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Contrasting styles of Alpine deformations at the eastern part of the Veporicum and Gemericum units, Western Carpathians

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Abstract: Contrasting styles of Alpine deformations at the eastern margin of the Western Carpathian Internides are the result of a poly-stage process comprising progressive modification of the deformation regime, from thrusting to wrenching, and corresponding downward reworking of pre - Upper Carboniferous basement. The Alpine reworking of the Veporic basement complexes has been significantly influenced by a flat shear zone located at the base of the Late Variscan nappe pile.

AD_1 deformation stage is related to the development of recumbent folds of E - W axial direction and to pre - Senonian top - to - the N - NNE nappe stacking of the Choč and Silica nappes carrying, in the last case, the Meliata Unit slices at the base. The expressive NW - SE lithostratigraphic zonation of the area marked by regionally penetrative AF_2 folds development and corresponding south-westerly dipping reverse fault shear zones, have been formed during subsequent AD_2 deformation stage.

Local AD_3 fault/fold structures have opened AD_2 shear planes for either hydrothermal vein mineralisation or for a local thermal ascent in the Veporic Unit. NW - SE trending sinistral strike - slip zones of the AD_4 stage have been most probably created due to the eastward escape of the Western Carpathians from the Eastern Alps.

Introduction

The boundary between the Gemericum and Veporicum units belongs to the most important structures of the Alpine convergence within the Western Carpathian Internides. Its territory, known for decades as the Margecany - Lubenik line (scar, fan, etc.), was regarded to be both a remnant root zone and a homeland area for the Choč nappe (ANDRUSOV 1968, BIELY & FUSAN, 1967, MAHEĽ, 1967, 1986) and/or for the Silica nappe (ANDRUSOV, 1975, KOZUR & MOCK, 1973), respectively.

In a wider area of the eastern, i.e. Margecany part of this collisional structure, not only cover and crystalline sequences of the Gemericum, Veporicum and Tatricum units, but also nearly complete profiles of the Western Carpathians superficial nappes are present. The mentioned units stretch NE-SW, parallel to the Margecany shear zone. Structural data reveal a poly-stage evolution of the regional structure evolving from the Late Variscan and Alpine nappe stacking, continuing to pre - Upper Cretaceous fold/upthrust spatial reduction and the Tertiary wrenching, respectively. The aims of this contribution are: (1) to clarify the imprint role of the Late Variscan nappe structures to the formation of the Alpine ones within particular crystalline complexes. (2) to demonstrate the contrasting style of Cretaceous deformations among them, (3) to explain the Tertiary strike-slip phenomena within the structure of the region.

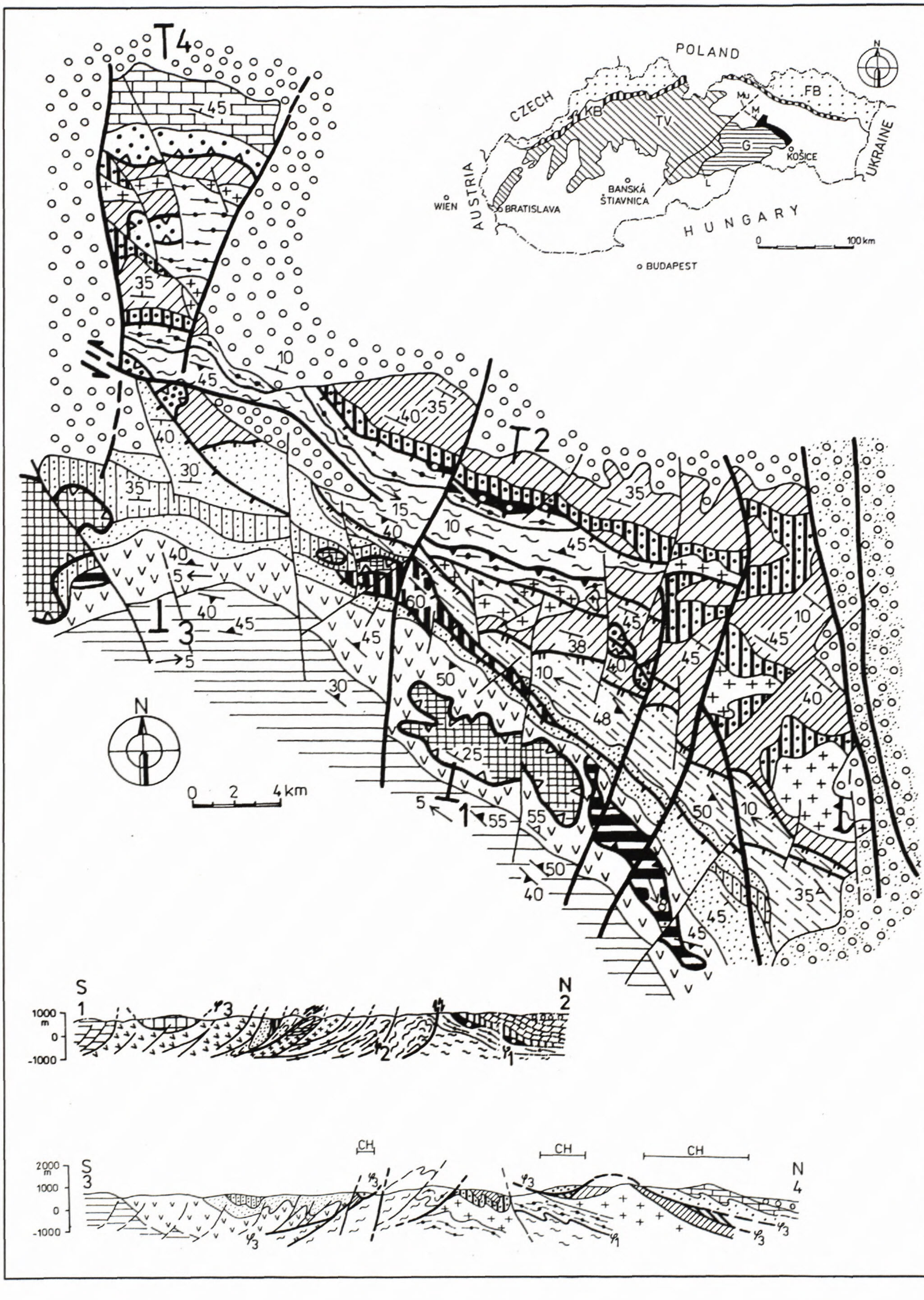
Main lithotectonic units

Six principal pre-Tertiary lithostratigraphical units, differing in metamorphic grade and style of Alpine deformations, form the extrermely reduced east-western part of the Western Carpathian Internides (WCI). From top to bottom (or from south to north) these are: the Silica nappe, the Meliata Unit, the Gemericum Unit, the Hronicum Unit, the Veporicum Unit and the Tatricum Unit (Figs.1a,b,c, 2,). All these units are more or less incorporated into the NW-SE regionally expressive zoning (Fig.1a), which culminates by the development of directionally related, NE vergent imbricate structures of the Gemericum and the Veporicum contact zone. (Fig.1c).

The Silica nappe - the highest tectonic unit of the WCI, is composed mainly of shallow water Triassic carbonates forming isolated flatly deposited klippes on both the Meliata and the Gemericum units (KOZUR & MOCK, 1973, MELLO & REICHWALDER, 1979).

Allochthonous - **the Meliata Unit** consists of Triassic to Jurassic LT-HP metamorphosed psammo-pelites, limestones, radiolarites, glaucophanitised basalts and serpentinised ultramafic rocks (KOZUR & MOCK, l. c., REICHWALDER, 1982). The unit is folded and stretched in SE direction, acquiring south-westerly inclined monoclinal position and finally elongated out along this strike (Fig.1a).

The Gemericum Unit, composed mainly of slightly metamorphosed Paleozoics volcanosedimentary sequences, is divided into four lithotectonic groups. From the bottom to the top they are : The Gelnica group, the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Rakovec group, the Klatov group, and the Late Paleozoic to Early Triassic successions.

The Gelnica Group is represented by a thick volcanogenic flysh formation (SNOPKO & IVANIČKA, 1978, IVANIČKA et al., 1989) of Late Cambrian to Early Devonian age (SNOPKOVÁ & SNOPKO,1979). Among volcanogenic interlayers the acid to calc-alcaline differentiates predominate. The sequence is regionally deformed by both, tight N-NE vergent folds and successive steeply dipping axial plane reverse faults.

The Rakovec Group, overlaying the northern part of the Gelnica group, has the same structural pattern as the former. It consists mainly of metabasalts, their volcanoclastics and phyllite intercalations. This ill - dated sequence is probably of Middle Devonian to Early Carboniferous age (BAJANÍK et al. 1983).

