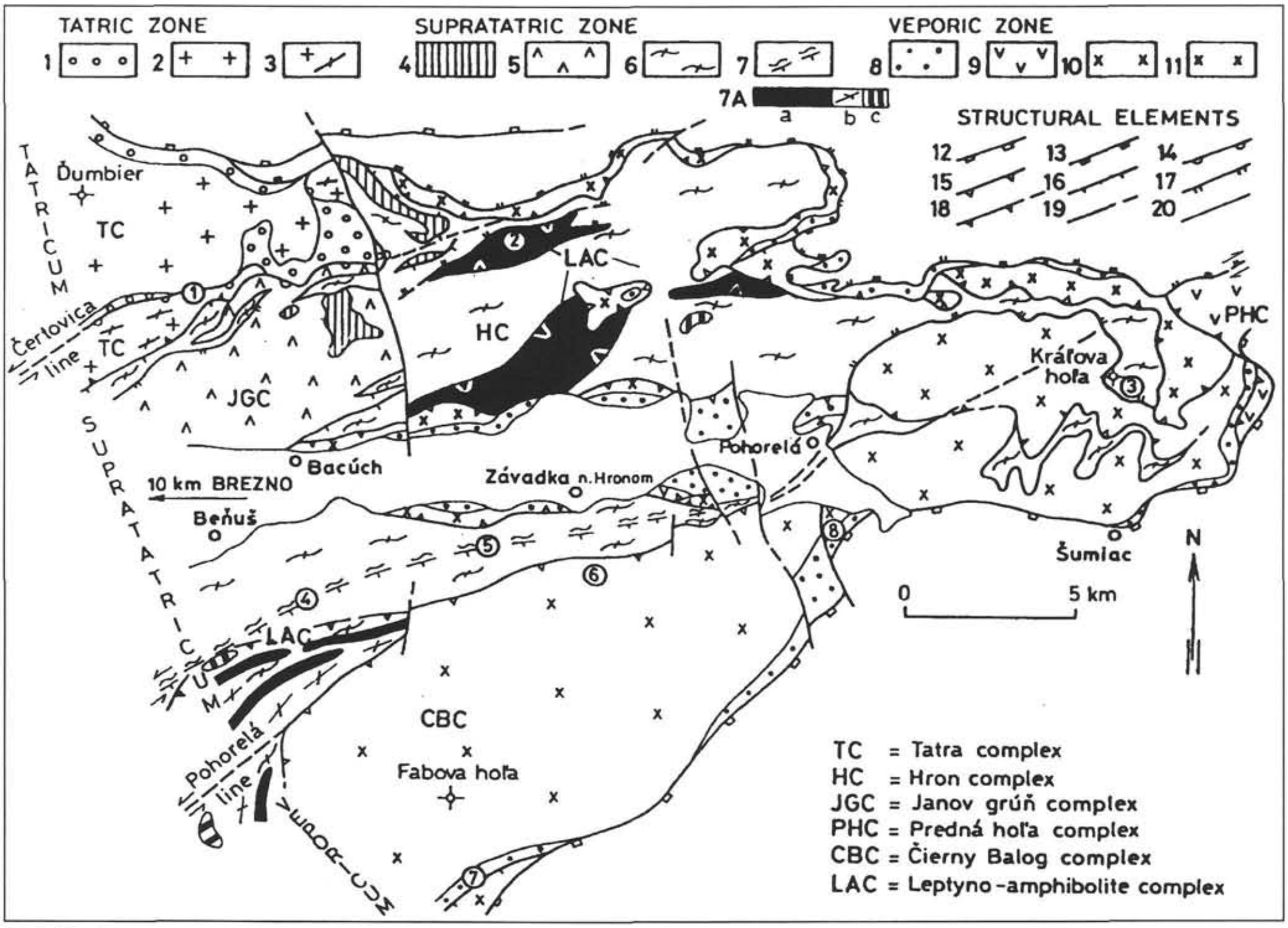
The purpose of this paper is the possible identification of the Variscan nappe tectonics within the Tatric (incl. the Supratatric) basement, as well as the Alpine thrust, strike-slip and extensional tectonics of the Supratatric and Veporic tectonic zones that roughly correspond to the Supratatric and Veporic tectonic units. The basis of the tectonic-sketch map of the Supratatric-Veporic basement (Text-Fig. 3) are recently published geological-tectonic maps of this area (PUTIŠ, 1981, 1987a, 1989, 1991a; MIKO, 1981). Special attention is devoted to successions of deformation stages, their tectonic styles, structural element associations, the recrystallization processes and quartz fabrics.

An attempt to define Variscan and Alpine shear zones has been made on the basis of the previous criteria.

The nappe structure of the crystalline basement is one of the characteristic features of the Alpidic Western Carpathian orogeny. There no doubt about the existence of Alpine nappes including the crystalline basement (KETTNER, 1938; KOUTEK, 1931; JAROS, 1971; KLINEC; 1966; KAHAN, 1969; GRECULA, 1974, 1982; JACKO, 1979; PUTIŠ, 1983, 1987a,b, 1989, 1991a,b, 1992; KRIST et. al., 1992). A possible Varis-

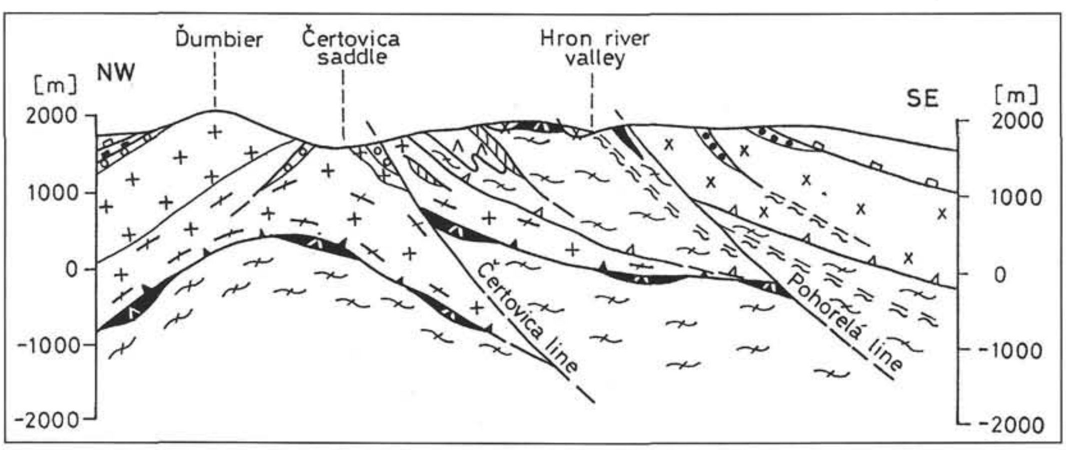


Text-Fig. 2.
Variscan-Alpine structure of the Western Carpathian crystalline basement (PUTIŠ, 1992).
1 = Hron Nappe; 2 = Tatra Nappe; 1+2 = Early Variscan nappes of the lower Variscan structural level; 3 = Late Variscan nappes of the Tatric zone; a part of the upper Variscan structural level; 4 = north Veporic Cierny Balog complex; 5 = south Veporic Kohut, Hladomorna dolina and Predna hola complexes; 6 = Gemeric crystalline basement: Klatov, Rakovec, Gelnica and other complexes; 7 = Late Variscan granitoid Vepor pluton; 8 = Zemplin type of crystalline basement (pre-Cambrian?); 9 = Krizna Nappe; 10 = Foederata (Struzenik) succession; 11 = Meliata unit; 12 = Silica unit; 13 = Middle-Upper Cretaceous sediments; 14 + 20 = Early Variscan thrust; 15 + 16 = Late Variscan thrust; 21 = extensional faults; 17 + 22 = Early Alpine (Late Cimmerian) thrust; 18 + 23 = mid-Cretaceous thrust; 19 + 24 = Laramian and younger thrust.
The central Western Carpathians are considered as a part of African (Adriatic) plate like the Austroalpine units in the Eastern Alps (compare Text-Fig. 15).



Text-Fig. 3.
Geological–tectonic sketch map of the Low Tatra Mts.-E and the Slovak Ore Mts.-NW (PUTIŠ; origal fig.).
Tatric zone: 1 = Tatric cover (Upper Carboniferous–Middle Cretaceous) rocks: Lower Triassic shales and quartzites; Middle Triassic limestones and dolomites here; 2 = Tatra complex (see text); 3 = Lubietova succession of the Tatra complex.
Supratatric zone: 4 = Permian-Triassic remnants (roots) of the Velky bok (Supratatric cover) succession included into the Krizna Nappe; 5 = Janov grun complex (see text); 6 = Hron complex (see text); 7 = mylonitic schists (phyllonites); 7A = Leptyno-amphibolite complex (sensu HOVORKA & MERES; 1993): a = banded amphibolite, b = orthogneiss, c = serpentinite.
Veporic zone: 8 = Veporic cover (Permian–Triassic) rocks: Permian arcoses, shales, acid volcanics and volcanoclastics, Lower Triassic quartzites, acid volcanics and volcanoclastics, Middle Triassic limestones and dolomites, Upper Triassic limestones, dolomites and dark calcareous shales; 9 = Predna hola complex (see text); 10 = Cierny Balog complex (mostly late Variscan granitoids of the Vepor pluton with gneissous mantle; 11 = tonalite nappe (a part of the Vepor pluton).
Structural elements: 12 = thrust of the higher (non-metamorphosed) Mesozoic nappes (the Muran and Choc Nappes); 13 = thrust of the Krizna Nappe; 14 = mid-Cretaceous thrust of the Supratatric tectonic unit; 15 = Late Jurassic–mid- Cretaceous thrust of the Veporic tectonic unit; 16 = internal subhorizontal thrusts within the tectonic units; 17 = reverse fault-thrust; 18 = Variscan thrust; 19 = tectonic boundary; 20 = primary geological boundary.

can age of thrust tectonics in the High Tatra Mts. was considered by KAHAN (1969). GRECULA (1982) considered Variscan nappes in the Gemeric unit. Recent petrological and structural data (JANAK, 1991, 1992; JANAK & ONSTOTT, 1993; FRITZ et al., 1992; PUTIŠ, 1992; PUTIŠ et al., 1991, 1993) support this idea.



Text-Fig. 4.
Tectonic (partially idealized) profile through the south Tatric; Supratatric and north Veporic area; between the Dumbier and Fabova hola massifs (PUTIŠ, original fig.).
For explanation see Text-Fig. 3.

