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The Malé Karpaty Mts. — constituent of the transitional segment between the Carpathians and Alps; important tectonic window of the Alpides

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Малые Карпаты — составная часть сегмента между Карпатами и Альпами; знаменательное тектоническое окно альпид

Татрикум Малых Карпат является составной частью тектонических окон на рубеже Альп и Карпат. Альпинские покровы в татрику маскируют выразительные герцинские перемещения.

Высоцкая единица Малых Карпат является продолжением Семеринской чешуйчатой системы, злиеховская на франкенфельский покров а манинская на киеселкалкзону. В почве неогена венской впадины высшие покровы плавно перестроены с карпатского структурного плана (с единицами над собой) на альпский (с единицами возле себя). Брезовская мелово-палеогенная секвенция не является продолжением типичной госавской формации. Она составная часть высшего структурного этажа, пересунутая через северный пик гисгубелской структуры и через вздыбленные структуры низшего этажа, строенного хочским, крижнянским и манинским покровом и мелово-неогенной секвенцией Суровин.

The Malé Karpaty Mts. — constituent transitional segment between the Carpathians and Alps; important tectonic window of the Alpides

The Tatricum of the Malé Karpaty Mts. is a part of the system of inliers at the boundary of the Alps and Carpathians. The Alpine nappes in the Tatricum are obscurring distinct Hercynian overthrusts.

The Vysoká unit of the Malé Karpaty Mts. is linked with the Semmering sliced system, the Zliechov unit with the Frankenfels nappe and the Manín unit with the Kieselkalkzone.

In the substratum of the Neogene of the Vienna basin is gradual rebuilding of the Carpathian structural plan (with units lying above one another) to the Alpine plan (with units in juxtaposition) in the higher nappes.

The Brezová Cretaceous-Paleogene sequence is part of the higher structural stage, which overlaps northern corner of the Giesshübler mulde and erected structures of the lower structural stage (Choč nappe, Krížna — Manín nappes and Upper Cretaceous-Paleogene Surovín) sequence.

The Malé Karpaty Mts. are known to geologists as marginal mountains, situated at the southwestern corner of the Central Carpathians, nearest from all to the Eastern Alps. Morphostructurally they are one-sided core mountains, typical of the West Carpathian — a horst elongated in West Carpathian direction (SW — NE) with a vast Tatric „core", Subtatric Krížna, Choč and higher nappes. In the southern part, in the Pezinské Karpaty Mts., the horst is homogeneous morphostructurally; in the northwestern part it is dissected by the Buková depression filled up with an aberrant (transitional) type of the Central Carpathian Paleogene sequence. The morphostructurally more dissected northern part of the mountains — the Brezovské Karpaty Mts. together with the Myjavská pahorkatina Upland (prevailingly built up of Upper Cretaceous — Paleogene sequences) represents the Periklippen zone (Fig. 1, 2).

Besides the content of the fundamental members and whole sequences, also those typical of the West Carpathians, each of the fundamental tectonic units displays several differences in the content and structure, which appear as specific properties from the Carpathian view (Maheľ, 1983). They are, however, a consequence of approaching the Alps.

The crystalline core is built up of granitoids and metamorphites. The differences of granitoids from the fundamental

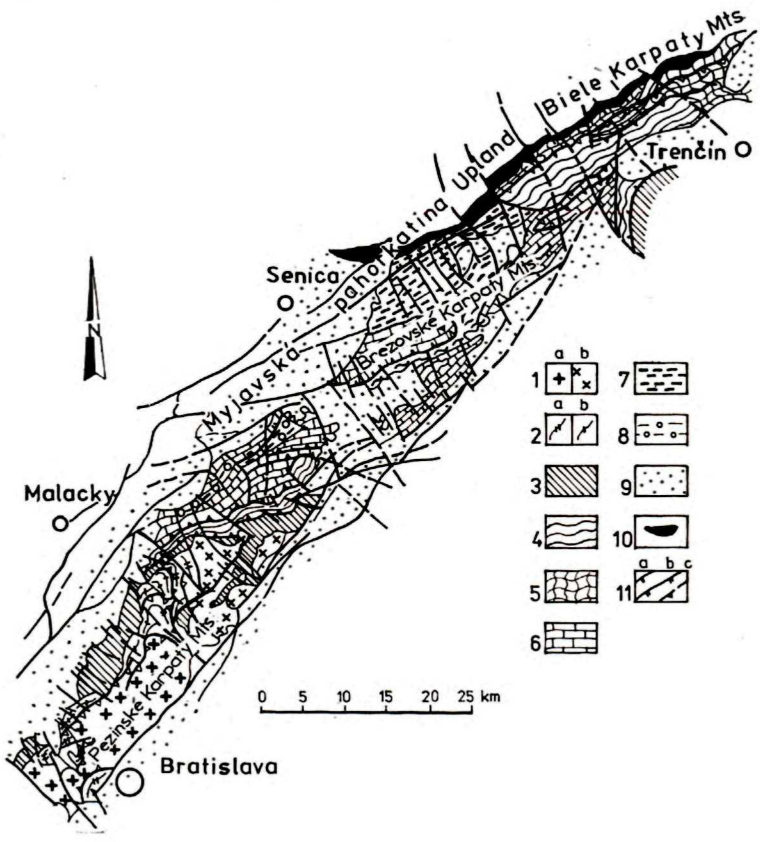

Fig. 1. Tectonic sketch-map of the Malé Karpaty Mts. 1 — 3 — Tatricum: 1 — granitoids: a — Bratislava type, b — Modra type, 2 — metamorphites: a — paragneisses and mica schists, b — epimetamorphosed sequences, 3 — envelope Mesozoic sequences, 4 — Krížna nappe, 5 — Manín nappe, 6 — Choč and higher nappes, 7 — Upper Cretaceous-Paleogene periklippen units, 8 — Paleocene subflysch, 9 — Neogene sediments, 10 — Klippen Belt, 11 — overthrust lines, upthrusts, faults