The Late Paleozoic and Early Triassic successions form NW-SE stretching syncline at the NE part of the Gemericum Unit (Fig.1c). The basal part of this pile consists of *Dobšiná Group*, a Carboniferous suite - starting with flysh sequence containing volcanites and volcanoclastics and continuing with shallow marine carbonate - clastic formations (VOZÁROVÁ in BAJANÍK et al. 1981).

Unconformably deposited Permian suite of the *Krompachy Group* (Fig. 2) comprises continental clastic formations interlayered with rhyolite dacite volcanites and volcanoclastics, capped by clastic - evaporite formation (VOZÁROVÁ & VOZÁR, 1988). The suite transits into *Early Triassic shales*, forming the core of the mentioned syncline.

The Klatov Group. This tabular nappe unit (Fig. 2), comprising isoclinally folded gneisses, amphibolites (sporadically interlayered with limestones) and serpentinites, is thrusted onto the Rakovec Group (ROZLOŽNÍK, 1965, HOVORKA et al., 1984). Presence of clasts of this unit within uncomformably overlayered Wesphalian conglomerates (VOZÁROVÁ, 1973) reveals the upper displacement limit of the nappe.

The Hronicum Unit is represented by its partial, the Choč nappe sequence (Figs.1 b,c,2). This north vergent nappe pile, coming most probably from homeland area between the Gemericum and Veporicum units (ANDRUSOV 1968, BIELY & FUSÁN, 1967, MAHEĽ, 1967, 1986), comprises Late Paleozoic clastic formations and Triassic, mostly carbonate successions. Within the area of outcrop of the Veporicum Unit only the first ones are preserved.

The Veporicum Unit, exemplified by its Čierna hora Mts. segment, consists of crystalline basement and Late Paleozoic to Mesozoic cover formations. The crystalline basement is made of three lithotectonic complexes. From the bottom to the top these are (Figs.1 b, c, 2), the Lodina Complex, the Miklušovce Complex and the Bujanova Complex (JACKO, 1985). The first one is composed of strongly diaphtoritised gneisses, micaschists and tiny intrafolial amphibolite bodies, the Miklušovce Complex is formed by migmatites and intrafolial aplitic granites and the Bujanova Complex consists of gneisses, migmatites, amphibolites and Variscan granodiorites.

The cover sequence of the unit starts with Late Carboniferous and Permian clastic formations, comprising rhyolitic volcanics within the latter. Triassic to Late Jurassic part of the sequence is mainly composed of carbonates.

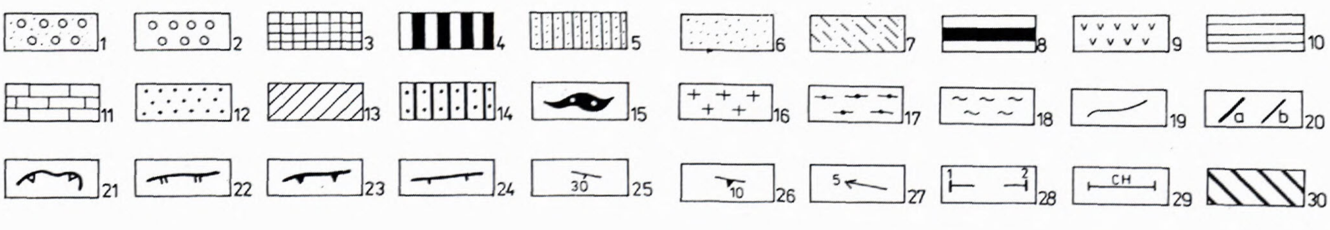


Fig. 1. (a) Position of the studied area in the Western Carpathians. FB - Flysh Belt, KB - Klippen Belt, TV - Tatric and Veporic units, G - Gemeric unit, Mu - Murán fault, L - Lubeník shear zone, M - Margecany shear zone, black strip - Studied area position
Fig.1 (b-c) Geological map and cross sections of the area. 1 - Neogene molasse sediments, 2 - Flysh successions of the Intra Carpathian Paleogene, 3 - Silica nappe limestones, 4 - Sediments and matabasites of the Meliata Unit, 5 - 10 Gemericum Unit, 5 - Early Triassic shales, 6 - Permian greywackes, rhyolitic volcanites and evaporites, 7 - Carboniferous flysch metabasite sequence with conglomerate and carbonate intercalations, 8 - Klatov Group gneisses and amphibolites, 9 - Metabasalts and phyllites of the Rakovec Group, 10 - Sandstones, phyllites and rhyolite volcanites of the Gelnica Group, 11 - 12 - Choč nappe of the Hronicum Unit, 11 - Late Carboniferous shales, sandstones and conglomerates, 12 - Triassic and Jurassic carbonates, 13 - 18 Veporicum and Tatricum units, 13 - Triassic to Late Jurassic cover - prevailingly carbonate, successions, 14 - Permian greywackes, shales and rhyolite volcanites, 15 - Late Carboniferous conglomerates and shales, 16 - Veporicum (Bujanova Complex) and Tatric (Branisko Mts.) granodiorites, 17 - migmatites gneisses and amphibolites of the Tatric and Veporic (Bujanová and Miklušovce complexes) units, 18 - diaphtoritised gneisses and amphibolites of the Lodina Complex (Veporicum Unit), 19 - Geological boundaries, 20 - Normal faults, a - regionally significant, 21 - Soles of the Alpine nappes (φ_3 in cross sections only), 22 - Margecany shear zone, 23 - Alpine reactivated sole of the Late Variscan nappe (φ_2 in cross sections only), 24 - others important shear zones, 25 - bedding position, 26 - Alpine schistosity orientation, 27 - Alpine fold axes orientation, 28 - Cross sections lines, 29 - Choč nappe extent (in cross sections only), φ_1 - sole of the Late Variscan nappe (in cross sections only).