KLINEC (1966) defined a few Alpine N-vergent crystalline nappes in the Veporic zone. The first data on Alpine metamorphism of the basement and the cover rocks were presented by VRANA (1964, 1966, 1980) from the southern parts of the Veporic unit.

2. Geology and Tectonics of the Supratatric and Veporic Zones (Low Tatra Mts.-E, Slovak Ore Mts.-NW)

2.1. The Supratatric Zone

The Alpine (mid-Cretaceous) Supratatric zone can be defined as a root zone with a parautochthonous position of the Mesozoic cover rocks later included into the Krizna Nappe and thrust N-NW over the Tatric zone. The Supratatric zone (Text-Figs. 1, 3) is bordered by the Certovica (in the N) and the Pohorela lines (in the S). The basement rocks are covered by the Permian–Middle Cretaceous Velky bok type lithostratigraphic succession included in the Alpine basement imbrication structures.

Geographically the Supratatric zone (Text-Fig. 1) comprises the eastern part of the Low Tatra Mts. (east of Certovica line), the Hron river Valley, the northwest part of the Slovak Ore Mts. (S of the Hron river) and the Tribec Mts.

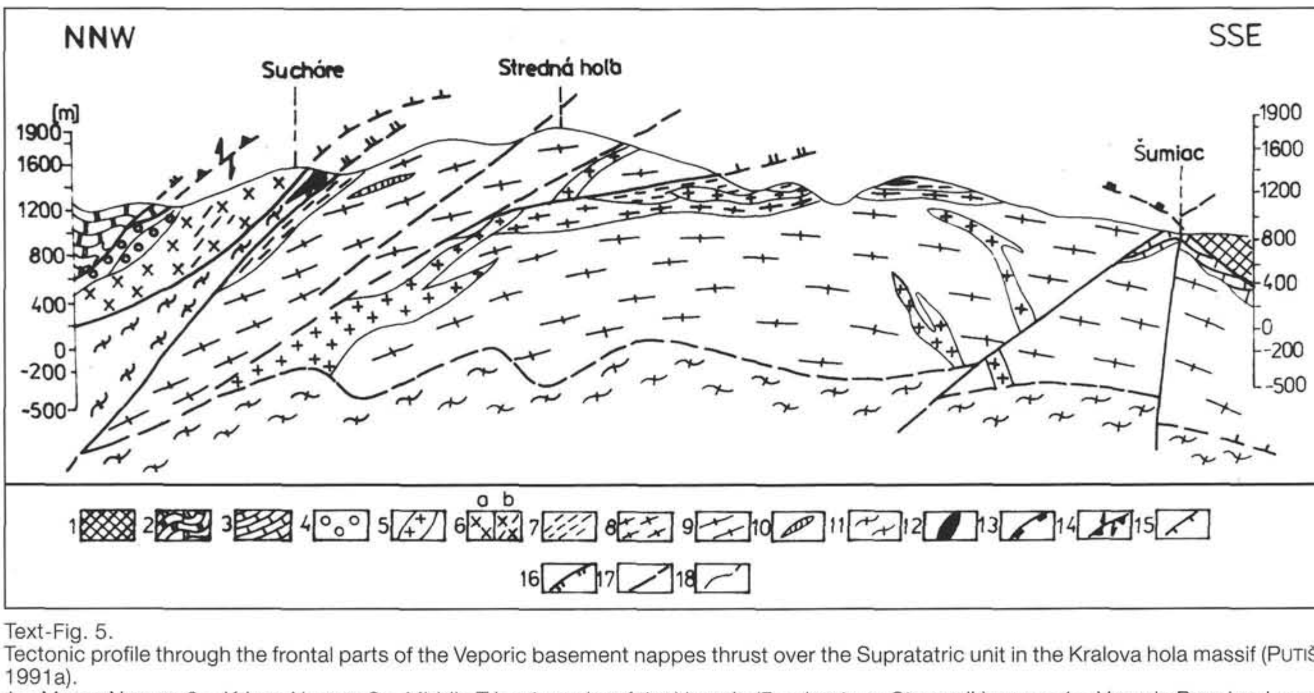
The Supratatric basement is built up of the crystalline nappes covered by the same Mesozoic (the Velky bok type) succession (Text-Figs. 3, 4). They are:

1) The Janov grun Nappe, formed by the Janov grun complex (greenschists, metarhyolites, granite metaporphyrs, metadacites, phyllites, metasandstones, mica schist phyllites, Upper Silurian-Lower Carboniferous in age).
2) The Hron Nappe, formed by the Hron complex (micaschists, micaschist-gneisses, metaquartzites, amphibolites, less paragneisses and orthogneisses, Lower Paleozoic, Cambrian-Silurian?, Precambrian? in age).
3) The Tatra Nappe, represented here by the Lubietova succession (paragneisses, augen to layered gneisses, migmatites with large bodies of mylonitic orthogneisses, less amphibolites, Lower Paleozoic, Cambrian-Silurian?, Precambrian? in age).
4) The "Leptyno-amphibolite" Nappe (?) formed by the Leptyno-amphibolite complex (LAC, sensu HOVORKA et al., 1992; HOVORKA & MERES, 1993) consisting of banded (layered) amphibolites, orthogneisses and tiny bodies of serpentinized (antigorite) metaperidotites (Lower Paleozoic ?) in the area studied.

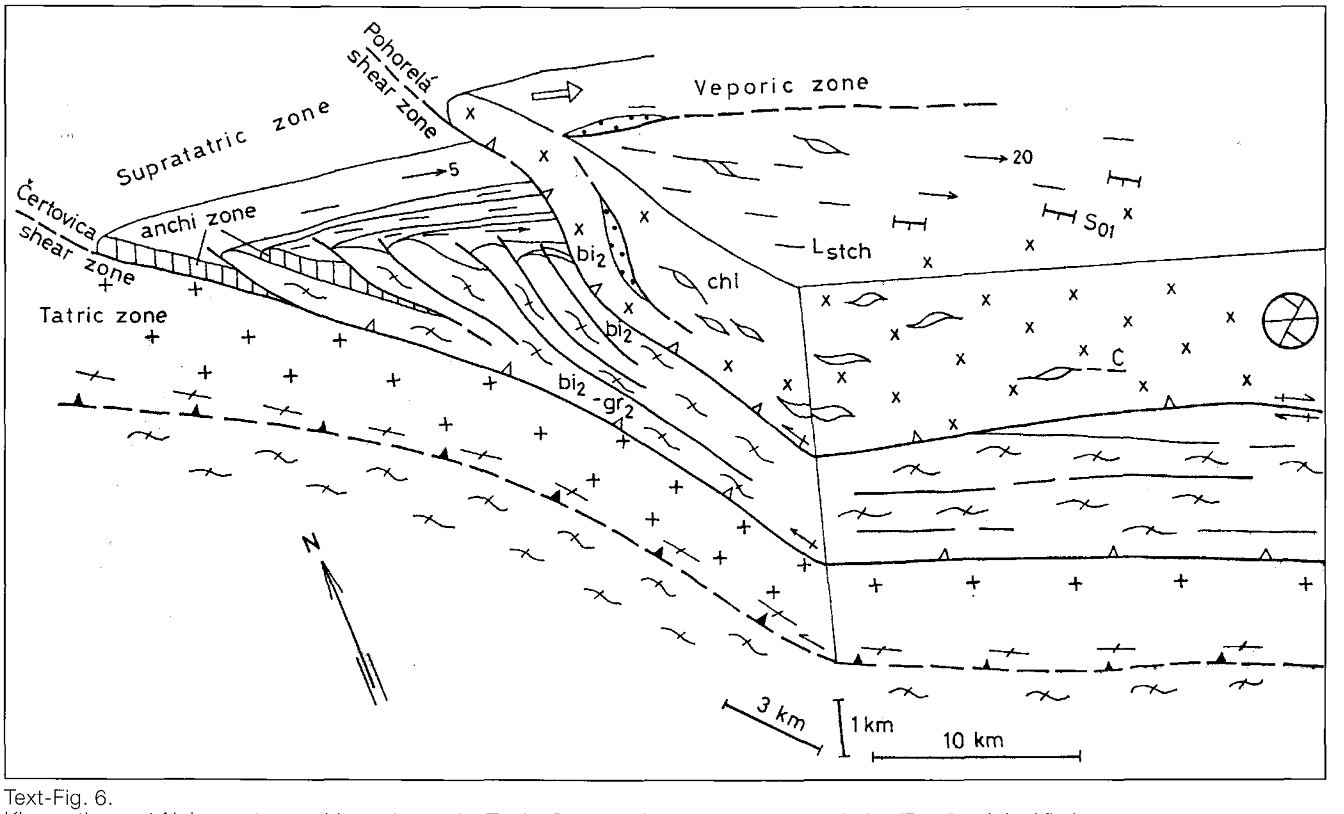
The Tatra, Hron and Leptyno-amphibolite complexes (nappes) belong to the lower Variscan structural level of the Western Carpathian crystalline basement (PUTIŠ, 1992) with features of the Early Variscan tectonometamorphic evolution, especially in the Tatric, including the Supratatric basement (Text-Figs. 1, 3, 4).

The Janov grun complex (nappe) belongs to the upper Variscan structural level of the Western Carpathian basement, together with the Gelnica, Rakovec, Klatov? (in the Gemeric basement), the Predna hola, Hladomorna dolina, Kohut? and Cierny Balog? complexes (in the Veporic basement) and the Male Karpaty (Marianka, Pezinok, Pernek, Harmonia, Dolany) complexes together with the Klinisko complex, in the Tatric basement (Text-Figs. 1, 2). These low-grade volcano-sedimentary complexes indicate an extensional regime during their formation in the Silurian to Late Devonian (Text-Fig. 15).