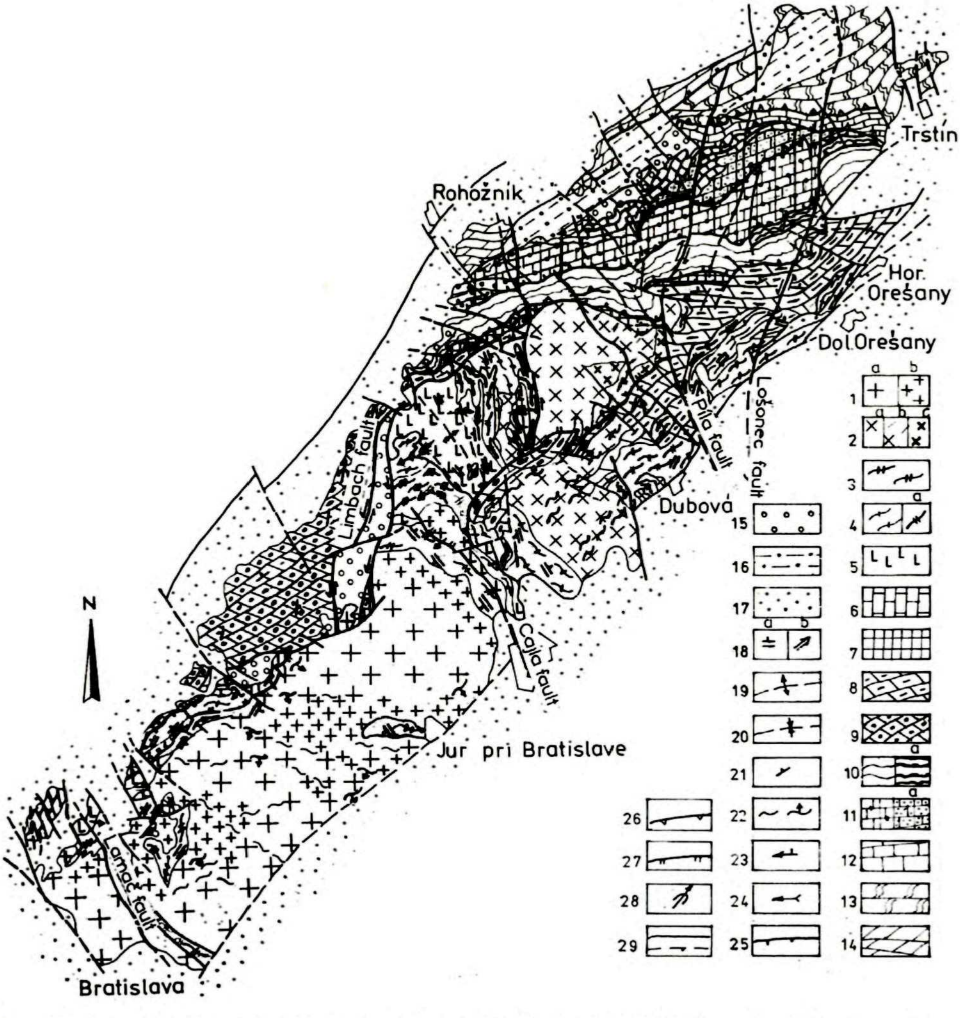

Fig. 2. Tectonic map of the SW part of the Pezinské Malé Karpaty Mts. 1 — 5 -- crystalline rocks: 1 — a — Bratislava two-mica granite, b — leucocratic granites, 2 — a — Modra granodiorite, b — two-mica granite, c — autometamorphosed granite, 3 — mica schist gneisses, in places migmatized, 4 — a — quartz phyllites to quartz mica schist gneisses, b — graphite phyllites, metaquartzites, metalydites and graphite sandy schists to phyllites with layers of limestones, diabases — Harmónia formation, 5 — amphibolites, 6 — 8 — envelope units: 6 — Devín unit, 7 — Kadlubek unit, 8 — Orešany unit, 9 — Borinka unit, 10 — Krížna nappe, a — Vysoká nappe, b — Zliechov nappe, 11 — 14 — Choč and higher nappes: 11 — base of the Melaphyre series, 12 — Veterník nappe, 13 — Havranica nappe, 14 -- Jablonica nappe, 15 — Upper Cretaceous (?) conglomerates, 16 — Paleogene subflysch, 17 — Neogene on the whole, 18 — 20 — pre-Alpine (Hercynian) structural elements, 18 — a — metamorphic foliation (S_1), b — B-axes of metamorphic mesofolds, 19 — axis of antiform, 20 — axis of synform, 21 — 28 — Alpine structural elements: 21 — Paleoalpine foliation in the Mesozoic, 22 — mylonites and graphite sandy schists to phyllites with layers of limestones and diabases — and cataclastic foliation in granitoids, 23 — B-axes of mesofolds, 24 — B-axes of kink folds, 25 — overthrust planes of I. order, 26 — overthrust planes of II. order, 27 — upthrusts, 28 — recumbent folds, 29 — normal faults and strike-slip faults

West Carpathian Ďumbier and Prašivá types are, however, such ones that they are distinguished as particular types: the Bratislava granite close to leucocratic types and the Modra granodiorite, both with zonal periplutonic metamorphism, at the Modra type with distinct contact metamorphic manifestations (Cambel, 1976).

The metamorphic mantle — the Pezinok sequence — is formed by gneisses and micaschist-gneisses but also by migmatites as in other core mountains. The prevailing portion in the frame of the Tatricum is however, formed by particular lower — grade metamorphosed members, moreover, arranged into several sequences: the Častá sequence of flysch type in the upper part with the Harmónia formation with a high portion of graphite schists with intercalations of crystalline limestones and the Pernek volcanogenic sequence with abundant basic rocks including gabbros. Preservation of the Hercynian structures in the Malé Karpaty crystalline rocks belongs among typical Tatric features.

The envelope Mesozoic displays the fundamental features of Tatric Mesozoic sequences with the stratigraphic range from the Lower Triassic to Lower Cenomanian, but with less portion of Middle and mainly Upper Triassic members; a so typical member as the Carpathian Keuper is missing. And on the contrary, characteristic Malé Karpaty lithotypes are slope lithotypes, the Borinka limestones and conglomerates of Somár, also the deep-sea Marianka shales of wider stratigraphic range. The paleotectonic variety and contrastness of whole sequences (Fig. 3) and from structural viewpoint the considerable extent of Mesozoic members folded in amidst crystalline rocks of the Modra „massif“ are conspicuous (Mahel, 1972, 1979).

The Krížna nappe in the Malé Karpaty Mts. has all fundamental features as in other core mountains: the stratigraphic range from the Lower Triassic to Lower Cenomanian, distribution of the rear part of the nappe overlying the Tatric units, recumbent folds-digitations and subordinate nappes as the fundamental tectonic style. It, however, differs in a disproportionately great portion of a unit with shallower-water members — the Vysoká unit (Mahel, 1959; Fig. 7). The Zliechov sequence takes part in the structure of the nappe rear part to a small extent only; it is however, piled up in its frontal part and refolded with the Manín unit.

The Manín unit, close in content to one of the developments of the Vysoká unit, formed by the Bošáca sequence (Mahel, 1978), has a considerable portion of Upper Triassic members and a particular Liassic lithotype.

The Choč nappe is characterized also in the Malé Karpaty Mts. by the typical West Carpathian Melaphyre series, moreover, thick with several slices. The presence of a dark shaly formation with intercalations of limestones and silicites is characteristic of the southwestern corner of this unit. The Čierny Váh nad Biely Váh sequences, typical of the Central Carpathians, occur only in smaller slices in the Malé Karpaty Mts., more abundant nearer to the frontal part of the Subtatric nappes accompanied by Jurassic — Lower Cretaceous members. The sequences with the presence of the Reifling limestones, but also with the Wetterstein limestones (Veterník, Havranica and Jablonica sequences) are typical of the Malé Karpaty Mts.; on the basis of this fact they are more often ranged to the higher nappes (Andrusov, 1936; 1967; Biely et al., 1980).