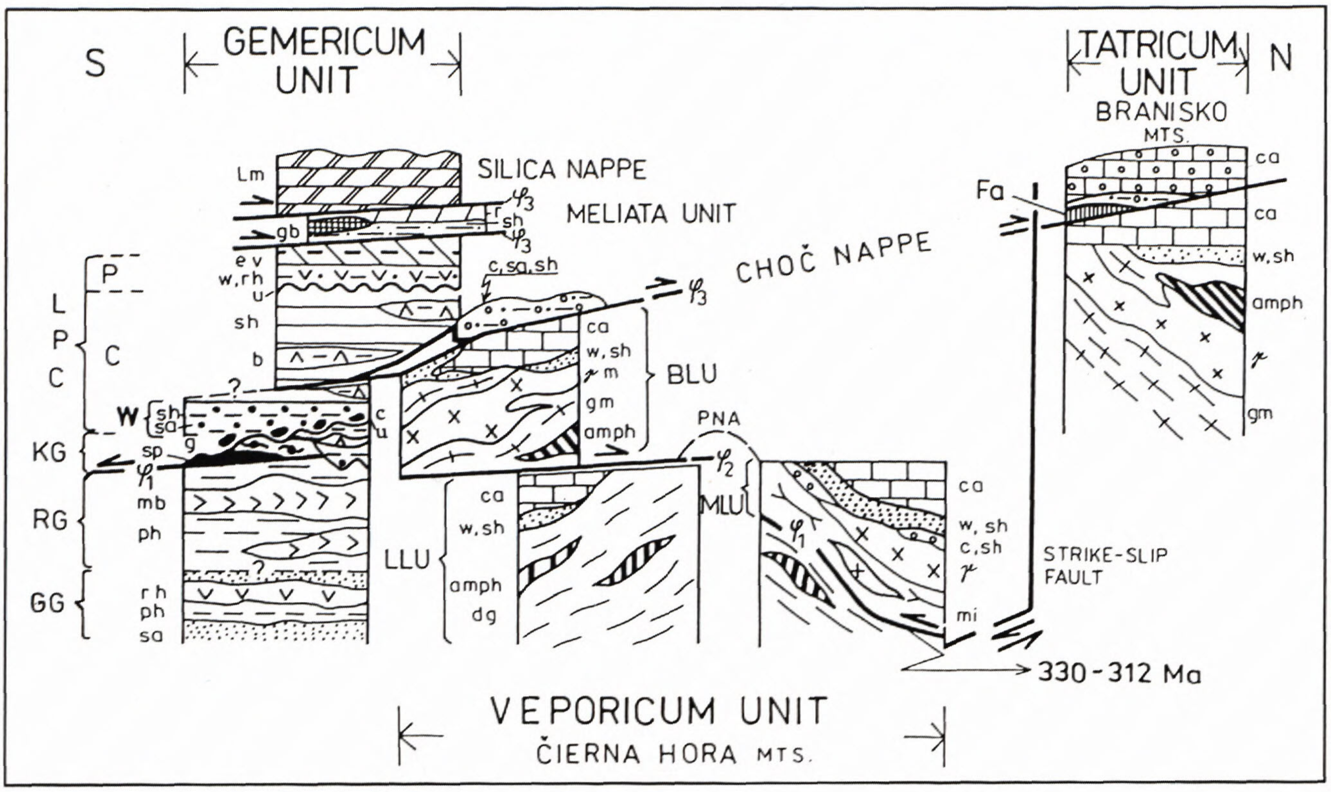


Fig. 2. The Alpine post - nappe position of lithotectonic units at the eastern part of the Western Carpathian Internides. LPC - Late Paleozoic complexes, P - Permian, C - Carboniferous, KG - Klatov Group, RG - Rakovec Group, GG - Gelnica Group, BLU - Bujanová lithotectonic Unit, MLU - Miklušovce lithotectonic Unit, LLU - Lodina lithotectonic Unit, Lm - limestones, r - radiolarites, gb - glaucophanitised basalts and serpentinites, sh - shales, ev - evaporites, w - greywackes, rh - rhyolites and their volcanoclastics, b - basalts, c - conglomerates, sa - sandstones, g - gneisses and amphibolites, sp - serpentinites, mb - metabasalts and their volcanoclastics, ph - phyllites, ca - dolomites and limestones, γm - mylonitised granodiorites, gm - gneisses and migmatites, amph - amphibolites, γ - granodiorites, mi - migmatites, dg - diaphtoritised gneisses, Fa - Fatric unit, u - unconformities, PNA - post - nappe anticline, φ_3 - soles of Alpine nappes, φ_2 - Alpine reactivated sole of the Late Variscan nappe, φ_1 - sole of the Late Variscan nappe.

Mesozoic sequences of the **Fatricum Unit** likely underlie buried parts of the Hronicum nappe in the Branisko Mts. (POLÁK, 1987)

The Tatricum Unit, forming the Branisko Mts. (Figs.1 b,c,2), is composed of crystalline basement, corresponding compositionally and in age to the Bujanova Complex of the Veporicum Unit, and to Permian to Late Jurassic cover formations, comparable to the cover sequence of the Veporicum Unit.

Pre-Tertiary sequences of the region are in the northern and north-eastern part roofed by flatly deposited flysh formation of the Intra Carpathian Paleogene suite. Their S-SE continuation is covered by Neogene molasse formations (Figs.1 b,c).

Outline of essential Features of Tectonic development of the region

Principal aspects of structural development of the Gemeric part of the area were evaluated by REICHWALDER & SNOPKO (in BAJANÍK et al., 1983). They consider the overall NW-SE zoning of the north-eastern part of the unit to be a result of an extensive and polyphase tangential shortening between the Gemericum and Veporicum units, which had caused both a reduction of the homeland area of the Hronicum Unit and nearly complete obliteration of pre-Alpine structures within the Gemeric basement.

JACKO (1979) described typological features of two Variscan and four Alpine deformation stages within the Veporicum Unit. Their adjusted modification, based on structural, petrological and geochronological data, is outlined in Fig. 3.

According to the mentioned data the crystalline basement of either the Miklušovce and Bujanova complexes, or the Branisko Mts., corresponds to the Upper basement unit of the Western Tatra (FRITZ et al.,1992) and/or to the Upper unit (BEZÁK,1994) of the Late Varriscan nappe structure of the Western Carpathian Tatric and Veporic basement. The underlying Lodina crystalline complex is, in the mentioned sense, complementary to either the Lower basement unit of the Western Tatra

(FRITZ et al., l.c.), or to the Middle unit (BEZÁK, l.c.) of the cited nappe structure.

The Late Variscan nappe cleavage set played a significant role in the formation of Alpine structures within the Veporic crystalline complexes. The same function for the evolution of contrasting styles of Cretaceous deformations within the region have had different mechanical properties of particular lithotectonic suites and their structural position, respectively. Kinematic analysis of the most pronounced shear zones confirms a connection of their prominent, sinistral, strike-slip activity to the AD_4- the post - Paleogene evolution stage of the area. (Fig. 3.).

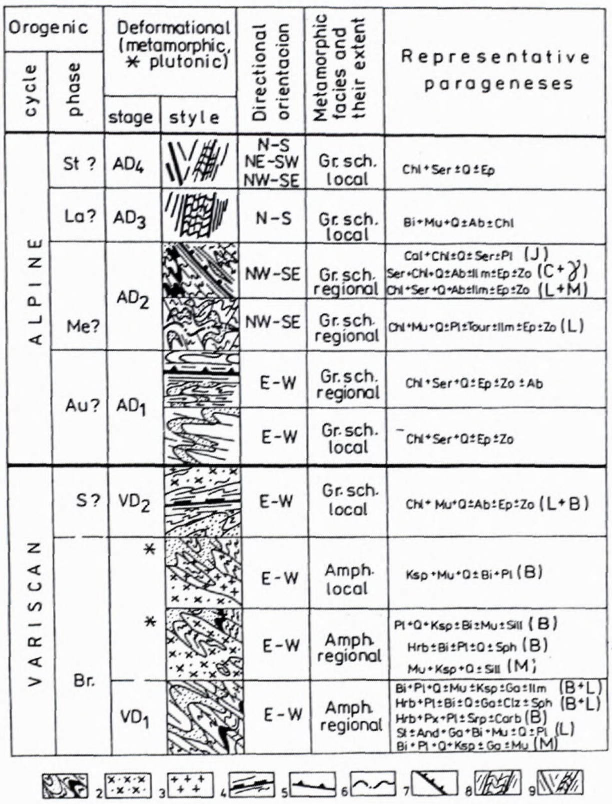


Fig. 3. Tectonometamorphic development scheme of the Veporicum Unit of the area. 1 - gneisses and amphibolites, 2 - biotite granodiorites, 3 - granites, 4 - Late Variscan nappe sole and its tectonites, 5 - Alpine nappe sole, 6 - Axial plane of the post - nappe recumbent folds, 7 - reverse fault shear zones of the Margecany type, 8 - normal faults and contemporaneuos upright folds, 9 - strike - slips and normal faults. St - Styrian, La - Laramian, Me - Mediterranean, Au - Austrian, S - Sudetian, Br - Bretonian, J - Jurassic cover stratas, C - Carboniferous cover strates, γ - biotite granodiorite of the Bujanova Complex, B - metamorphics of the Bujanova Complex, M - metamorphics of the Miklušovce Complex, L - metamorphics of the Lodina Complex, Gr.sch. - green schist metamorphic facies, Amph. - amphibolite metamorphic facies, Chl. - chlorite, Ser. - sericite, Q - quartz, Ep. - epidote, Zo. - zoisite, Clz - clinozoisite, Cal. - calcite, Ab. - albite, Pl. - plagioclase, Ilm. - ilmenite, Carb - carbonates, Mu - muscovite, Bi - biotite, Ga - garnet, Sph -sphene, Hrb - hornblende, Px - pyroxenes, Ksp. - kalifeldspar, St -staurolite, And - andalusite, Sill. - sillimanite, Crd - cordierite.

Imprint of the Late Variscan nappe stacking to Alpine structures formation

The Late Variscan nappe emplacement of Miklušovce and Bujanová crystalline complexes onto the Lodina one (Figs. 2,3), dated betwen 330 and 312 Ma (R.D. DALMAYER, pers. commun, 1993), has caused a significant reworking of their rock successions. The nappe sole of the overthrusted pile is subparallel to the cleavage set of the oldest recognizable, the Variscan VF_1 folds (Fig. 3.). Their similar cm - m rootless remnants, belonging to 3C & 4D category of HUDLESTON´s (1973) classification, have generally the southern vergency and they are distingtly modified throughout the nappe pile (JACKO et al. 1995).

Significant nappe emplacement reworking of rather homogenous and more rigid migmatites of Miklušovce Complex - forming the base of the Late Variscan nappe, is rectricted to their norther flank only. In this zone the moderately N-NE dipping penetrative clevage set contains tight SSW vergent asymetric folds with brittle-ductile stretching lineations of micas, quartz and feldspars indicating top- to-the SSW transport direction. The southern part of the suite, namely its basal margin, is strongly overprinted by Alpine structures, indicating a more effective emplacement shearing of the basal edge of the migmatite slice.