Ductile deformation of quartz and feldspars in mylonitic orthogneisses indicate temperatures of mylonitization over 450°C. The deformation is assigned to the Late Variscan nappe thrusting of the Tatra Nappe over the Hron Nappe (PUTIŠ, 1992) in the Tatric, incl. the Supratatric basement (KAHAN, 1969; JANAK, 1991; PUTIŠ et al., 1991; PUTIŠ, 1992;



Text-Fig. 5.
Tectonic profile through the frontal parts of the Veporic basement nappes thrust over the Supratatric unit in the Kralova hola massif (PUTIŠ, 1991a).
1 = Muran Nappe; 2 = Krizna Nappe; 3 = Middle Triassic rocks of the Veporic (Foederata or Struzenik) cover; 4 = Veporic Permian-Lower Triassic cover; 5 = aplitoid and pegmatitoid granites; 6 = metatonalites (tonalite mylonitic orthogneisses), 6a, tonalite mylonitic schists, 6b; 7 = phyllonites of the medium-grade metapelites; 8 = garnet micaschists; 9 = augen granitic mylonites; 10 = leptinites (sensu KRIST et al., 1986); 11 = micaschists to gneisses of the Hron complex (the Supratatric basement unit); 12 = amphibolites; 13 = thrust of the Muran Nappe; 14 = thrust of the Krizna Nappe; 15 = thrust of the tonalite nappe; 16 = reverse thrust-fault; 17 = fault; 18 = primary geological boundary.



Text-Fig. 6.
Kinematics and Alpine metamorphic zoning at the Tatric; Supratatric and Veporic boundaries (PUTIŠ, original fig.).
Black square-line in the Tatric zone means the Variscan overthrust plane of the (higher) Tatra Nappe over the Hron Nappe, with orthogneiss mylonites in the hangingwall of the Tatra Nappe. Other relationships are obvious according to Text-Fig. 3, 4.

FRITZ et al., 1992; JANAK & ONSTOTT, 1993; PUTIŠ et al., 1993; HOVORKA & MERES, 1993). The Tatra Nappe is formed by the Tatra complex, including the Lubietova succession – paragneisses, anatectic migmatites, S-type granitoids, orthogneisses and lesser amphibolites.

The Hron Nappe is formed by the Hron complex micaschists, micaschist-gneisses, metaquartzites, amphibolites, lesser paragneisses and orthogneisses. The lower Variscan Hron Nappe dominates in the Supratatric zone.

The higher Tatra Nappe, on the other side, dominates in the Tatric zone, more to the north, with tectonic windows into the lower Hron Nappe (Text-Fig. 1).

The upper part of the Hron Nappe consists mainly of amphibolites, including a few km large bodies of banded (layered) amphibolites (Text-Fig. 3) resembling the Leptyno – amphibolite complexes of Variscides. These rocks were defined as an independent Leptyno-amphibolite complex (= LAC, in HOVORKA & MERES, 1993) comprising small bodies of serpentinites disappearing within the Hron complex, as a part of the Hron Nappe.

The WNW–ESE orientation of hornblendes and biotites indicate the direction of the Variscan nappe transport. The quartz c-axis fabric patterns (Text-Fig. 7) from the layered amphibolites indicate high-temperature prisma <c> glide in quartz within the light-coloured layers and mostly a pure shear regime of deformation.

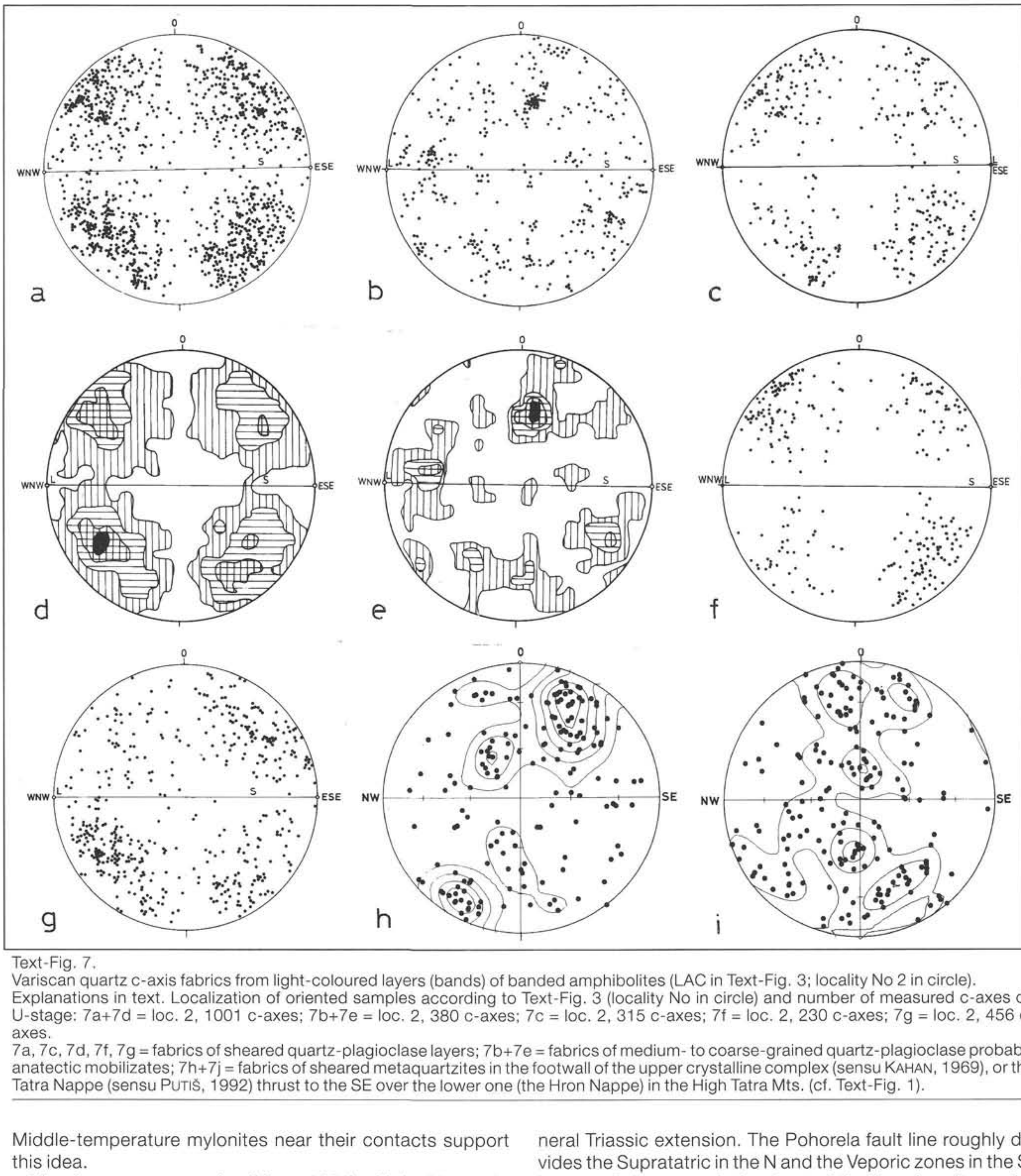
This type of fabric strongly differs from the patterns along the Alpine shear zones (Text-Figs. 8, 9) and can be interpreted to be due to Variscan deep crustal thinning and thrusting of the LAC together with the upper Variscan Tatra Nappe over the lower Variscan Hron Nappe. South to southeastward thrusting was confirmed in the High Tatra Mts. by FRITZ et al. (1992).

The mid-Cretaceous Certovica sinistral shear zone incorporates the Lower Triassic quartzites and rauhwackes of the Middle Triassic limestones and dolomites of the Tatric cover overlying the basement rocks of the Dumbier massif (the western part of the Low Tatra Mts.). The Certovica line can be defined as a surface along which the Supratatric unit (or the Northern Veporicum according to other authors) was overthrust towards the NW onto the Tatric tectonic unit and at the same time as a scar left after the expulsion of the Mesozoic Krizna Nappe to the NW (ZOUBEK, 1931, 1935; ANDRUSOV, 1937; BIELY & FUSAN, 1967, etc.).

The Certovica shear zone does not separate distinct basement rocks. Both sides are formed by augen bearing, banded orthogneiss – mylonites derived from migmatite to granitoid rocks occurring in both the Dumbier (the Tatric zone) and Lubietova (the Supratatric, or the North Veporic zone) crystalline divided by the Certovica line.

The only anchimetamorphic recrystallization of the Permian-Mesozoic cover incorporated into the basement tectonic structures in the south Tatric and north Supratatric area (PLASIENKA et al., 1989; KORIKOVSKY et al., 1992) is reflected by low-temperature mylonites to cataclasites of the basement rocks. The degree of recrystallization is weak. Only local quartz subgrains along the quartz/quartz and quartz/feldspar boundaries, or only deformation lamellae are present (PUTIŠ, 1991b).

In the structural style of recumbent folds of the first Alpine deformation stage AD1 (PLASIENKA, 1981, 1983; PUTIŠ, 1981, 1987a) the Janov grun, Hron and Tatra (the Lubietova succession) complexes have identical cover rocks (the Velky bok succession). It is strongly believed that these complexes approached one another (probably in the form of nappes) during the pre-Alpine, i.e. Variscan orogeny.



Text-Fig. 7.
Variscan quartz c-axis fabrics from light-coloured layers (bands) of banded amphibolites (LAC in Text-Fig. 3; locality No 2 in circle). Explanations in text. Localization of oriented samples according to Text-Fig. 3 (locality No in circle) and number of measured c-axes on U-stage: 7a+7d = loc. 2, 1001 c-axes; 7b+7e = loc. 2, 380 c-axes; 7c = loc. 2, 315 c-axes; 7f = loc. 2, 230 c-axes; 7g = loc. 2, 456 c-axes.
7a, 7c, 7d, 7f, 7g = fabrics of sheared quartz-plagioclase layers; 7b+7e = fabrics of medium- to coarse-grained quartz-plagioclase probably anatectic mobilizates; 7h+7j = fabrics of sheared metaquartzites in the footwall of the upper crystalline complex (sensu KAHAN, 1969), or the Tatra Nappe (sensu PUTIŠ, 1992) thrust to the SE over the lower one (the Hron Nappe) in the High Tatra Mts. (cf. Text-Fig. 1).

Middle-temperature mylonites near their contacts support this idea.

The Janov grun complex (MIKO, 1981) with its Mesozoic cover is a segment of the core of a recumbent megafold deeply eroded in the Bacuch valley (Text-Figs. 3, 4). It is overlain by the upper flank of the megafold built up by the Hron complex. The formation of the recumbent folds is related to the Alpine–mid-Cretaceous thrusting of the Supratatric over the Tatric zone, that is also tectonically connected to the Krizna Nappe formation.