The northern part of the Malé Karpaty Mts. and the adjacent Myjavská pahorkatina Upland are characterized by the presence of thicker Upper Cretaceous-Paleogene sequences, moreover, of two developments: the Periklippen Surovín development without a more distinct break between the Cretaceous and Paleogene members and the Brezová development with a distinct hiatus (Salaj — Began, 1983). Both are equivalent to the East Alpine Gosau Cretaceous, which represents the Mesoalpine stage of nappes of the Limestone Alps. In the Malé Karpaty Mts. (Buková depression), however, also a member typical of the West Carpathians — the Central Carpathian Paleogene — is present, in a development close to the Periklippen development (it begins with the Paleocene and not with the Lutetian, moreover, the typical flysch is missing).

The presence of Alpine elements in the structure of the Malé Karpaty Mts. is natural. The easternmost parts of the units of the Limestone Alps display Carpathian features as are the occurrences of the Carpathian Keuper, the West Carpathian orientation of direction of structural elements (SW — NE; Tollmann, 1975). We assign to the Carpathian elements in the structure of the eastern corner of the Alps also the presence of the so called Kieselkalkzone, which we consider as the southwestern corner of the Manín (Bošáca) unit, but also as the corner of the Klippen Belt near Vienna. Several structural particularities of the Malé Karpaty Mts., such ones as piling up of the Zliechov unit, moreover, also with accompanying Triassic members of the Čierny Váh and Biely Váh units in the frontal part of the Subtatric nappes are a consequence of approaching the Alpine structural model, with such a feature as distribution of the more northern Paleoalpine nappes (Frankenfels and Lunz nappes) in the frontal part of the nappe system of the Limestone Alps and Late Alpine subsequent thrusting of nappes, incorporation of Upper Cretaceous — Paleocene complexes between them. The validity of the Alpine structural model in the substratum of the Neogene of the Vienna basin is proved by layers of Upper Cretaceous and Paleogene members amidst older nappe masses (Kröll — Wessely, 1973; Němec — Kocák, 1976).

To the features specific for the segment transitional between the Alps and Carpathians called the Devínske Karpaty Mts. (Maheľ, 1983) indubitably erection of folded structures and steep back-upthrusts belong, often veiling the nappe character. This structural feature, distinct in the structure of the Mesozoic substratum of the Neogene of the Vienna basin, is also evident in the Malé Karpaty Mts. in higher nappes, in the Vysoká nappe (Maheľ, 1967; Michalík, 1984) and partly also in crystalline rocks.

In the structural plan of the Malé Karpaty Mts. also further disjunctive elements of the Neoalpine tectonics, mainly transversal faults of NW — SE direction (perpendicular to the course of the horst), but also faults of N — S direction connected with more significant faults in the Vienna basin are manifested much more intensely than in whatever core mountains. At several from the strike slips faults (mainly north-southern) are distinct displacements of 3 — 5 km. It is not always easy to consider, which from the particular features is a manifestation of approaching of the Malé Karpaty Mts. structure to the Alps and which it is necessary to assign to endemites of the transitional segment of equal category as the molassoid complexes of the Ždanice — Hustopeč beds in the Flysch Belt, but also the transversal orientation of the structural elements of the lower stage of the Vienna basin.

We put the endemitic features into connection with a deep phenomenon- a transversal ridge, which connects the Bohemian massif with the Hungarian massif (Maheľ ,1983) and probably forms a barrier to spreading of Alpine earthquakes into the Carpathians (Zátopek, 1979). A more distinct manifestation of the ridge is uplifting of the deep substratum, documented by a deep seismic profile in the Malé Karpaty Mts. (Beránek — Weiss, 1980). We put the presence of Tatric units unknown from other core mountains, which are lowermost structurally, paleogeographically the northernmost elements of the Tatricum and possibly already also of the Penninicum, into connection with uplifting of the Malé Karpaty Mts. (Maheľ, 1981).

In such a conception the Malé Karpaty Tatricum is essentially an inlier, a part of the system of inliers known from the eastern margins of the Alps (Tollmann, 1977).

From the view of the Tatricum in the Malé Karpaty Mts. as an inlier of the Alpides several new views of relations between the Carpathians and Alps, but also of the structure of the deep substratum, which could be the marginal parts of the Bohemian massif (s. s.) including the Mesozoic envelope of transitional-slope type, result. So the possibility of extension of areas perspective for oil and gas arises.

For solution of these questions particular attention was concentrated in the last years in the frame of the purpose project „Investigation of geological structures of the SW part of the West Carpathians in relation to perspective oil and gas deposits" (Maheľ, 1984) with the leading ideas:

— allochthonity of the Tatricum of the Malé Karpaty Mts. with several nappe slices; contradiction of the idea of the autochthonous position of crystalline rocks of the Malé Karpaty Mts. and its negative influence on the perspective of bitumen deposists in the eastern part of the Vienna basin,

— the undeep position (partly exposure) of the underlying Penninicum and autochthonous substratum (Bohemian massif), or with its Mesozoic envelope,

— connection of the rear parts of the Krížna nappe (Vysoká unit) with the Semmering sliced system and of the frontal parts of the nappe refolded with the Manín unit to the Frankenfels-Lunz sliced system including the Kieselkalk-zone-structures, which are the bearers of several deposits of natural bitumens in the substratum of the Vienna basin.

— linking of the Veterník, Havranica, Jablonica nappes, but also of the lower nappe slices of Čierny Váh and Biely Váh types from the Malé Karpaty Mts. with the Alpine nappes of the Lunz and Ötscher group,

— incorporation of the Upper Cretaceous-Paleogene sequences of the Myjavská pahorkatina Upland in the nappe structure as a higher structural stage.

Allochthonity of the Malé Karpaty Tatricum and its relation to units from the Alps

The Malé Karpaty crystalline rocks, equally as the essential part of the Tatricum were generally considered as autochthonous. The opinions of the nappe style began to be formulated consequently with distinguishing of the Vahicum-continuator of the Penninicum into the West Carpathians (Maheľ, 1981a, b). Up to now ,however, there are two contradictory conceptions of the structure. One sets out from detailed knowledge, mainly of material composition of crystalline rocks and its argument for autochthonity is zonal periplutonic metamorphism in the Bratislava as well as Modra massif (Cambel, 1976; 1984; Korikowskij — Cambel et al., 1985), but also distinct manifestation of transversely oriented structures. The differences between the type of granitoid bodies (more acid Bratislava massif) with their metamorphic effects (the Modra massif with more distinct contact effects) also in representation of the type of metamorphites in the individual parts are explained by differences in the age and depth of intrusion levels. Three groups of radiometric data obtained by Rb/Sr method (Cambel et al., 1977); the Middle Devonian age (388 ± 38 mil. y.) of regional metamorphism, Lower Carboniferous (347 ± 4 mil. y.) of the intrusion of the Bratislava granite at 300 — 350 MPa and of the early Middle Carboniferous (324 ± 18 mil. y.) of the intrusion of the Modra granodiorite at 100 — 150 MPa testify to several stages of the Hercynian tectonometamorphic processes. These, however, formed the Hercynian structural plan not only by vertical displacement of blocks, but also with action of the horizontal component of movements. The fan-shaped structure in Paleozoic complexes, known earlier, testifies to considerable intensity of horizontal compressions and indicates horizontal displacements, which use to accompany the fans. The orientation of the Hercynian structural elements, often transversal to Alpine directions, quite characteristic of the Hercynian structures of the Tatricum — indicates more distinct differences of the Hercynian and Alpine structural plan.