A lack of the Miklušovce Complex migmatites at the southern flank of the Veporic basement of the area suggests a partial delamination of the nappe pile during its emplacement. The Bujanova Complex has been, at this part of the basement, prevailingly thrusted over the metamorphics of the Lodina Complex. Two regionally significant shear zones have developed as a consequence

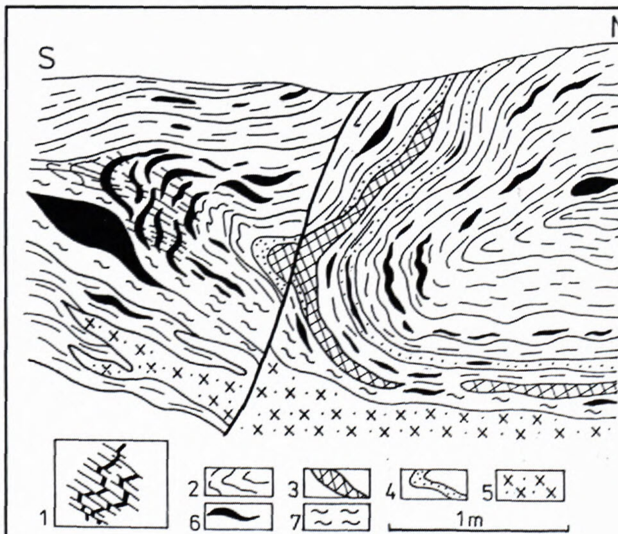


Fig. 4. Brittle - ductile modification of the pre - Carboniferous folds in the Bujanova Complex metamorphites due to the Alpine - nappe delamination of the complex. 1- detail of the modified fold closure, 2 - biotite gneisses, 3 - amphibolites, 4 - quartz - biotite gneisses, 5 - biotite granodiorites, 6 - quartz segregations, 7 - mylonites.

of the Bujanová Complex emplacement, the basal one and the shear zone, following the synformal closure of the Bujanova metamorphics. Both are several 10 m thick and dip moderately south-westwards (Figs. 1,c).

A strongly foliated, over 100 m thick shear zone, rimming either the northern edge of the Bujanova, or the southern margin of the Miklušovce Complex, follows the top part of subautochthonous diaphtoritised gneisses of the Lodina Complex. The zone has typicaly an extremely hight content of intrafolial quartz segregations, deformed by Alpine structures.

The foregoing relationships indicate that the emplacement of the Late Variscan nappe pile within the Veporic basement of the area have caused the most significant reworking, either within the basal zone of the overthrusted suite, or in the central part of Bujanova Complex. Both mentioned shear zones are accentuated by involvement of cover strata in them, namely, the typological structures of all Alpine deformation stages of the area are observable in the latter. Following geological and structural criteria show that the discussed shear zones have played a catalytic role for both, the Alpine delamination of the Veporic basement slices, and the penetrative development of the Alpine structures, namely within the Lodina Complex metamorphics.

First Alpine Deformation stage (AD_1)

Structures of this pre-Upper Cretaceous deformation stage are directly related to the Alpine nappe shortening in the region. Striation remnants, preserved on contemporaneous AS_1 cleavage set, indicate top-to-the N - NE movement of the nappes.

AD_1 deformations in the Veporicum Unit

Two closely related tectonometamorphic events of the AD_1 stage are recognizable in the Lodina and Bujanová crystalline complexes and their cover formations (Fig.3). Recumbent isoclinal AF_1 folds of both, parallel and similar geometry with axial plane dipping gently south, to - south-westwards, are typical for the first event (JACKO, 1979).

The AF_1 folds are regularly developed either in tectonites of the Late Variscan nappe emplacement zone of the Lodina basement rocks, or within relatively less competent cover strata. In the mentioned basement shear zone, cm - dm remnants of AF_1 folds are preserved only in quartz medium segregations (Fig. 6). A common occurrence of AF_1 folds of the order of m - 10 m, observed in the Liassic limestones at the south-western

Fig. 5. Recumbent paleo - Alpine AF_1 folds with axial plane cleavage developed in the Liassic cover limestones due to ramp effect of the more rigid Veporicum Unit. (cf. Fig.3. for correspoding deformation stage).

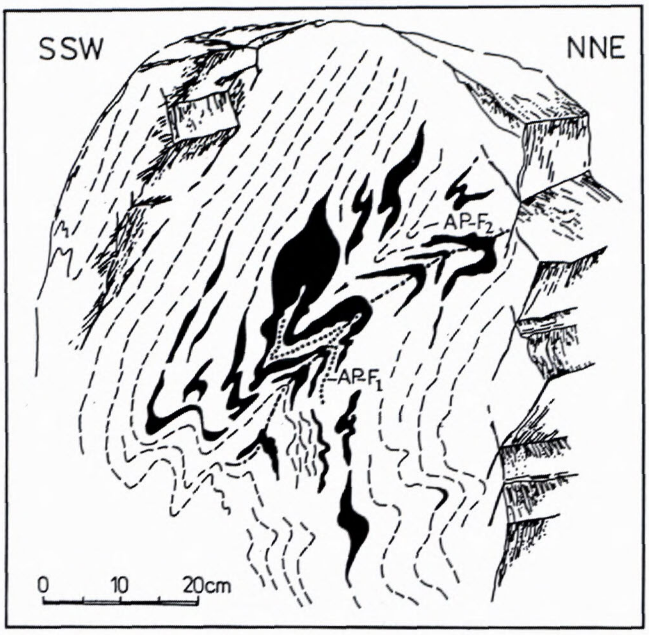


Fig. 6. Refolding of paleo Alpine recumbent AF_1 folds by post - nappe AF_2 folds at quartz segregation lenses of the Lodina Complex diaphtoritised metamorphites, APF_1 - axial plane of AF_1 folds, APF_2 axial plane of AF_2 folds.

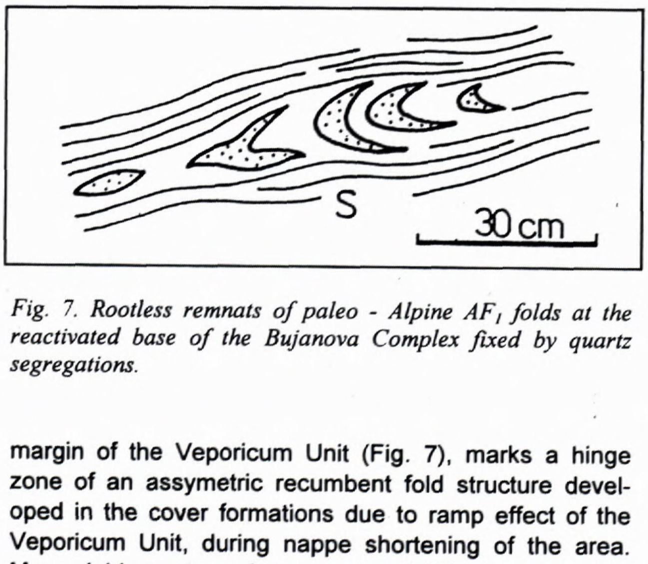


Fig. 7. Rootless remnats of paleo - Alpine AF_1 folds at the reactivated base of the Bujanova Complex fixed by quartz segregations.

margin of the Veporicum Unit (Fig. 7), marks a hinge zone of an assymetric recumbent fold structure developed in the cover formations due to ramp effect of the Veporicum Unit, during nappe shortening of the area. More rigid overturned segments of Triassic dolomites regionally overlayered Jurassic strata of the zone to stress the regional extent of this structure (Fig. 1c).

Some 100 m thick penetrative zones of AS_1 axial plane clevage set of AF_1 folds spatially correspond with soles and clevage position of paleo - Alpine nappe units of the region. They are probably a product of the second tectonometamorphic event of the more or less continuous AD_1 deformation stage. In the basement complexes (except of Miklušovce one) the cover strata (prevailingly Early Triassic quarzites) are incorporated into these zones. No other than successively contemporaneous or superimposed structures have been found in these markers.

Subhorizontally lying AS_1 cleavage plane set, occuring within 450 m of the vertical profile of the Lodina complex diaphtoritised gneisses, has been most probably developed due to reverse, (top-to-the northeast) overthrusting of the Bujanova Complex suite along reactivated the Late Variscan sole. According to extent of the superimposed AF_2 folds within tectonics of corresponding shear zone in the central part of the Bujanova Complex metamorphics, the thicknes of the zone reached over 100 meters.

A penetrative set of AS_1 cleavage developed in cover formations is rather restricted to either less rigid media of Jurassic limestones (Fig.7) or nearly to the sole of overlying Choč nappe.