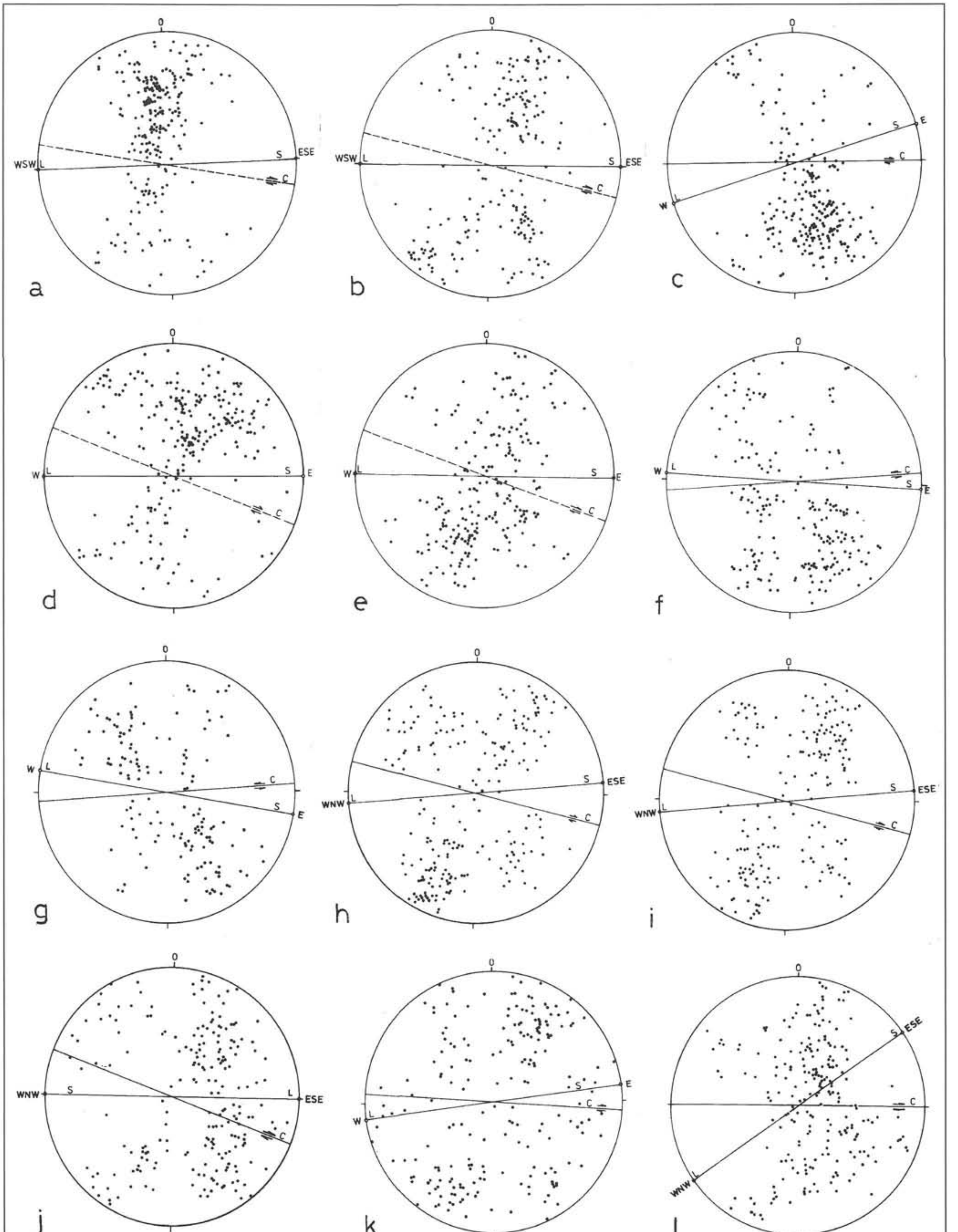
2.2. The Veporic Zone

The Alpine (mid-Cretaceous) Veporic zone of the Central Western Carpathians belongs to an area of an earlier, general Triassic extension. The Pohorela fault line roughly divides the Supratatric in the N and the Veporic zones in the S, but equally important is the thrust of the Veporic unit over the Supratatric one (Text-Figs. 3, 4, 5, 6). The Lubenik fault line the same way divides the Veporic and the Gemeric zones.

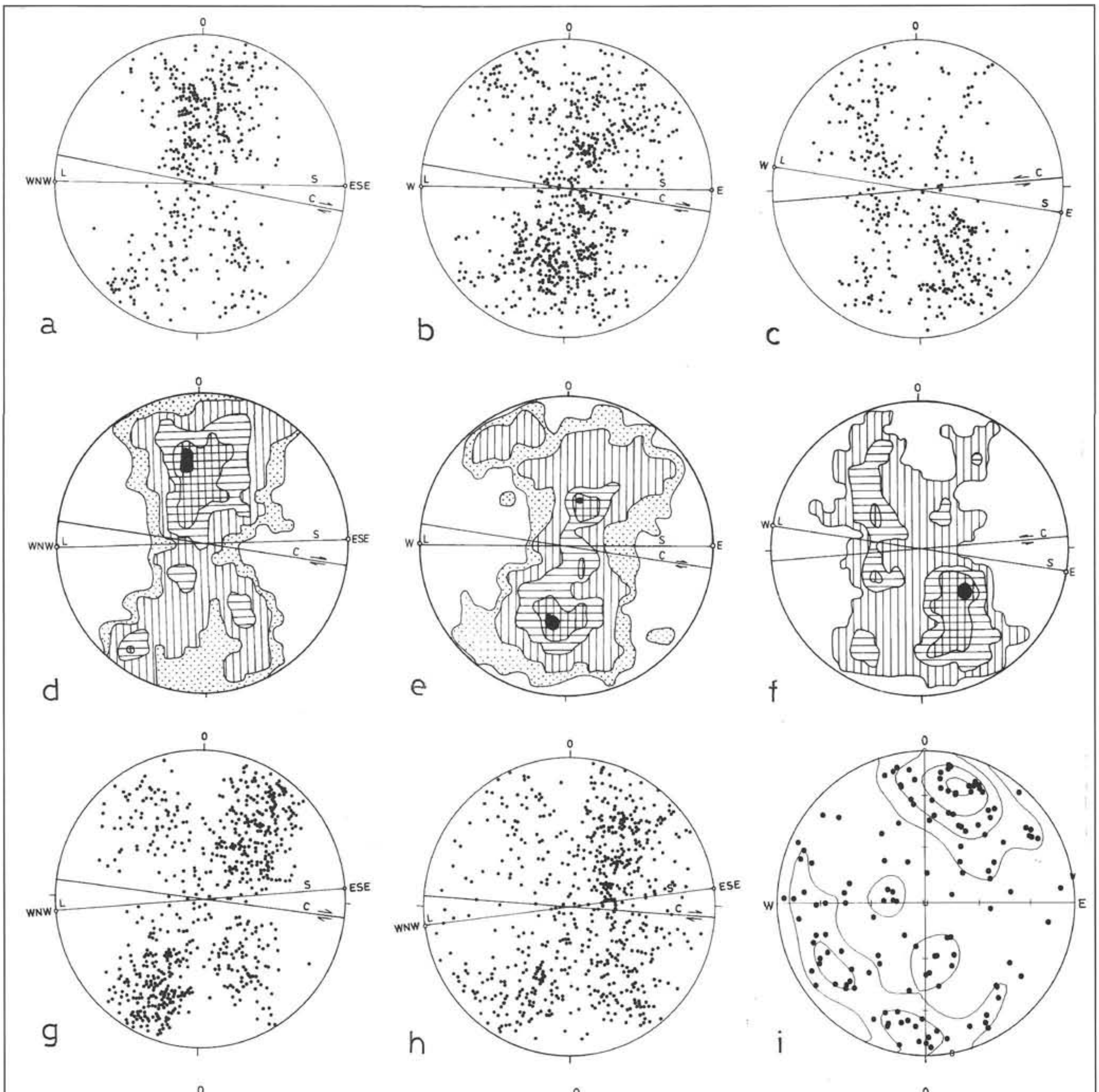
Geographically, the Veporic zone (Text-Figs. 1, 3) comprises the easternmost part of the Low Tatra Mts. (Kralova hola massif) and the W part of the Slovak Ore Mts.

The present-day Alpine tectonic structure of the Veporic unit includes different crystalline complexes:

The northern and central part of the Veporic unit is formed by the Cierny Balog complex (KRIST, 1976, 1977) composed of gneisses, leptites, amphibolites, (Lower Paleozoic?) intruded by the Late Variscan Hroncok granite body and the large Vepor granitoid pluton (granite to tonalite) 303–279 Ma



Text-Fig. 8. (explanation in common with Text-Fig. 9)
Alpine quartz c-axis fabrics from the shear zones in Text-Fig. 3. Localities No 1, 3 = 8 in circles. Explanations in text. Point and iso-line diagrams from the same sample are located one over another (e.g. a above d) in Text-Fig. 9.
Most of samples appear strogly recrystallized and oriented quartz oblique to S-planes (original metamorphic foliation) in phyllonitized quartzitic metapelites to metaquartzites of the Hron complex (Text-Fig. 8a–8g; 9a–9f) and low-temperature orthogneiss mylonites of the Tatra complex (9i+9l) in the Supratatric basement.



Text-Fig. 9. (explanation in common with Text-Fig. 8).
Fabrics in diagrams 8f + 8g; 9c + 9f are related to S-planes already overturned and dipping to the N during transpression.
Fabrics of Triassic metaquartzites (8h+8i; 9g+9j) are comparable with those of the granitoid mylonitic schists (8j–8l; 9h+9k) of the Veporic basement. All diagrams indicate top-to-E(ESE) thrusting (sliding). Localization of oriented samples according to Text-Fig. 3 (locality No in circle) and number of measured c- axes: 8a = loc. 3, 208 c-axes; 8b = loc. 3, 170 c-axes; 8c = loc. 4, 200 c-axes; 8d = loc. 4, 200 c-axes; 8e = loc. 4, 200 c-axes; 8f = loc. 5, 190 c-axes; 8g = loc. 5, 160 c- axes; 8h = loc. 8, 190 c-axes; 8i = loc. 8, 175 c-axes; 8j = loc. 8, 180 c-axes; 8k = loc. 8, 170 c-axes; 8l = loc. 6, 190 c-axes. Text-Fig. 9a+9d = loc. 3, 378 c-axes; 9b+9e = loc. 4, 600 c-axes; 9c+9f = loc. 5, 350 c-axes; 9g + 9j = loc. 8, 600 c-axes; 9h + 9k = loc. 8, 540 c-axes; 9i = loc. 1, 235 c-axes; 9l = loc. 1, 220 c-axes.

in age according to U-Pb method on zircons (BIBIKOVÁ et al., 1990; BIBIKOVÁ, written communication).