The impression of homogeneity and so of competence to one tectonic unit of the Malé Karpaty crystalline rocks is evoked by representation of epimetamorphosed complexes in the whole extent of the Malé Karpaty Mts. (Fig. 2). It is a feature of approaching to the Alps where in the Unterostalpin, but also in the Penninicum analogous complexes are particularly wide-spread, e. g. the Late Paleozoic Wechsel series and the Early Paleozoic Ranach series. But the differences in the individual bodies cannot escape from nearer geotectonic view of metamorphites in the Malé Karpaty Mts. Particularly distinct differences between the Bratislava and Modra „massif", which enhance the differences in the petrographic character and age of granitoid intrusions, are in their relation to the mantle. The Bratislava granitoid „massif" is accompanied by a complex of paragneisses and mica-schist-gneises complex with thinner layers of amphibolites; a sequence analogous to the gneiss complexes of most core mountains, we designate it as the *Pezinok sequence*. Its particularity is structural connection, in places through a layer of tectonic breccias, with the phyllite-amphibolite formation designated by us as the *Pernek sequence*, or with the Harmonia formation. In the Modra „massif" the Pezinok sequence is missing.

Detailed studies (Klukan — Putiš) prove the different lithological, structural and metamorphic character of gneisses and mica schists of the Pezinok sequence from other less metamorphosed members typical of the Malé Karpaty crystalline rocks. With a nearly equal age (Planderová in Cambel — Planderová, 1985) of these obviously genetically different sequences their assignment to the same tectonic unit may be a consequence of tectonics only, evidently Hercynian. Moreover, more distinct differences are also between lower-grade metamorphosed complexes in the individual areas-bodies of the Malé Karpaty crystalline rocks.

The Modra area is characterized by a

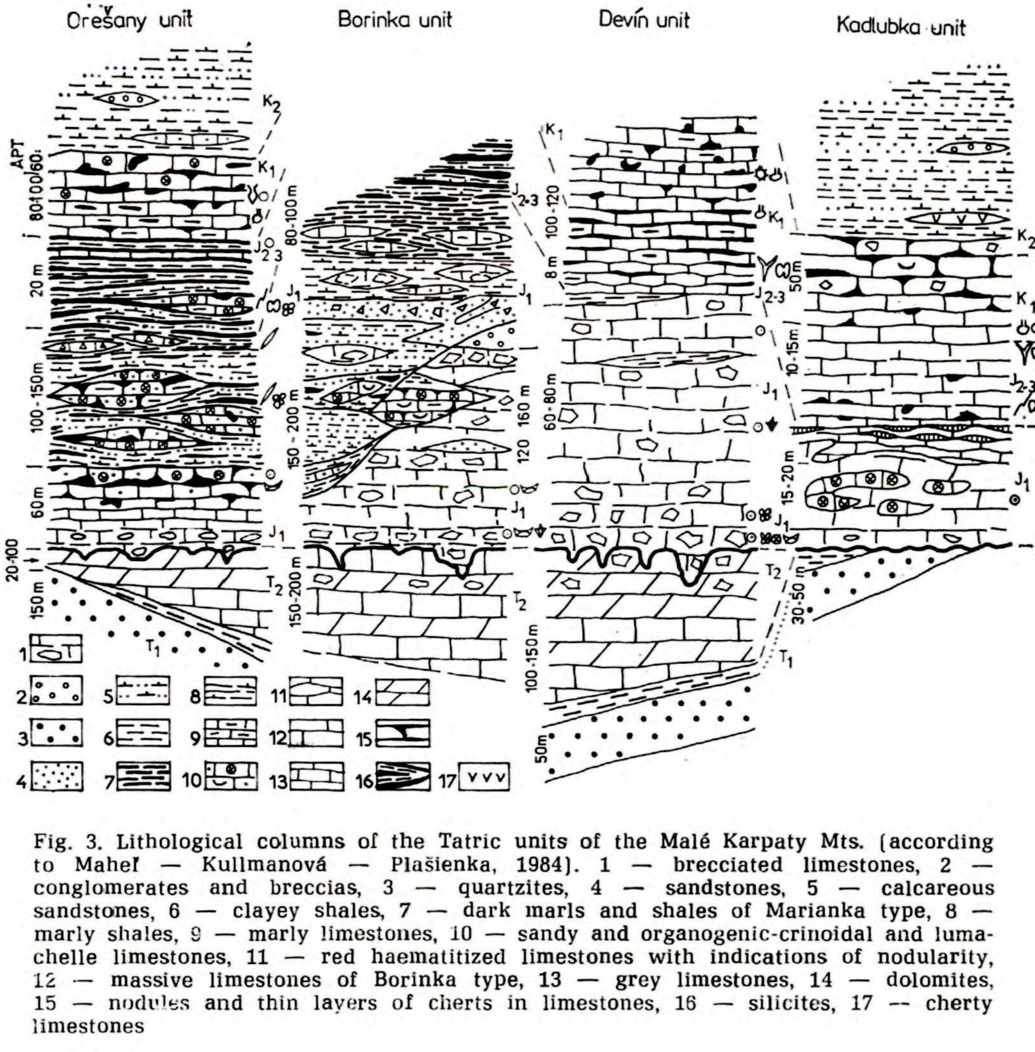

Fig. 3. Lithological columns of the Tatric units of the Malé Karpaty Mts. (according to Maheľ — Kullmanová — Plašienka, 1984). 1 — brecciated limestones, 2 — conglomerates and breccias, 3 — quartzites, 4 — sandstones, 5 — calcareous sandstones, 6 — clayey shales, 7 — dark marls and shales of Marianka type, 8 — marly shales, 9 — marly limestones, 10 — sandy and organogenic-crinoidal and lumachelle limestones, 11 — red haematitized limestones with indications of nodularity, 12 — massive limestones of Borinka type, 13 — grey limestones, 14 — dolomites, 15 — nodules and thin layers of cherts in limestones, 16 — silicites, 17 — cherty limestones

complex of sericite-biotite and quartz phyllites to quartzites or a flysch formation — the *Častá sequence* and thicker Harmónia formation of sericite-chlorite phyllites with a higher portion of bituminous component with lenticles of crystalline limestones (often altered into erlans) and smaller bodies of basic rocks.