AD_1 deformations in the Gemericum Unit

Within the lithotectonic groups of the Gemericum Unit the structures of the AD_1 deformation stage have been nearly completely obliterated by superimposed ones (BAJANÍK et al., 1983, MAHEĽ, 1986). Remnants of AF_1 folds of the same geometry as in the Veporic part of the area, measuring few dm, have been found by JACKO & REICHWALDER (1992, unpubl. data).

A flatly lying cleavage set, corresponding to AS_1 cleavage of the Gemericum Unit, scarcely occurs above the soles of the Silica nappe klippes. A similar, few dm thick, planar set, partly deformed by AF_2 folds, has been observed in serpentinised ultramaphics of the Klatov group (JACKO et al.,1995).

AD_2 deformation stage

Regionally developed NW - SE trending AF_2 folds and subsequently formed monoclinal SW dipping reverse shear zones are typical products of the AD_2 deformation stage. AF_2 folds deform the soles of the Silica and Choč nappes, as well as the structures of the AD_1 deformation stage (JACKO, 1979). Their AS_2 axial plane cleavage set, and corresponding reverse fault shear zones occur nearly throughout the exposed vertical profile of both the Gemeric and Veporic units.

Structural reworking of the units was accompanied by a low grade progressive metamorphism of cover formations and by a retrogressive metamorphism in the basement complexes (Fig.3). A successive evolution of two tectonometamorphic events of the AD_2 deformation stage (Fig. 3) is indicated by : (i) - a progressive flattening and shearing of AF_2 folds towards and inside shear zones, (ii) - absence of corresponding mineral parageneses of the second tectonometamorhic event in folded domains, located besides shear zones. The fact that the Middle Eocene conglomerates of the overlying Intra Carpathian Paleogene contain the tectonites of the reverse shear zones of both, the basement and cover formations, confirms that the upper limit of the last event predates the Paleogene.

AD_2 in Veporicum Unit

The intensity of the first tectonometamorphic event of the AD_2 deformation stage was heterogenous thoroughout the unit. It was controlled mainly by the rock mechanics, including the distribution of earlier tectonic zones within the basement suites. The AF_2 folds are regularly, developed in the cover formations, except of more rigid Triassic dolomites. These occur as remnants in the phyllonite zone at the base of Miklušovce and Bujanova basement complexes, as well as in the central tectonite zone of the latter. Diaphtoritised gneisses of the underlying Lodina complex are nearly penetratively refolded by AF_2 folds thoroughout the exposed profile (JACKO, 1979).

Overall geometric pattern and style of the AF_2 folds, fixed by representative rock suites of the unit (Fig.8a) indicates a significant flattening of originally open, upright and mostly parallel AF_2 folds. Majority of AF_2 folds in the Veporicum Unit are close to tight folds with significant thinning of the fold limbs and distinct AS_2 cleavage set, inclined monoclinally (at 40° - 60°) to SW.

Distinct modification and shearing of AF_2 folds reflect a progressive shortening of the Veporicum Unit during a subsequent, the second tectonometamorphic event of the AD_2 deformation stage. Modified AF_2 folds have stronger NE vergency than original open ones, but their shallow hinge line dips (i.e. 5°-10° either to NW or to SE, cf. Fig. 1b.) are identical in both mentioned evolution types.

According to the distribution of typological parameters of AF_2 folds in ZAGORCEV's (1993) diagram (Fig.8a) the dominant part of AF_2 folds of the Veporicum Unit belong to 2-nd class and/or to 1C and 3A subclasses, respectively. The layer parallel (or oblique) compression is regarded to be the dominant folding mechanism for the development of such fold types (l.c.), which agrees with the orientation of striation observed on folded bedding planes in the Jurassic limestones. Open to close folds with changing layer morphology, projected around 1 A_2 subclass line (Fig. 8a), most probably reflect a change of the strain field during repeated reactivation of the shear zones.

A continuous shortening of the area, which took place probably in the same stress field orientation, led to delamination of the Veporicum Unit according to NW-SE trending, moderately (45°-65°) SW dipping reverse fault zones (Fig.1b,c). The shear zones either reactivated the lithostratigraphical formation boundaries, or the early developed tectonite zones in the basement of the unit and they progressivelly climbed into the cover strata in the latter case. The most pronounced of them, the Margecany shear zone, strongly reactivates the boundary between the Gemericum and Veporicum units. It has no earlier kinematic indicators than the top-to-northeast motion striations (JACKO, 1979), which are consistent, as regards the sense of their movement, with the mica fish orientation (LISTER & SNOKE, 1984) in the biotite granodiorite S-C mylonites of the Bujanova basement complex.

The same sense of movement is indicated by displacement of the reverse fault sets in the diaphthoritised gneisses of the Lodina complex (Fig.10). The displace-

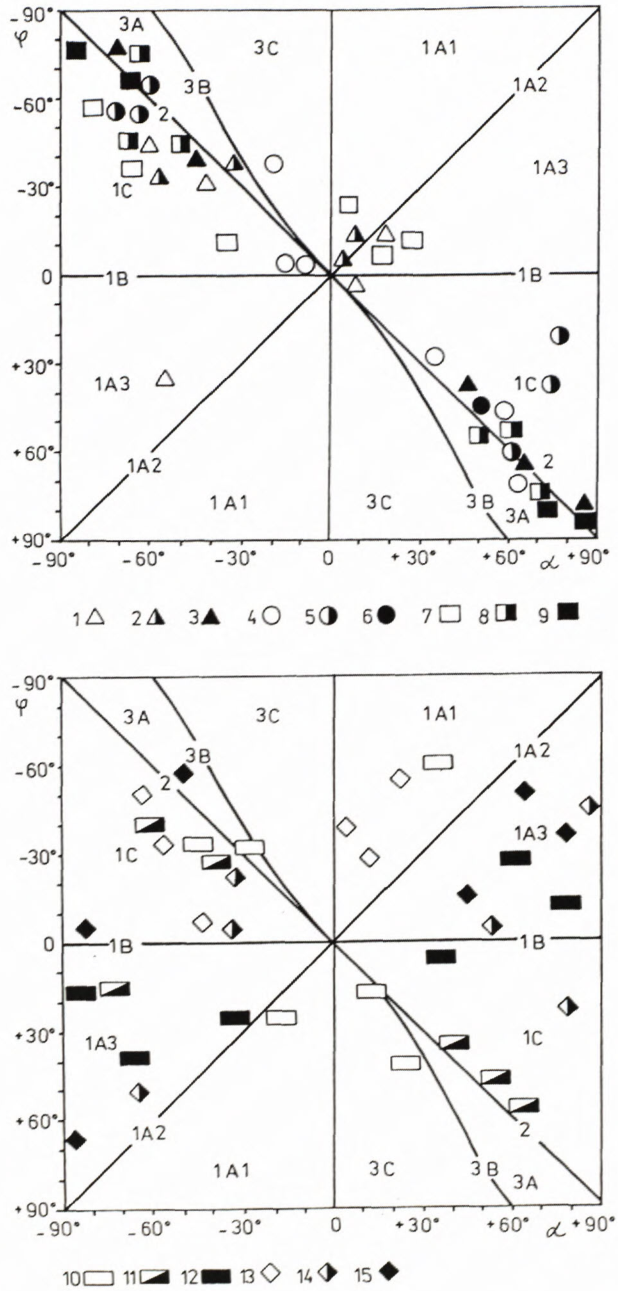
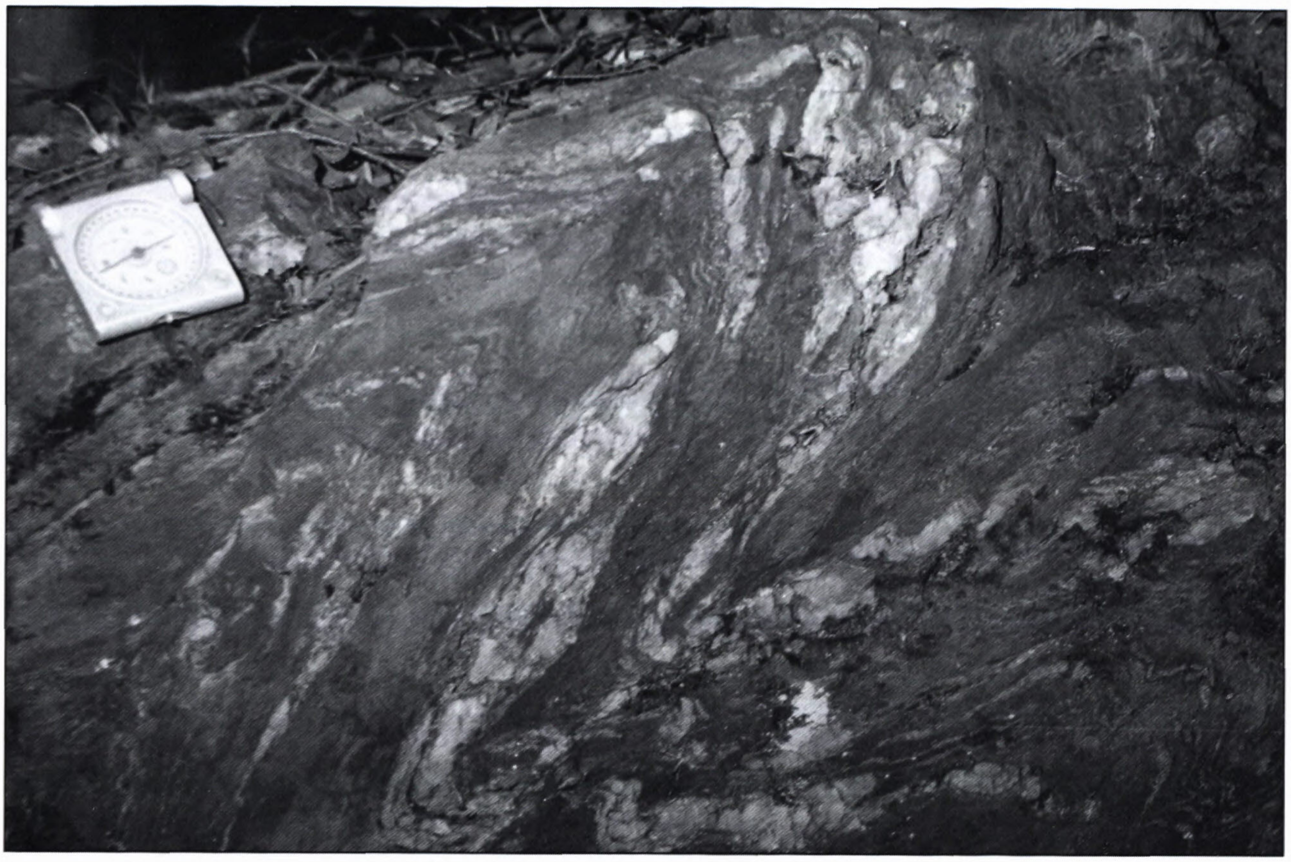