The Muran gneiss complex – orthogneisses, paragneisses to micaschist gneisses, amphibolites – (Lower Paleozoic?) represents a distinctive tectonic element of the south-Veporic Kohut area (e.g. HOVORKA et al., 1987), dragged and uplifted along the Muran fault zone.

The Kohut complex (MASKA & ZOUBEK in BUDAY et al., 1961) is dominated by garnet micaschists, locally with staurolite and kyanite, intercalated with graphitic and micaceous metaquartzites, hematite quartzites, as well as metacarbonates, erlans, small bodies of albite-epidote amphibolites, serpentinites, chloritic schists and metasomatic magnesite, dolomite and talc, (Lower Paleozoic?, Precambrian?). The unit tectonically borders the Cierny Balog complex (or Alpine Kralova hola nappes) along a reverse-fault plane steeply dipping to the S.

The southern rim of the Veporic zone is dominated by low-grade metamorphic rocks of the Hladomorna dolina complex, phyllites to garnet micaschists, greenschists to albite amphibolites, (Lower Paleozoic in age) and the Predna hola complex (greenschists, porphyroids-metakeratophyres, phyllites, metasandstones, lesser marbles, Devonian in age) (KLINEC, 1966; BAJANIK et al. 1979). The Kohut and Hladomorna dolina complexes are intruded by the Variscan (BIBIKOVÁ et al., 1988) Rimavica leucocratic granites. The superposed contact metamorphism on the edge of the Rochovce granite (Permian?) was described by VOZAROVÁ & KRISTIN (1986).

The north Veporic Variscan granites occur mainly as a part of the Alpine nappes. They do not form a singular intrusion but several non-comagmatic massifs with slightly various ages.

The geochemical and geochronological data indicate relatively broad variability of granitic types. The Sihla leucotonalites represent a typical example of I-type allanite – (± magnetite, ±sphene) series (BROSKA & UHER, 1991; BROSKA & PETRIK, 1993) of the Late Carboniferous (U-Pb zircon dating: 303±2 Ma, BIBIKOVÁ et al., 1990). The Vepor and Ipel granites – granodiorites have mixed S to I-type characteristics of previously monazite – (xenotime, garnet) series with younger – Late Carboniferous to Early Permian – Rb-Sr isochron data (284±22 Ma, BAGDASARYAN et al., 1986).

The whole Veporic crystalline basement is covered with uniform Foederata (or Struzenik) cover rocks represented by swell-basin facies of the Permian-Triassic succession. Arcoses, quartzites, acid volcanics and volcaniclastics, mid-Triassic limestones and dolomites, Carnian limestones, dolomites and black calcareous shales instead of the Carpathian Keuper occur.

The Veporic unit situated along the Pohorela line is mainly represented by granitoids of the Late Variscan Vepor pluton incorporated into the Alpine Kralova hola nappes, thrust over the Supratatric Hron crystalline complex. The lower Kralova hola nappe comprises augen gneisses to homogeneous metagranites, metagranodiorites with abundant xenoliths of the gneiss mantle and phyllonitized crystalline schists. The upper – Vapenica – nappe is composed of metatonalites (tonalite orthogneisses, with diorite enclaves) of an independent nappe, thrust further to the N than the lower nappe (Text-Figs. 3, 4, 5).

The Vapenica (tonalite) nappe overlies the common recumbent folds (AD1 deformation in the Supratatric unit) of the Hron Nappe crystalline complex and its parautochthonous Permian-Mesozoic succession (Text-Fig. 3). The Vapenica Nappe was thrust into this area to the N in the Middle Cretaceous (thick-skinned tectonics) after the main mass of the Permian–Mesozoic Velky bok succession had been formed as the Krizna Nappe.

Younger, Late Cretaceous to Paleogene combined south-vergent and right-lateral movements caused a steep backthrust of the Supratatric Hron Nappe over the front of the lower Veporic Kralova hola Nappe (Text-Figs. 3, 4, 5). Another important feature of this deformation stage is a backthrust of the southern edge of the Krizna Nappe over the frontal parts of the overthrusted Veporic tonalite (Vapenica) nappe including its cover rocks, in the Supratatric zone (Text-Figs. 3, 4, 5). Fan-like deep synforms of the Foederata cover in the Veporic basement are also characteristic for this deformation stage (Text-Figs. 4, 6). The latest tectonic history of the Veporic unit in the time interval 80–55 Ma is indicated by fission-track data on apatites (KRÁL', 1977, 1982).

Previous analysis of the mid-Cretaceous and later deformation stages however, does not explain the higher grade Alpine metamorphism within the Veporic unit and the inverted Alpine metamorphic zoning in the Supratatric zone, where the Alpine higher-grade Veporic metamorphic rocks are overlying the lower-grade Supratatric rocks.

The geological situation S of the Hron river (Text-Figs. 3, 4, 6) indicates thrusting of only one large granitoid body over the Hron Nappe during the first Alpine deformation stage AD1 that is diachronous, earlier than AD1 in the Supratatric unit.

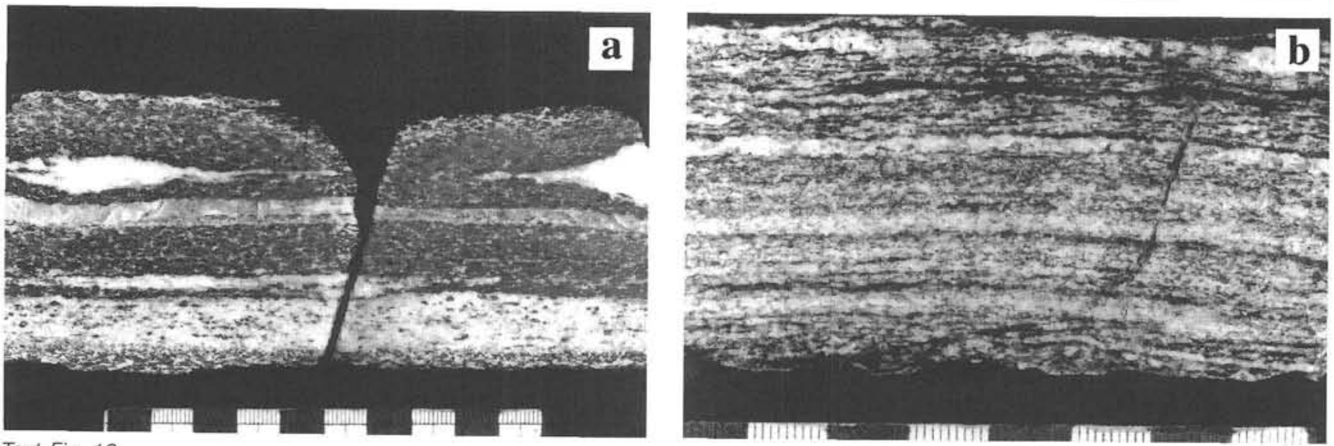
The hangingwall of the granitoid nappe is marked by a few tens-of-meters thick mylonitic schist and phyllonite of the granite to tonalite-gneisses. The Pohorela sinistral shear zone from the N makes the thrust plane of the granitoid nappe steeper, measured to be 50°.

Subhorizontal to 50–60° south-dipping shear zones with phyllonitic rocks subdivide the Hron Nappe into a few tectonic slices one over another with boundaries subparallel to the Pohorela line.

The mylonite-phyllonite zones in both Veporic and southernmost Supratatric units can be firstly interpreted as the result of compressional thick-skinned north to northwestward thrust tectonics followed by sinistral transpressional uplift, N-ward thrusting and top-to-E(ESE) extensional sliding (Text-Figs. 6, 3, 4).

The low-grade metamorphism of the Veporic unit is related to internal thrust tectonics and due to nappe-thrusting of the Gemeric over the Veporic unit. We connect it with the continental shortening phase that occurred in the area adjacent to the closed Triassic-Jurassic basins such as the Meliata oceanic basin situated S of the Veporic and Gemeric zones. The only published Ar-Ar age (155 Ma, MALUSKI et al. 1992) from a Meliata unit schist near Kosice indicate already the Late Cimmerian (Late Jurassic-Early Cretaceous) thrust and uplift history of the zones with a general Triassic extension, comprising the southernmost Supratatric, the whole Veporic, Gemeric and Meliata units (compare with PUTIŠ, 1991a).

Large phyllonite (mylonite) zones slightly dipping to the SE (Text-Figs. 3, 4) are accompanying the deep parts of significant faults such as Pohorela and Lubenik faults with a complex tectonic history. They are thought to be originally extensional (master detachment) faults, in time, when the Veporicum in the Permian-Triassic formed. Compressional tectonics during the Late Jurassic–Early Cretaceous changed their function to thrust faults and later as in the Early to Late Cretaceous they operated as transpressional and extensional faults.



Text-Fig. 10.
Layered structures of banded amphibolites (10a) with geological position according to Text-Fig. 3 (loc.2 in circle) and mylonitic orthogneisses (10b) with geological position according to Text-Fig. 3 (N of loc. 1 in circle).

3. Petrotectonics of the Shear Zones in the Supratatric and Veporic Units

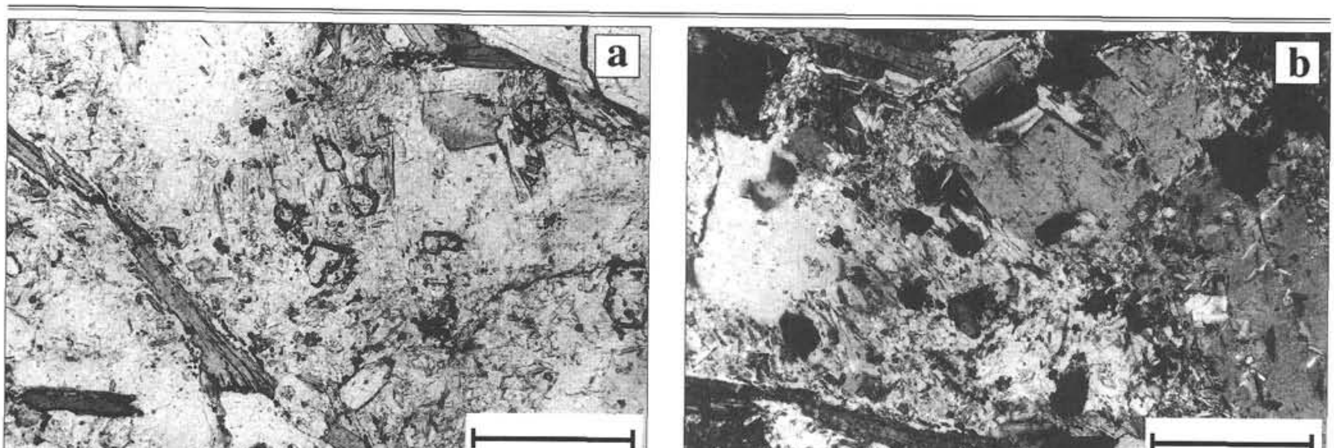
Principially, two age-groups of shear zones exist in the Supratatric-Veporic basement: relics of the Variscan shear zones, and Alpine shear zones.