The extensive fan, which links up the Bratislava and Modra body and the Baďurka slice is mainly built up of a volcanogenic complex with bodies of amphibolites and gabbros — the Pernek sequence.

The differences in the type of metamorphites in the individual areas and bodies of the Malé Karpaty Mts. cannot be overlooked, the more that the accompanying sequences of the envelope Mesozoic (formely considered as developments of the Malé Karpaty unit: the Devín, Borinka, Kalubek and Orešany developments; Maheľ, 1961; 1967) show such paleotectonic differences of the Jurassic members that the opinion of their tectonic approaching-Alpine is justified (Fig. 3). Moreover, each of the sequences forms an „envelope" of other crystalline complex:

— the Devín sequence with thicker Triassic limestones and dolomites and brecciated Liassic limestones-envelope of the *Bratislava massif*,

— the Kadlubek sequence with thin shallow-water and slope members is found in envelope position of the *Baďurka nappe* slice,

— the Orešany sequence with deeper-water Jurassic and Lower Cretaceous members forms the envelope of the *Modra nappe*,

— the Borinka sequence with slope lithotypes (Borinka limestones, Somár conglomerates), especially specific in the frame of the Tatricum, is piled up in the marginal part of the crystalline complex. The flyschoid Liassic formation with smaller, and larger olistholiths (Plašienka) is connected with it and the Marianka beds with shales — a thick complex of calcareous shales and marlstones with lenticles of manganese shales are obviously a part of the lowermost nappe. The thick masses of the Marianka beds of probably wider stratigraphic range (Upper Liassic — Lower Malm?) situated in a particular *marginal structure* in the section Stupava — Lozorno are analogous in development to the known Alpine lithotype „Bünderschiefer", a *representative of the Penninicum.* On the basis of this circumstance we consider competence of the marginal structure (situated between Stupava and Lozorno) to the Vahicum — the continuator of the Penninicum into the West Carpathians (Mahel', 1981b). Facial proximity of the Marianka beds to the Posidonia beds, a member so charactestic of the Klippen Belt indicating the beginning of more distinct oceanization, is not uninteresting.

Distribution of different Paleozoic and Mesozoic sequences in juxtaposition and above one another is obviously a result of their tectonic Hercynian and Alpine approaching. The Alpine tectonic processes did not wipe out the Hercynian elements, perhaps owing to a shallower po-

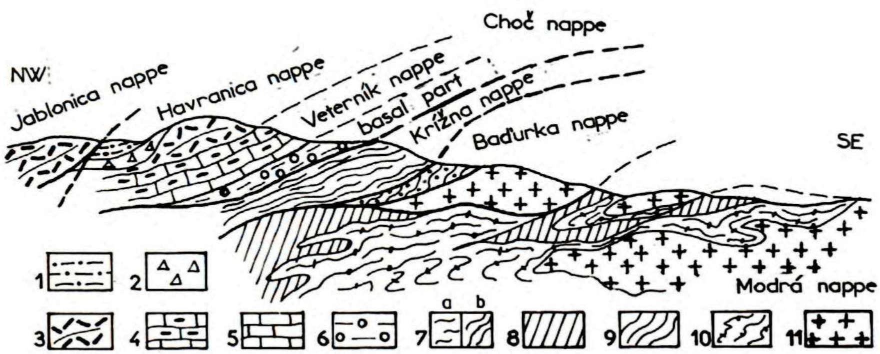

Fig. 4. Schematic profile through the Malé Karpaty Mts. 1 — Paleogene filling of the Buková depression, 2 — breccias-Upper Cretaceous, 3 — higher nappes, 4 — 5 — lower partial unit of the Choč-nappe: 4 — upper stage, 5 — lower stage, 6 — basal part of the Choč nappe (Melaphyre series), 7 — Krížna nappe: a — Zliechov nappe, b — Vysoká nappe, 8 — 9 — envelope Mesozoic: 8 — deep-water units (Orešany and Borinka units), 9 — shallow-water units — Kadlubek unit, 10 — Paleozoic complexes, 11 — granitoids