Fig. 8.a,b. Geometrical relationships of the Alpine AF_2 folds (cf. Fig.3 for the complementary deformation stage) within competent layers of the Veporicum and Gemericum units, as results from ZAGORCEV'S (1993) modified diagram of HUDLESTON'S (1973) and RAMSAY'S (1967) classification. φ - dip isogon angle, α-dip angle, empty symbols - open folds, half filled symbols - close folds, full filled symbols - tight folds, Fig. 8a., modification trend of AF_2 folds of the Veporicum Unit: 1-3, in the Lodina complex diaphtorised gneisses, 4 - 6, in the Early Triassic quarzites, 7-9, in the Jurassic limestones. Fig. 8 b, modification trend of AF_2 folds of the Gemericum Unit: 10-12, in the Carboniferous limestones, 13 - 15 in the Carboniferous basalts and their volcanoclastics.



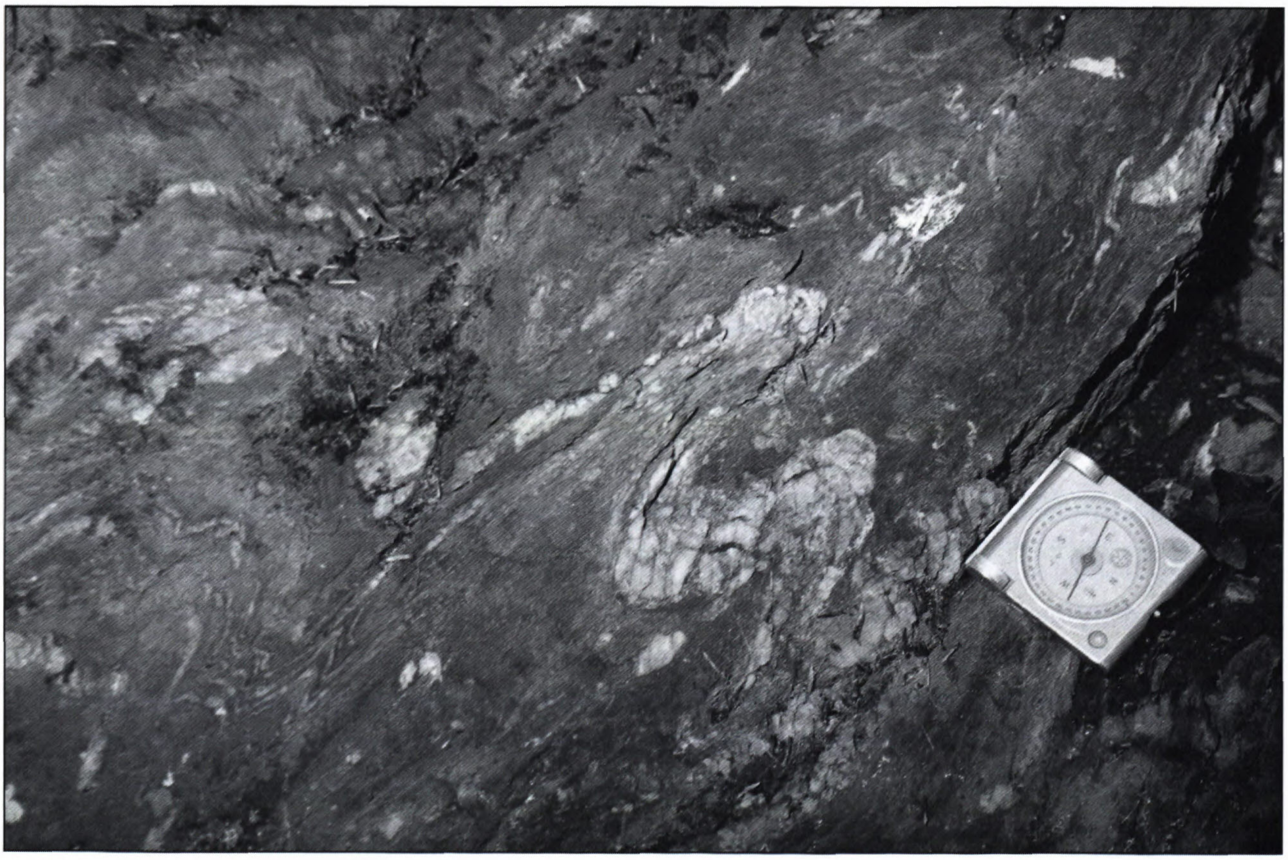


Fig. 9. Monoclinal south-westerly dipping cleavage set developed due to shearing of AF_2 folds in the Gemeric Carboniferous basalt volcanoclastics nearby the Margecany shear zone.

ment in the discussed shear zones has been accompanied by synchronous growth of lower greenschist facies metamorphic assemblages (Fig.3).

AD_2 in Gemericum Unit

Due to extensive shearing in the repeatedly activated AS_2 cleavage planes the AF_2 folds irregularly occur only in more competent layers of both the Gelnica group and the Carboniferous formations of the unit. To compare these folds with folds of the same deformation stage in the Veporicum Unit, the AF_2 folds of the adjacent Gemeric Carboniferous formations have been plotted in the ZAGORCEV'S (1993) diagram (Fig.8b). Except for clear common features with a general modification trend of the AF_2 folds in the Veporicum Unit (Fig. 8a), much more evaluated folds belong to $1A_1$, $1A_2$ and $1A_3$ fold types fields i.e. into the field of supratenuous 1A subclass of RAMSAY's (1967) classification. Relatively great number of these folds with strongly convergent isogons and thickened limbs at the NE margin of the Gemericu Unit, were probably produced during superimposed deformations in this strongly mobile contact zone of two rheologically contrasting units.

For analogous reasons as in the Veporicum Unit the extensive shearing of AF_2 folds in their AS_2 axial plane cleavage set (Figs. 9a,b), and the development of corresponding reverse fault shear zones are the result of the second tectonometamorphic event of the AD_2 deformation stage. Generally, both structures are moderately inclined to SW ward (Figs. 1b,c) and they are an original cause of monoclinally imbricated structure of the contact zone of the Gemericum and Veporicum units (JACKO, 1979).