3.1 Variscan Shear Zones

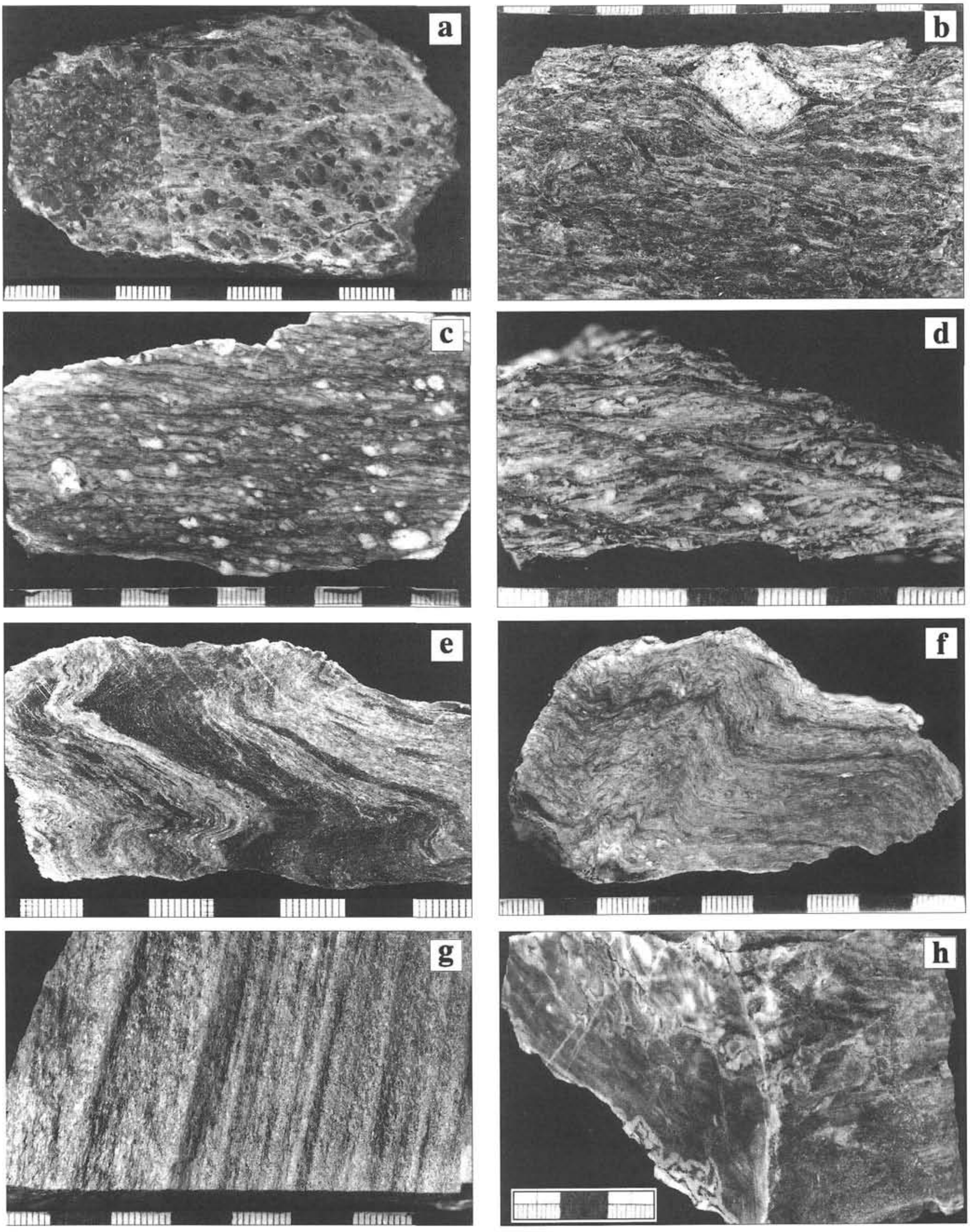
The relics of the Variscan shear zones were identified by structures, textures and some quartz c-axis fabrics, because the original thrust surfaces had been strongly modified during the Alpine tectogenesis. Despite, even in quartz fabric patterns (Text-Fig. 7) a pre-Alpine high-temperature prisma <c> glide has been found in the light-coloured quartz-plagioclase layers of the banded (layered) amphibolites (the Leptyno-amphibolite complex, or LAC sensu HOVORKA & MERES, 1993). Quartz c-axes tend to concentrate along small circles near the mineral and stretching lineations. Quartz of coarse-grained quartz-plagioclase veins and aggregates forms a high-angle circle round the foliation poles. The patterns are symmetric, obviously due to a pure shear regime in a deep-crustal thinning deformation process. The result of the deformation are layered structures of amphibolites. But the light coloured layers composed of quartz, plagioclase, amphibole, garnet, biotite, epidote, rutile, ilmenite, magnetite, hardly can be assigned to leptinites. More real appears their tectonic origin in a deep-seated shear zone, due to deep-crustal thinning, extensional uplift and accompanying melting processes (e.g. LACs in NEUBAUER, 1989), within the metagabbro-metaperidotite-amphibolite formation, which have been defined by MIKO & PUTIŠ (1989, in KRIST et al., 1992, Text-Fig. 74) in the uppermost part of the Hron complex. The so-called Leptyno-amphibolite complex as an analogy of the above mentioned formation has thus a close tectonic relationship to the upper part of the Hron Nappe in the Supratatric zone, where the higher Variscan Tatra Nappe is practically not present (Text-Figs. 3, 4). Large amphibolite successions assigned by PUTIS (1992) to the top of the Hron Nappe are also present in the Tribec and Povazsky Inovec Mts.

In other places, however, in the West High Tatra Mts. (JANAK, 1991) and in the Mala Fatra Mts. (HOVORKA & MERES, 1989) they appear close tectonic relationship to the footwall of the Tatra Nappe. The possibility that the leptyno-amphibolite complex (LAC) represents an independent complex coming from the lower crust (HOVORKA & MERES, 1993) is not excluded.

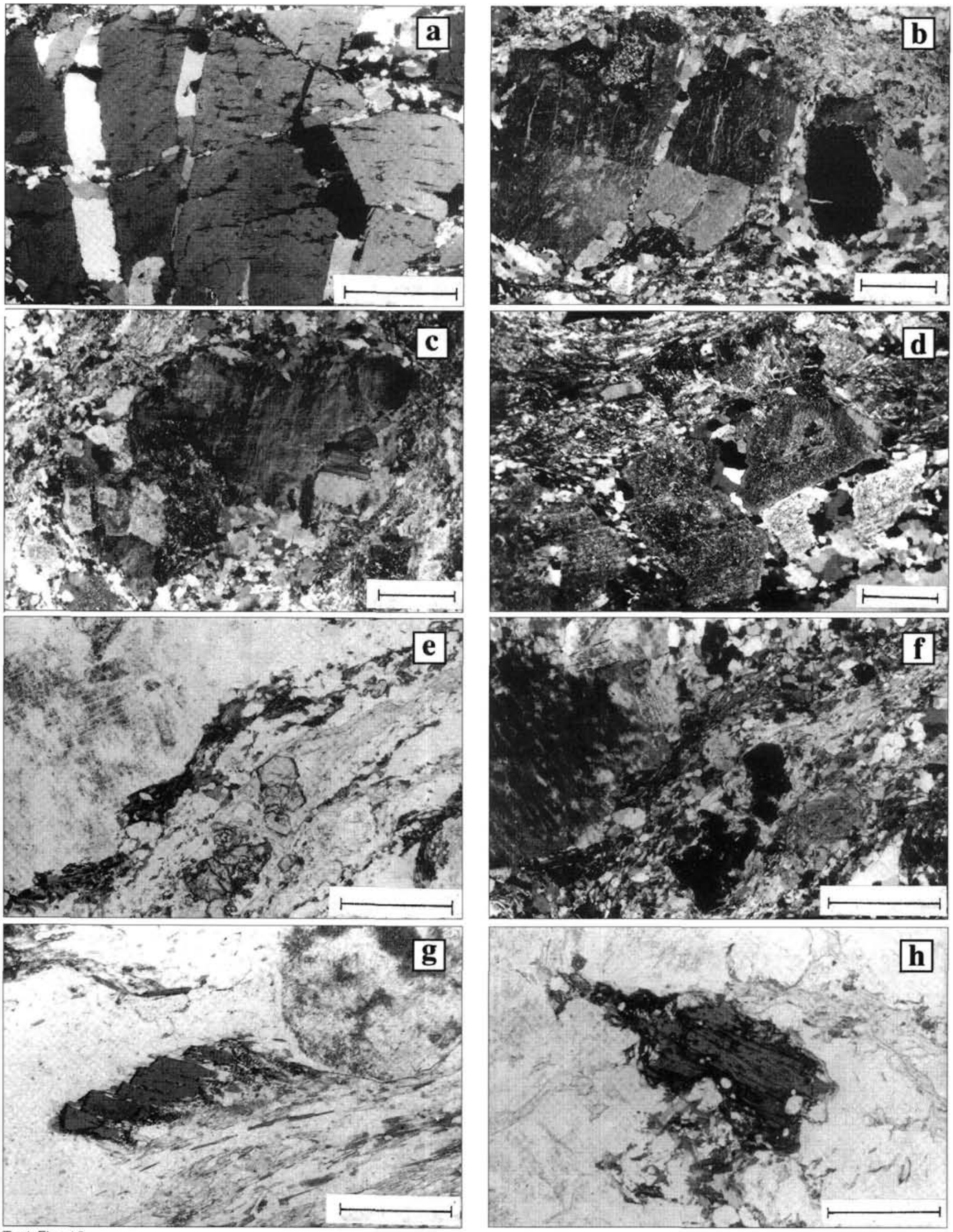
The orthogneiss mylonites with ductile deformations of quartz and feldspars already belong to the hangingwall of the Tatra Nappe exposed in the Low Tatra Mts. (Text-Figs. 3, 4).