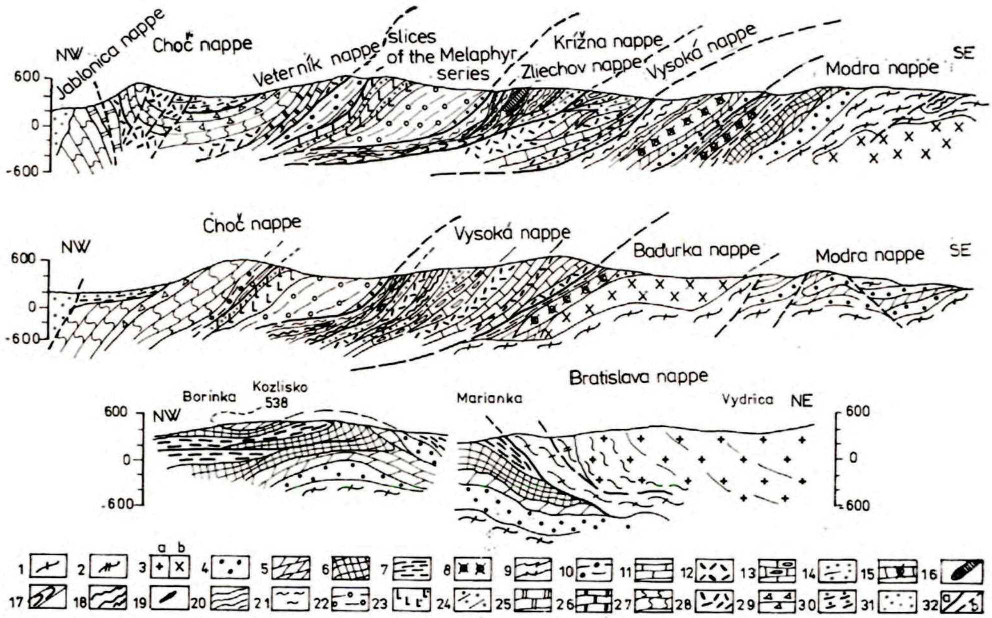

Fig. 5. Geological profiles through the Pezinské Karpaty Mts. 1 — 10 — Tatricum: 1 — epimetamorphosed sequences, 2 — mica schists to paragneisses, 3 — granitoids: a — Bratislava type, b — Modra type, 4 — Lower Triassic-quartzites, 5 — Middle-Upper Triassic-limestones, dolomites, 6 — Jurassic — Borinka formation, 7 — Jurassic deep-water sequence, 8 — Jurassic-shallow-water sequence, 9 — Lower Cretaceous-limestones with cherts, 10 — Albian-Lower Cenomanian-marly shales, sandstones, 11 — 21 — Krížna nappe: 11 — Middle Triassic-limestones, 12 — Ladinian-Carnian-dolomites, 13 — Carnian-organodetrital and cellular limestones, 14 — Carpathian Keuper, 15 — Liassic-cherty-crinoidal limestones, 16 — Dogger— silicites, 17 — Malm-nodular limestones, 18 — Tithonian-Lower Albian-platy limestones, cherty limestones (15 — 18 — Vysoká sequence), 19 — Dogger and Malm-radiolarites, 20 — Tithonian-Barremian-marly limestones (19 — 20 — Zliechov sequence), 21 — Albian and Cenomanian-marls, sandy limestones (flysch), 22 — 28 — Choč nappe: 22 — Permian-variegated shales, sandstones, 23 — Permian-basalts of melaphyre type, 24 — Lower Triassic-sandstones, sandy shales, in the upper layers the Werfen beds, 25 — Anisian-Gutenstein and Annaberg limestones, 26 — Illyrian-Cordevolian-Reifling limestones, 27 — Illyrian-Cordevolian-Wetterstein limestones, 28 — Upper Triassic (partly Ladinian) dolomites, 29 — Upper Cretaceous? — limestone-dolomite breccias, 30 — Paleocene-subflysch, 31 — Neogene sediments, 32 — a — overthrust lines, b — faults

sition. The differences of the Hercynian structural elements are conspicuous, as follows:

— in the gneiss of the Pezinok complex the B-axes of folds are striking paralelly with the course of Hercynian metamorphic schistosity, i. e. NW — SE (Klukan),

— in lower-grade metamorphosed members (Pernek, Harmónia) with sporadical micro- and mesofolding besides NW — SE also SW — NE directions are shown more distinctly.

A manifestation of Alpine tectonics is the extensive mylonitization in the Bratislava as well as Modra body, especially distinct at the contact with Mesozoic members.

A more distinct action of Early Alpine

horizontal movements in the Tatricum of the Malé Karpaty Mts. is proved by (Figs. 4, 5):

— recumbent folds built up of Mesozoic sequences but also Paleozoic members and granitoids, expecially distinct in the Modra body (Mahel', 1979),

— thrusting position of the Bratislava granites on the Borinka limestones and Marianka beds at the western margin of the Bratislava granitoid body,

— allochthonous position of gneisses and mica schists of the Bratislava body proved by boreholes at its western margin (Polák — Rak, 1981),

— occurrence of Mesozoic basic rocks with xenoliths of Mesozoic limestones amidst the metamorphic mantle of the Baďurka slice (Hovorka — Spišiak, 1983),

— new gravimetric maps and profiles according to which the granitoids in the Bratislava massif are not reaching deeper than 1.000 m (Bárta, 1985),

— seismic deep profile carried out, across the Bratislava „massif" at the connection line Lozorno — Jur near Bratislava with the thrust plane of granitoids reaching deepest 1.500 — 2.000 (communication by Tomek).

Several particularities, (in the frame of the Tatricum) of the Malé Karpaty crystalline rocks are indubitably features of approaching the Unterostalpin, partly the Penninicum. When comparing the essential part of the Tatricum in the Malé Karpaty Mts. with units of the Alps, it is, however, necessary to take into account several fundamental features of the Tatricum, also valid in the Malé Karpaty Mts., such as:

— more variegated and more complete development of the Mesozoic sequences from the Lower Triassic to Lower Cenomanian with two distinct paleotectonically different types — a northern deeper-water and southern shallower-water,

— an essentially greater portion of granitoid masses in the crystalline complex, with the tendency to form particular nappe slices,

— preservation of pre-Alpine structures and so also less Alpine reworking, mainly less distinct Alpine metamorphism and less distinct penetrative Alpine tectonization, mainly bound to overthrust lines in the Malé Karpaty Mts.

Connection of the Krížna nappe with the East Alpine units

The Krížna nappe in the Malé Karpaty Mts. provides the possibility to know two different tectonic styles in two areas: the rear part of the nappe in the Pezinské Karpaty Mts. and the frontal part in the northernmost spurs of the mountains and the adjacent Biele Karpaty Mts. The essential mass of the Krížna nappe is piled up immediately on the youngest elements of the Tatricum in form of digitations erected by Late Alpine tectonics. The two lower, extensive — fundamental sliced digitations (Figs. 6, 7) — the digitation of Pristodolok and digitation of Vývrať — are built up mainly of Triassic complexes quite typical of the Krížna nappe in their development (with smaller differences — abundant Carnian organogenic cellular limestones), are analogous to those forming the Semmering sliced system (Cornelius, 1940), ranged by some geologists to the Unterostalpin, by other to the Mittelostalpin (Tollmann, 1963; 1977), but also to the rear part of the Frankenfels nappe (Clar, 1965). Linking of the Krížna nappe with the Frankenfels nappe is, however, evident. The Malé Karpaty Mts. provide the possibility of removing contradictions important in the conception of the structure of the Northen Limestone Alps, but also in solution of relation of the East Alpine and Carpathian