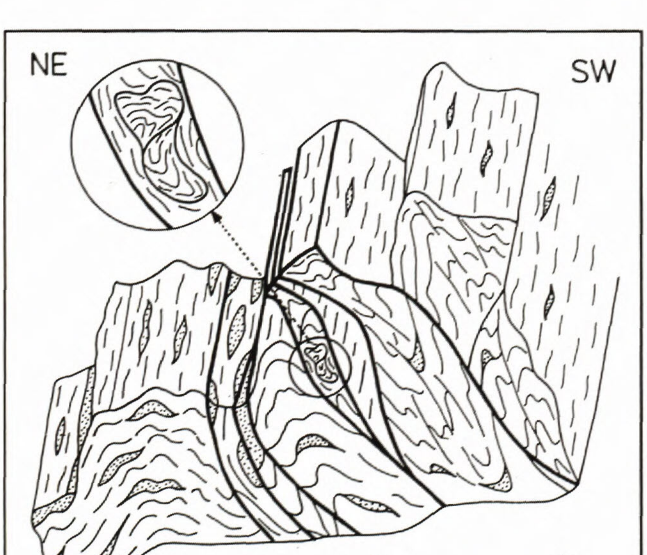


Fig. 10. Axial plane reverse fault shearing of AF_2 folds and contemporaneous mullions development within the Lodina Complex diaphtoritised gneisses. Lenses of segregation quartz are dotted.

AD deformation stage

Locally developed N - S trending fault/AF_3 fold structures of this deformation stage (Fig. 3) are clearly superimposed on structures of previous deformation stages (JACKO, 1979). Very scarce AF_3 folds of metric order, which originally accompanied normal fault zone, occur only in the cover formations of the Veporicum Unit. These open, upright folds, slightly similar in geometry, have well developed AS_3 axial plane crenulation cleavage, subparallel to corresponding fault zone. Fold axis and parallel crenulation cleavage dip gently (5°-10°) to S - SSW.

AD_4 deformation stage

This stage comprises an expressive, post - Paleogene wrenching of the previous structure of the area. Dominant strike-slip zones within all the units of the region are several 10 m thick, they have NW-SE orientation and moderate to steep dip to SW (Figs. 1b,c, 11,12). Three significant - sinistral strike-slip zones developed either within the Veporicum Unit, or at its south-western boundary with the Gemericum Unit (Fig.11). Brittle deformations in all of them reactivated tectonic zones produced during earlier deformation stages. The overall paleostress field, determined from the fault slip data analysis, reveals a subhorizontal, roughly E-W oriented compression for these wrenching deformations (Fig.11).

Both the fault slip data (Figs. 12B, D, E, F) and the average stress ratio of abount 0,5, confirm the subhorisontal motion component (GUIRAUD et al. 1989) within the most pronounced, the Margecany strike - slip zone. The stress ratio (above 0,5) (Figs. 12J, K, L), calculated for the strike - slip zone running along NE boundary of the Miklušovce basement rocks with cover formations (Fig.11), indicates prevailingly inclined normal faulting in the zone (Fig.12 M). An analogous movement pattern has been obtained from corresponding data (Fig.12 G,H,I) for the central strike-slip zone of the Veporicum Unit (Fig.11), which reactivated the phyllonite zone at the to boundary of the Bujanova and the Lodina crystalline complexes, respectively.

Steeply SW dipping normal fault zone, developed at the NW edge of the unit, (Figs.11,12 A) along which the Intra Carpathian Paleogene strata submerged into the pre-Tertiary complexes, reveal a composite movement pattern in the strike-slip zones of the area. GRECULA et al. (1990) described dextral shearing in directionally analogous shear zones in the Gemericum Unit.

Discussion and conclusions

Alpine deformations of the studied area have developed in a poly-stage process, influenced by either rock formations anisotropy, or by a change of bulk strain regime during its evolution.

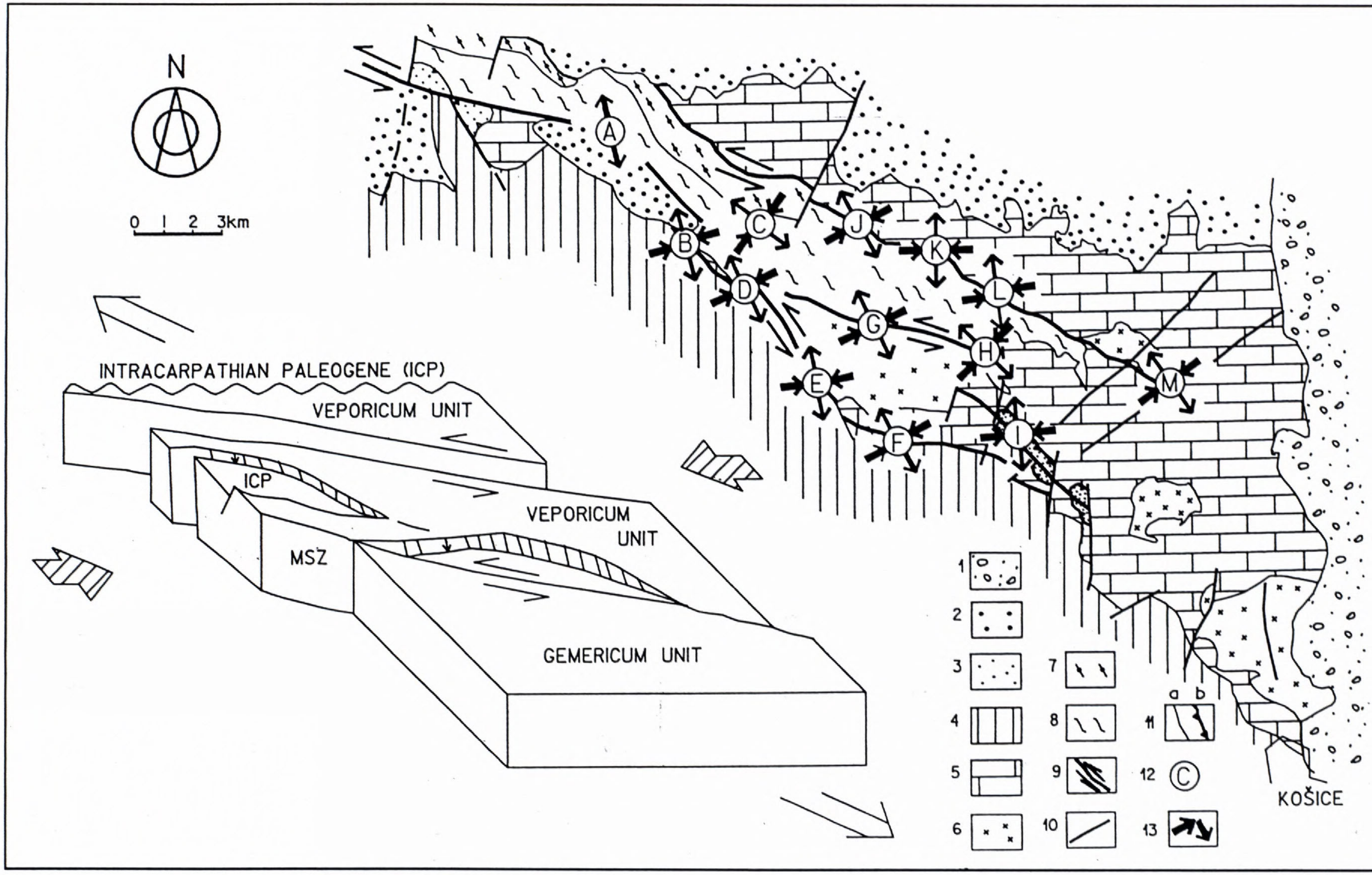


Fig.11. Map scheme and the kinematic model of dominant post-Paleogene strike - slip zones in the Veporicum Unit of the area.
1 - Neogene molasse sediments, 2 - Intra Carpathian Paleogene flysch, 3 - Late Carboniferous of the Choč nappe, 4 - the Gemericum Unit (undivided), 5 - Veporic cover formations, 6 - Bujanova Complex (undivided), 7 - Miklušovce Complex, 8 - Lodina Complex, 9 - strike-slip zones, 10 - normal faults, 11 a - geological boundaries, 11b - sole of the Choč nappe, 12 - Location of paleostress analysed strike - slip zones sites plotted in Fig. 12.