Text-Fig. 11.
Newly-formed Alpine tiny (grossularite) garnet$_2$ and bitotite$_2$ in strongly albitized plagioclase of slightly mylonitized micaschist-gneiss (Hron complex).
Geological position according to Text-Fig. 3 (N of loc. 6 in circle) and Text-Fig. 6.
// and × nicols. Scale-bar = 1 mm.



Text-Fig. 12.
Mesostructures (kinematic indicators and fold-style) along the Pohorela shear zone.
a–d = augen mylonites of porphyric metagranite: a = flattened quartz grains in S-planes, oblique to horizontal C-shear planes (XY-cut, left and XZ-cut, right hand side); b = rotated K-feldspar porphyroclast (XZ cut); c = C-plane type of mylonite (XZ cut); d = extension crenulation cleavage (dipping to the right) cut the S-planes (XZ cut); a = d = indicate top to E (ESE) shearing along the stretching lineation.
e + f = fold style as the result of compressional component of tranpression, B-axes of folds are parallel or oblique at acute angle to stretching lineation: e = phyllonite; f = Permian metaarcose (Foederata cover).
g = Lower Triassic columnar muscovite-phengite-metaquartzite with distinct stretching lineation; h = metamorphosed phlogopite Middle Triassic limestone with stretching lineation marked by constrictional sheath-like folds; f–h = Veporic (Foederata) cover rocks.



Text-Fig. 13.
Microstructures (recrystallization-grade; kinematic indicators) of Veporic granitoid mylonites.
a+b = en-echelon fissures in K-feldspar porphyroclasts filled up by quartz, muscovite, biotite$_2$ (XZ cut), X nicols; c = chloritized biotite$_1$ enclosed in microcline; both of magmatic origin (XY cut), X nicols; d = stretched plagioclase (XZ cut), X nicols; e = mylonitic foliation with grossularite garnet, muscovite$_2$; biotite$_2$, quartz, epidote-zoisite minerals, calcite, chlorite, // nicols; f = same as e, but X nicols (XY cut); g = book-shelf sliding in biotite$_1$ indicating sinistral (top to ESE) shearing; mylonitic foliation is defined by fine- grained muscovite$_2$ and biotite$_2$ (XZ cut), // nicols; h = coarse-grained magmatic biotite$_1$ with sagenite enclosed in mylonitic foliation with newly formed muscovite and biotite (XY cut), // nicols; X+Y+Z = finit strain elipsoid axes. Scale-bar = 1 mm.

Characteristic diaphthorites of micaschist-gneisses derived from the paragneiss-migmatite-orthogneiss complex accompany the hangingwall of the Tatra Nappe. In the foot wall (at the top of the Hron Nappe) diaphtorites, new-formed white mica and chloritoid replacing staurolite have been found (PUTIŠ, 1987a).

3.2. Alpine Shear Zones

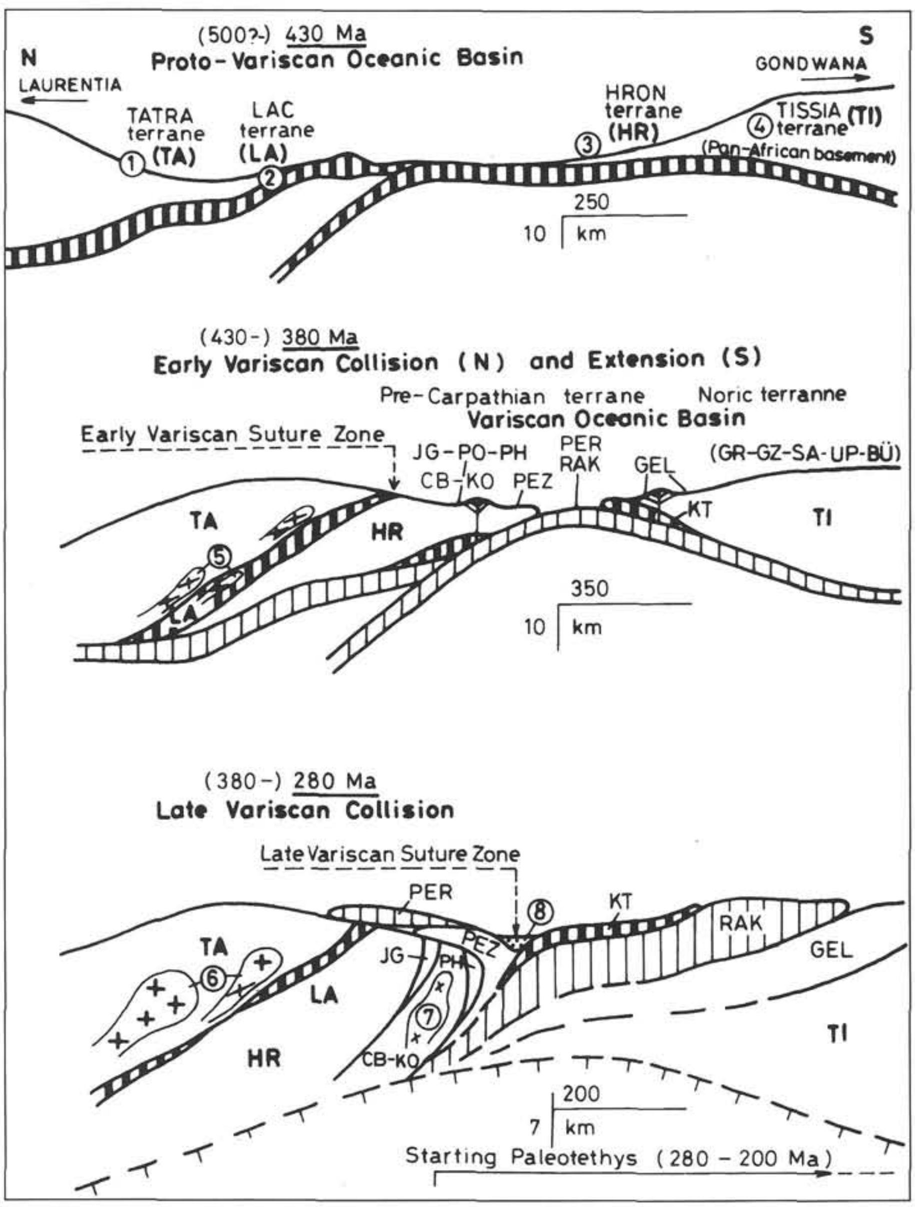
The Supratatric shear zones indicate a high mobility zone have been situated between the Tatric and Veporic units since the Early Alpine period (part 2.1.). The most intensive mylonitization-phyllonitization processes were bound to the Supratatric-Veporic boundary, along the Pohorela line. This part of paper is devoted to recrystallization proceses, kinematic indicators and quartz c-axis fabric patterns especially along the contact of the Supratatric and Veporic units.

Phyllonite zones N of the Pohorela line are situated within the Hron complex metamorphic rocks of the Supratatric basement (Text-Figs. 3, 4). The medium-grade pre-Alpine mineral assemblage of mainly metapelites contains: quartz, plagioclase, biotite, muscovite, garnet, locally staurolite, andalusite, or fibrolitic sillimanite (PUTIŠ, 1982, 1987a, 1989; KRIST et al., 1992). Superposed Alpine phyllonitization occured in biotite-garnet to sericite-chlorite metamorphic zone conditions, due to compressional thick-skinned NW-ward tectonics (in the Late Jurassic-Early Cretaceous). Newly-formed tiny grossularite $garnet_2$ grew on the older almandine cores or within albitized plagioclase grains usually together with fine-grained $biotite_2$ (Text-Figs. 7, 11). Other recrystallization minerals are: quartz, chlorite, epidote, sericite, calcite, tourmaline, albite.

Asymmetric meso- and microstructures indicate top-to-E thrusting along the E–W trending stretching lineation. They include: S-C planes, rotated porphyroblasts of new-formed albite, rotated relic porphyroclasts of feldspars and muscovite, pressure-shadow quartz tails, oblique quartz grain orientation within the synmetamorphic quartz veins parallel to the S-planes (metamorphic schistosity). The stretching lineations are parallel to the B-axes of tight folds in phyllonites.

The quartz c-axix fabrics confirm the E-ward sense of shearing (Text-Figs. 8, 9) according to asymmetry of the two-girdle skeleton to the S-planes. Distribution of c-axes maxima indicate combined prisma <a> and basal <a> glide in quartz and a plane strain type of deformation. Quartz patterns already reflect Cretaceous top-to-ENE transpression and top to ESE-extension movements.

The hangingwall of the Alpine Veporic basement nappe resembles tectonic style of the underthrusted Supratatric basement. The Veporic



Text-Fig. 14.
Interpretation of the Variscan tectonic evolution of the Western Carpathian basement (PUTIŠ, original fig.).
Early Variscan terrane complexes (nappes): TA = Tatra complex (1 = passive, later active margin); LA = Leptoamphibolite complex (2 = active margin); H = Hron complex (3 = passive margin); TI = 4 = Pan-African basement of Tissia; 5 = granitic orthogneisses.
Late Variscan Pre-Carpathian terrane complexes (nappes), mostly derived from the active margin of the northern plate: PER, RAK, KT = Pernek, Rakovec and Klatov (incomplete ophiolite) complexes; PH, PO, JG, PEZ = Predna hola, Pohorela, Janov grun and Pezinok complexes; CB, KO = Cierny Balog and Kohut complexes; GEL = Gelnica (rifted passive margin?) complex; 6, 7 = Late Variscan, granitoid plutons (6 = older, mainly S-type; 7 = younger, I, S-type); 8 = Late Varican collision flysch furrow.
Noric terrane complexes (nappes) derived from the passive continental margin of the southern plate: GR, GZ, SA, U-BÜ = Paleozoic complexes of Graz, Graywacke zone, southern Alps and Upony-Bükk zone.

basement south of the Pohorela line is built mostly of metagranitoids of the Late Variscan Vepor pluton (Text-Figs. 3, 4, 5, 6).