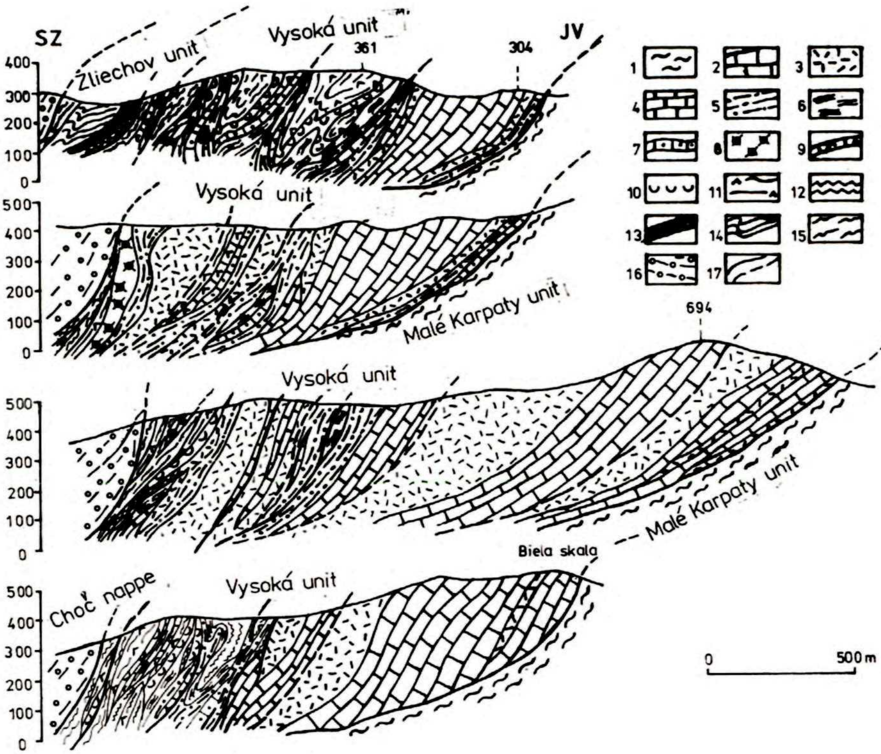

Fig. 6. Geological sections through the Križna nappe mainly built up of the Vysoká unit in the Malé Karpaty Mts. 1 — Tatric (envelope) unit; Albian-Cenomanian-marls with layers of sandstones, 2 — 15 — Krížna nappe: 2 — Middle Triassic-limestones, 3 — Middle Triassic-Carnian-dolomites, 4 — Carnian-light-coloured limestones, 5 — Upper Triassic-Carpathian Keuper, 6 — Rhaetian-Fatra beds, 7 — 11 — Vysoká sequence: 7 — Lower Liassic-sandy and cherty limestones and shales, 8 — Upper Liassic-Lower Dogger-crinoidal limestones, 9 — Dogger-cherty limestones, 10 — Malm-red, partly nodular limestones, 11 — Tithonian-Barremian-limestones, mostly with cherts, 12 — 14 — Zliechov sequence: 12 — Liassic-spotted marls, 13 — Dogger-Malm radiolarites and radiolarian limestones, 14 — Tithonian-Barremian-marly limestones, 15 — Albian-Lower Cenomanian-marly shales with layers of sandstones, 16 — Choč nappe-Permian-Lower Triassic-Melaphyre series, 17 — overthrust planes

nappes. The upper members of the fundamental digitations of the Vysoká nappe, mainly, however, the essential part of higher, smaller digitations mostly formed into an immature klippen style (Mahel' et al., 1967), are represented by Jurassic and Cretaceous members of the Vysoká unit (Fig. 8). They are essentially analogous in development to those building up together with members analogous to the Zliechov sequence the Frankenfels nappe in the Alps, well known mainly from the works of Plöchinger (1960) and Wessely (1975). Its marginal frontal slice is the Kieselkalkzone, the western corner of the Manín nappe.

The difference between the Malé Karpaty Mts. and the eastern section of the Alps is in the same Vysoká sequence distributed on the Carpathian territory:

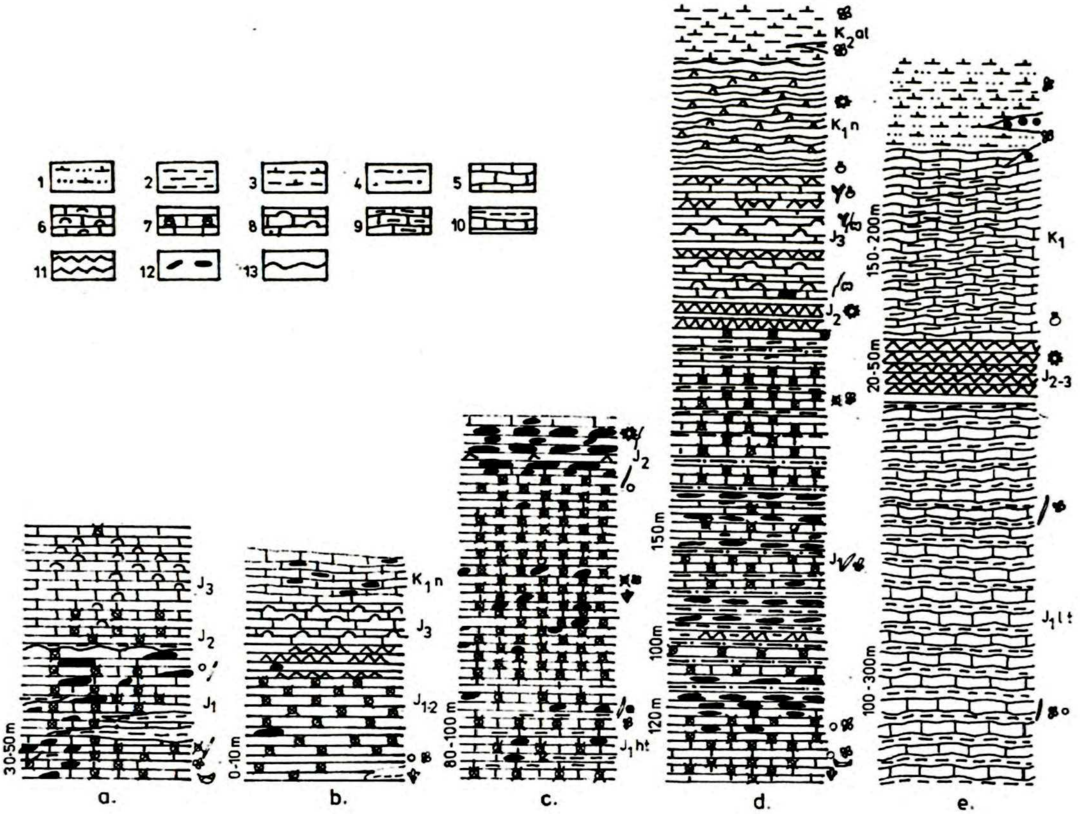

Fig. 7. Chart of fundamental developments of younger members of the Krížna nappe in the Malé Karpaty Mts. (according to Kullmanová — Maheľ, 1970). 1 — calcareous sandstones, 2 — clays, claystones, 3 — marls, 4 — sandy shales, 5 — limestones, 6 — lumachelle limestones, 7 — crinoidal limestones, 8 — nodular limestones, 9 — marly limestones, 10 — sandy limestones, 11 — radiolarites silicites, 12 — cherts (nodules of cherts), 13 — angular discordances; a — d: Vysoká unit, development, a — Prístodolok, b —at Kolovrátok, c — at Vývrat, d — in the northeastern part of the unit (area of Lošonec — Smolenice), e — Zliechov unit

— in the rear part of the Krížna nappe (equally as the Mesozoic of the Semmering slices),

— the frontal part of the nappe of higher order is represented by the Zliechov sequence accompanied by the Manín unit, its Bošáca sequence close to the Vysoká one.

Thicker complexes of the Zliechov and Bošáca sequences are cropping out in the section Bzince pod Javorinou — Drietoma in the Biele Karpaty Mts.

Connection of the Krížna nappe including the Manín nappe with the Frankenfels nappe (including the Kieselkalkzone) through the sliced zone situated at the inner margin of the Klippen Belt covered with the Neogene of the Vienna basin, is indubitable. The difference is, however, that the frontal parts of the Krížna nappe, equally as of the Manín nappe adjacent to the Klippen Belt in the