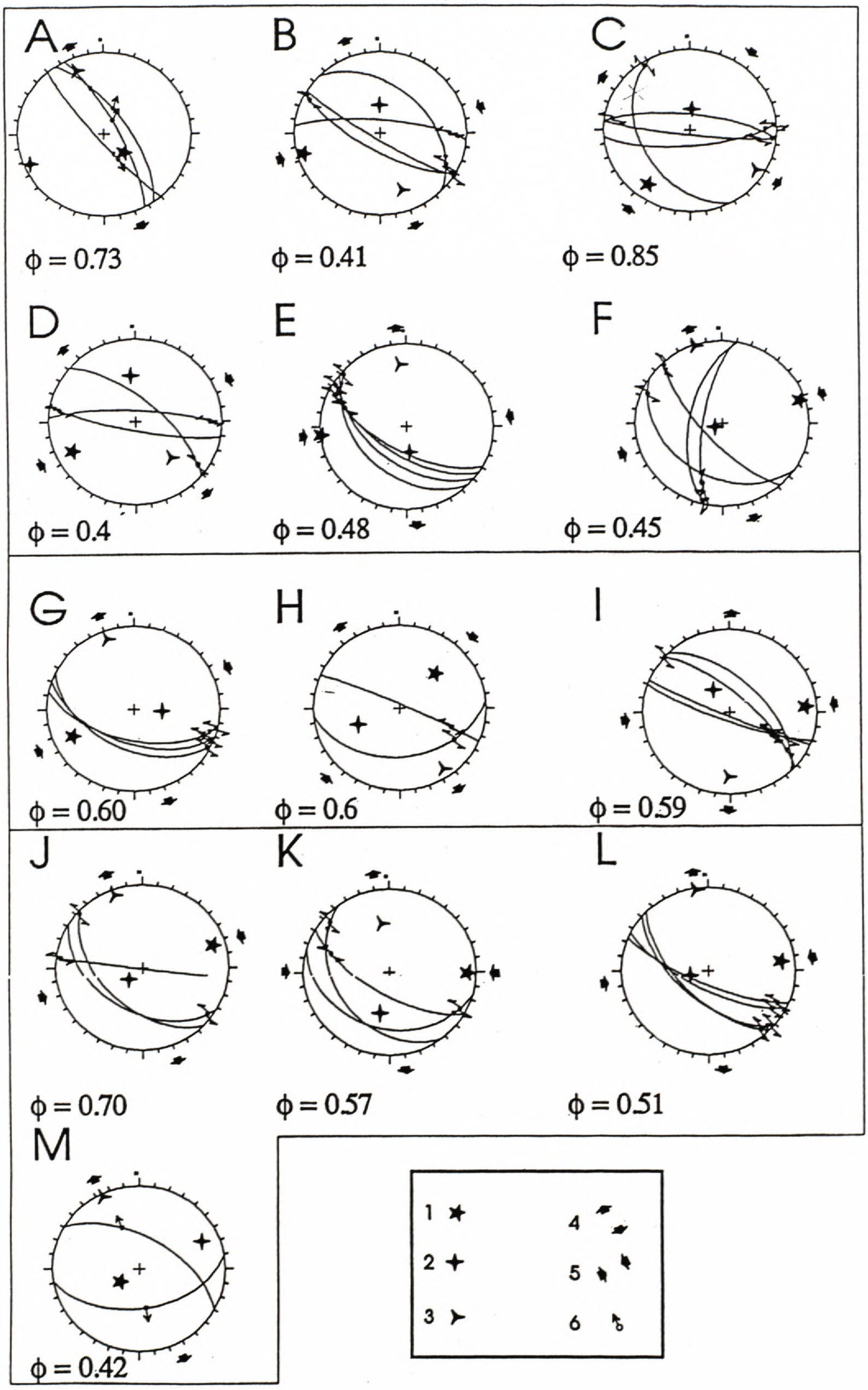


Fig. 12. Stereogram of paleostress analyse sites of strike - slip zones drawn in Fig. 11.
1-σ_1 (maximum compressive stress), 2 - σ_2, 3 - σ_3, 4 - direction of extension, 5 - direction of compresion, 6 - direction and sense of slip, ϕ - stress ratio.

Tectonite zones of the Late Variscan nappe stacking developed at the base and within the nappe slices of the Veporicum Unit cristalline complexes have played a catalytic role in the Alpine structural reworking of the basement complexes of this unit. Remnants of structural and mineral assemblages of AD_1 - AD_4 deformation stages occur in all these zones (Figs.3, 4, 5). The Late Variscan top - to - the SE nappe stacking of the Western Carpathian basement, recognized by FRITZ et al., (1992) in the Western Tatra basement has been confirmed to have occurred in the Veporicum Unit (geochronological dating 330-312 Ma, DALLMEYER, pers. commun., 1993) and by occurrence of clasts from the diaphtoritised gneisses of Lodina Complex in the Upper Carboniferous cover conglomerates (KORIKOVSKIJ et al., 1989).

The pre - Senonian AD_1 shortening of the area is characterised by formation of AF_1 recumbent folds, limited to either the less competent cover strata at the SW edge of the more rigid Veporicum Unit, or to analogous media at the top of Lodina basement complex and to the Gelnica Group of the Gemericum Unit, respectively. A successive top - to - the N - NNE emplacement of the Alpine nappes led to the closure of the Choč nappe homeland area and to thrusting of the nappe over a frontal Veporic ramp northwards, over the Tatric area of the WCI (Fig.2). In the Veporic basement this nappe shortening caused a reverse-thrusting of two delaminated slices of Bujanova basement complex onto the Lodina complex, along reactivated Late Variscan shear zones (Figs.1b,c, 2). The remmants of AF_1 axial plane cleavage, occurring in over 400 m of Lodina Complex diaphtoritised gneisses, indicate an extensive shearing of this basal, subachtonous (?) sequence of the Veporic crystalline complexes of the region.

Corressponding cleavage sets in the Gemericum Unit occur scarcely in more competent strata of both the Silica nappe klippes and the Late Variscan Klatov Group nappe pile (JACKO, et al., 1995). Analogous, i.e. flat position of about 6 km thick, strongly reflective zone, is also seen in the recently shot deep seismic profile G (VOZÁR et al., 1995), which intersects the area nearby the lines 3 - 4 of the cross - section (Fig.3c). This highly sheared northern Gemeric zone, followed within of the deph interval of 6 - 10 km, is regarded to be the root zone of both, the Křížna and the Choč superficial nappes (l.c.).

The AF_2 folds and complementary reverse fault shear zones control the main features of the recent NW-SE lithostratigraphic zoning of the area (Fig.1b,c). The AF_2 folds are penetratively developed throughout the lowest unit of the Veporic basement, i.e. throughout the Lodina diaphthoritic gneisses. Axes of the AF_2 folds, superimposed on the carlier structures, make an angle of about 60° with the Alpine nappe emplacement striations, which are presered on corresponding cleavage set. These data, as well as unlike mineral assemblages of both the AD_1 and AD_2 stages (Fig.3) either indicate a change in bulk strain orientation, or slightly different low temperature metamorphic conditions during the AD_2 deformation stage.

A close spatial connection between flattening intensity of AF_2 folds and reverse fault shear zones suggests a successive development of the latter. An extensive brittle- ductile shearing in the these shear zones, which reactivate the rheological boundaries of both the Gemericum and Veporicum units, transposed the majority of lithostratigraphical units into monoclinal, south-west dipping position (Fig.1c). The Meliata Unit slice in the core of the Northern Gemeric syncline is strongly stretched and finally sheared in NE direction, along one of these structures (Fig.1b,c). According to recent geochronological investigations carried out in the central part of the Veporicum Unit of the WCI, the disscussed zones have formed between 85 - 86 Ma (Ar-Ar, DALLMEYER et al., 1993), which corresponds with occurrence of their tectonics in the Intra-Carpatian Paleogene conglomerates in the area.

Subsequently developed AD_3 structures have opened the shearing planes of the AD_2 stage for both, hydrothermal vein mineralisation in the Gemeric and Veporic units, and for the local post - kinematic thermal ascent (Fig.3) in the latter unit (JACKO, 1979, 1983, ROZLOŽNÍK, 1990).

Sinistral AD_4 strike - slip zones, following the most weakened zones between and inside the units of the area (Figs. 1b, 11), are directionally, as well as in terms of paleostress orientation, compatible with the Badenian - Sarmatian widenig of the Eastern Slovakian molasse basin (KALIČIAK et al., 1991). We suggest that their origin was primaryly caused by the eastward escape of the Western Carpathians from the Alps (NEUBAUER & GENSER, 1990, RATSCHBACHER et al., 1991). The Margecany strike - slip zone, detected in the above mentioned deep seismic profile G_1 to dip at an angle of 45° down to the depth of 7 kms, continues as a flat tectonic zone below this depth horizon, at an angle of approximately 20°- 25° to a depth of 25 km (VOZÁR et al. 1995).

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