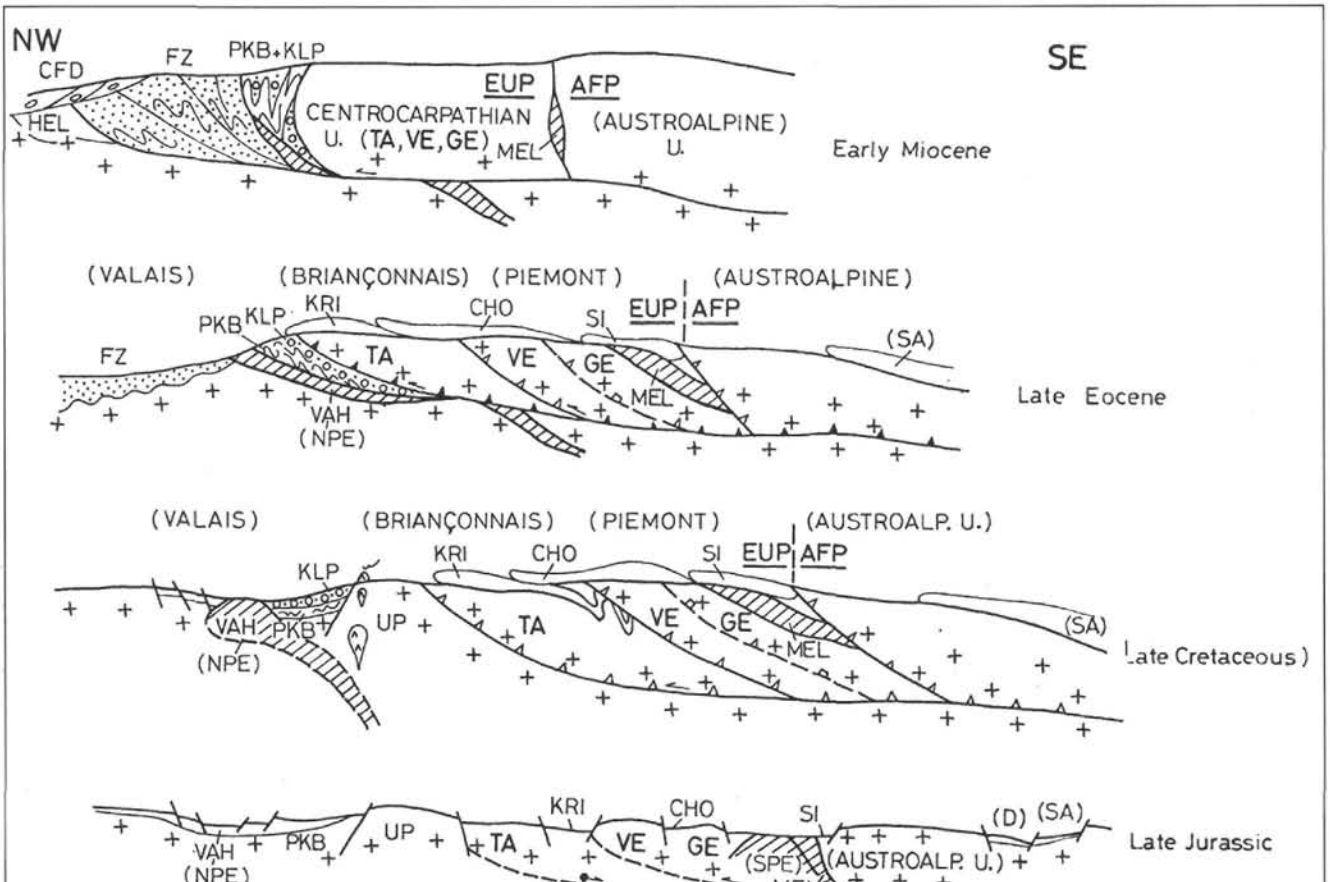
Magmatic minerals of tonalites, porphyric to homogeneous granites, granodiorites (quartz, plagioclase, kalifeldspar, biotite, muscovite, apatite, titanite, zircon) are recrystallized into the new-formed mineral assemblage (quartz, albite, low-Ti- biotite$_2$, muscovite, sericite, chlorite, calcite, titanite$_2$, less garnet) that defines the mylonitic foliation. Augen metagranitoids, originally porphyric granite varietes locally also contain tiny euhedral garnets with high grossularite (35–40 %) content within the mylonitic mineral assemblage (Text-Fig. 13). Presence of newly formed garnet (with high grossularite content) in metagranitoids of the Veporic tectonic unit is well-known for a long time (VRANA, 1964, 1966, 1980; PUTIŠ, 1981, 1989, 1991a, 1991b, 1992; MERES & HOVORKA, 1991). It is also characteristic for distinct Alpine phyllonite zones along the Pohorela line situated in the Veporic and Supratatric basement (Kralova hola and Fabova hola massifs, Text-Figs. 3, 4, 5).

The lineation visible on mylonitic foliation is defined by fine-grained biotite$_2$, chlorite, sericite, roughly in the E–W (to WNW–ESE) direction. There are common transitions from metagranitoids, through augen granite-gneisses to phyllonites (blastomylonites) with S-C asymmetries indicating top-to-E thrusting of the granitoid slices (Text-Fig. 12).

Kinematic indicators include: S-C planes, rotated feldspar porphyroclasts (σ-structures), book-shelf sliding structures in stretched feldspar, quartz and mica porphyroclasts, tails of recrystallized quartz round the quartz and feldspar porphyroclasts. These microstructures indicate perfect ductile behaviour of quartz and a semi-ductile behaviour of feldspars in biotite to biotite-garnet mylonites (Text-Fig. 13).

Quartz c-axis fabrics (asymmetric two-girdle diagrams) of the granitoid mylonites (Text-Fig. 8j–8l) and the Lower Triassic metaquartzites of the cover (Text-Fig. 8h+8i) are consistent with those of the footwall, coming from the Hron complex phyllonites (Text-Fig. 8a–8g, 9a–9f). They reflect mostly the last top-to-E(ESE) extensional deformation, distinct especially along the basement-cover contacts of the low- angle normal fault character (Text-Figs. 3, 4).

The basement mylonites reflect deformation conditions of about 350–450°C at the depths of 10–15 km. Such types of Alpine mylonites, closely related to the deformation and metamorphism of the cover rocks, are unknown in the deeper



Text-Fig. 15.
Alternative interpretation of the centrocarpathian basement (PUTIŠ, original fig.) as a part of the (Alpine) European plate (EUP); compare with Text-Fig. 2.
TA, VE, GE = Tatric, Veporic and Gemeric basement and cover (Triassic–Middle Cretaceous) units; MEL = Meliata (Triassic–Jurassic) oceanic unit; UP = Ultra-Pieniny Swell; VAH = Vahic (Late Jurassic?–Late Cretaceous) oceanic unit; KLP = Klape (Late Cretaceous–Early Paleogene) unit; PKB = Pieniny Klippen Belt (Jurassic–Upper Cretaceous) unit; FZ = Flysch Zone (Cretaceous–Paleogene); HEL = Helvetic epiplaformal unit; CFD = Carpathian Fore-deep (Late Oligocene–Miocene); KRI, CHO and SI = Mesozoic Krizna, Choc and Silica Nappes; AFP = African (Adriatic) plate with Austroalpine units; SPE and NPE = South and North Penninic oceanic units, as well as D, SA = Drauzug and Southern Alps = according to BAUER (1987).
Tectonic structures: Square line: Late Jurassic– Early Cretaceous thrust. Square- triangle line: Late Jurassic–Early Cretaceous thrust, reactivated in Middle Cretaceous. Triangle line: Middle Cretaceous thrust. Black-triangle line: Eocene thrust. Black dot and arrow = Early Alpine extensional fault. Arrows = sense of thrusting.

Tatric unit overriden by the Veporic unit. The higher-temperature Veporic mylonites appear to be older (pre-mid-Cretaceous), probably Late Cimmerian (PUTIŠ 1991a,b, 1992). They are related to N-ward compressional thick-skinned tectonics (Late Jurassic–Early Cretaceous) continuing by transpressional uplift (Early Cretaceous) accompanied by NW-ward thrust over the Supratatric unit (mid-Cretaceous) and top-to-E(ESE) extensional sliding (late Middle-Cretaceous–Early Paleogene).

4. Conclusions

❶ The Tatro-Supratatric basement comprises the remnants of Variscan thrust tectonics indicated by:
  a) the existence of nappe-bodies of regional meaning: the Tatra Nappe, the Hron Nappe (PUTIŠ, 1992); the LACWECA (HOVORKA et al., 1992; HOVORKA & MERES, 1993), (Text-Figs. 1–4, 14).
  b) the inverted metamorphic zoning in the High Tatra Mts. (JANAK, 1991, 1992) and in other regions (PUTIŠ, 1992),
  c) the ductile high-temperature deformational fabrics of feldspars and quartz (Text-Figs. 7, 10).

❷ The Alpine nappes of the southernmost Supratatric and the whole Veporic basement (incl. the cover rocks) formed mainly due to Late Jurassic-Early Cretaceous thick-skinned tectonics related to a continental shortening phase. It occured in the area adjacent to closed Triassic-Jurassic basins like the Meliata oceanic basin situated S of the Veporic and Gemeric zones (Text-Figs. 2, 15). Alpine metamorphism (in biotite-garnet, or kyanite-chloritoid-biotite zone conditions) is bound to this deformation stage.

❸ The inverted Alpine metamorphic zoning (Text-Fig. 6) in the Supratatric zone formed during the mid-Cretaceous thrust of the uplifted and metamorphosed Veporic unit (Text-Figs. 12, 13) over the Supratatric unit (Text-Figs. 3, 4, 6).

❹ E(ESE)-ward extensional sliding (late mid-Cretaceous–Early Paleogene) occurred in the southern Supratatric and Veporic (and Gemeric) units due to postcollisional uplift of the south Tatric and Supratatric units. The Alpine (low-grade) metamorphic complexes appeared near the surface (Text-Fig. 6).

❺ Quartz c-axis fabric patterns indicate:
  a) Variscan high-temperature deep-crustal shear zone, connected with thinning and uplift of deep-crustal complexes ("LAC");
  b) low- to middle-temperature Alpine shear zones, connected with thick-skinned and later extensional tectonics.

Acknowledgements

I would like to thank to F. NEUBAUER, R.D. DALLMEYER, H. FRITZ and M. JANAK, as well as to reviewers for their helpful discussions and comments. I thank to Mrs. M. TAKACOVA and Mr. O. KOLACKOVSKY for making the drawings.

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Manuscript received: 28. 10. 1992
Revised version received: 03. 07. 1993
Manuscript accepted: 06. 10. 1993