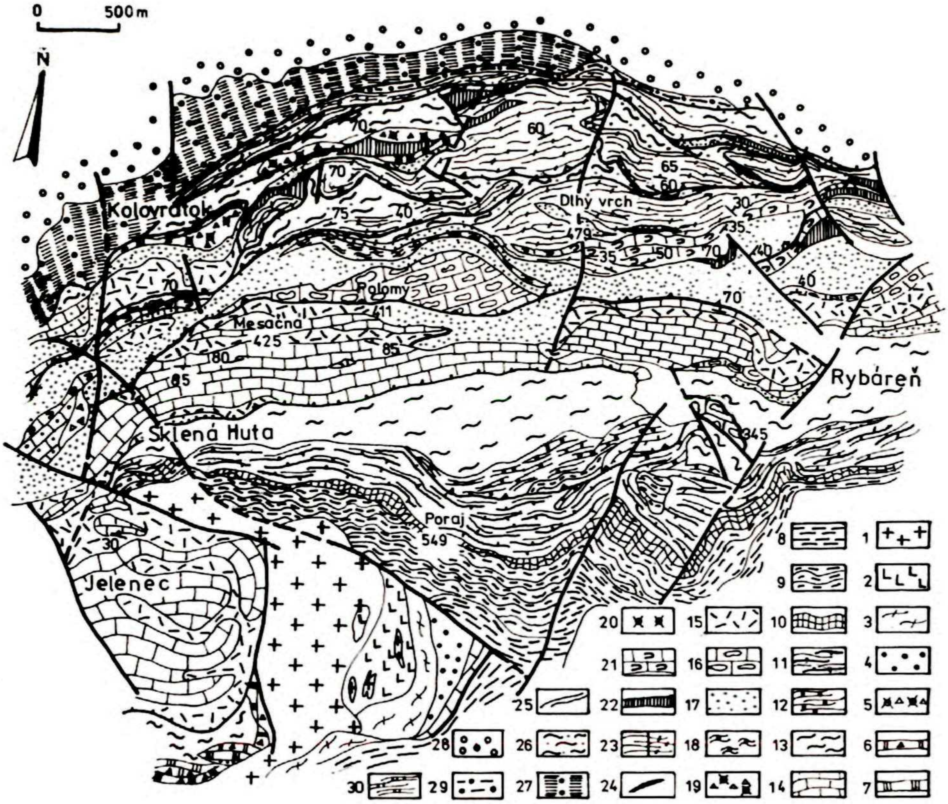

Fig. 8. Geological map of the Jelenec-Rybáreň area in the Malé Karpaty Mts. Tatricum: 1 — granitoids of the Baďurka nappe, 2 — amphibolites, 3 — phyllites to mica schists, 4 — 7 — Kadlubek unit: 4 — Lower Triassic-quartzites, 5 — Liassic-limestones, partly crinoidal with manifestations of sliding, 6 — Dogger-Malm-grey and pink limestones, 7 — Neocomian-light-coloured limestones; 8 — 13 — Orešany unit: 8 — Upper Liassic-marly limestones, shales, 9 — Dogger — platy limestones and cherty limestones, 10 — Malm-cherty limestones, 11 — Tithonian-Hauterivian-platy limestones with chert nodules. 12 — Barremian-Aptian-cherty crinoidal limestones, 13 — Albian-Lower Cenomanian-flyschoid sequence. Krížna nappe: 14 — 23 — Vysoká unit: 14 — Middle Triassic-limestones, 15 — Middle Triassic-dolomites, 16 — Carnian-limestones, 17 — Norian-Lower Rhaetian-Carpathian Keuper, 18 — Rhaetian-Fatra formation, 19 — Liassic-crinoidal-spongolite formation, 20 — Upper Liassic-Lower Dogger-crinoidal limestones, 21 — Dogger-Malm-nodular and organogenic limestones, 22 — Dogger-Malm-radiolarian limestones and radiolarites, 23 — Lower Cretaceous-limestones, 24 — 25 Zliechov unit: 24 — Dogger-Malm-radiolarites, 25 — Tithonian-Lower Cretaceous — marly limestones; 26 — Albian-Lower Cenomanian — flysch to flyschoid. Choč nappe, 27 — 30 — Melaphyre series, 27 — Permian-black shales, silstones, 28 — Permian-variegated shales with intercalations of conglomerates, 29 — Lower Triassic-sandstones to quartzites, 30 — Spathian-marly shales, intercalations of limestones

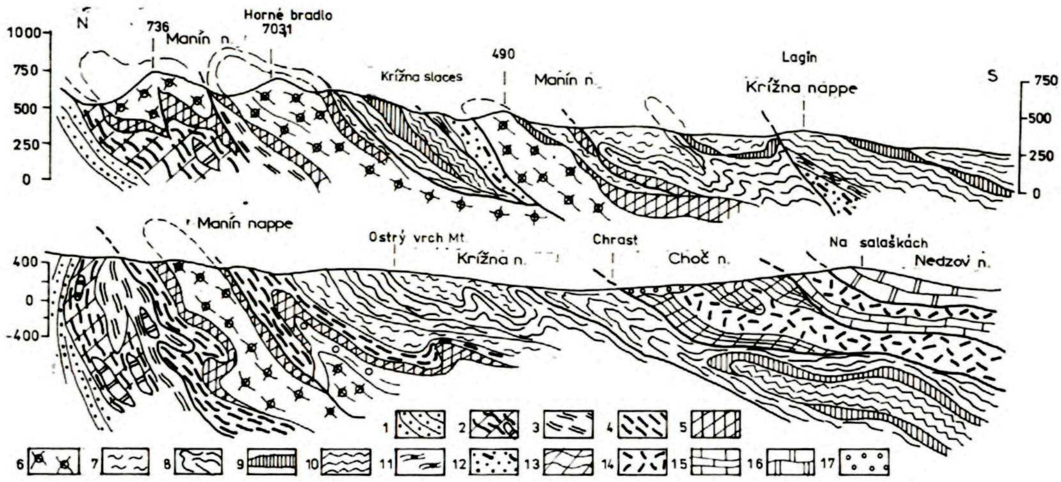

Fig. 9. Geological profiles of the Periklippen zone in the Biele Karpaty Mts. 1 — flysch of the Biele Karpaty unit, 2 — 3 — Klippen Belt: 2 — members of the Oravicum, 3 — members of the Klape nappe, 4 — 6 — Manín nappe: 4 — Lower Cretaceous-limestones with cherts and organodetrital limestones, 5 — Dogger and Malm-silicites, nodular limestones, 6 — Liassic-Bošáca formation, 7 — 11 — Krížna nappe: 7 — Albian and Cenomanian-flysch formation, 8 — Tithonian-Aptian-marly limestones, 9 — Dogger and Malm-radiolarian limestones, radiolarites, 10 — Liassic-Fleckenmergel 11 — Rhaetian-Fatra formation, 12 — Norian-Carpathian Keuper, 13 — 17 — Choč and higher nappes: 13 — Rhaetian-Hauterivian — Rohatá skala sequence, 14 — Upper Triassic — dolomites, 15 — Middle Triassic, limestones (Gutenstein and Schreyeralm limestones), 16 — Wetterstein limestones (Nedzov nappe), 17 — Upper Cretaceous members

Biele Karpaty Mts., have no thicker accompanying dolomite complexes. The Carpathian Keuper with layers of dolomite is, however, more abundantly represented also here (Began et al., 1984). Thick dolomites in the substratum of the Vienna basin, in the sliced zone designated as the Frankenfels — Lunz sliced system, most probably belong to the Krížna or also Manín nappe. A part of these dolomites belong to the Choč nappe of the Čierny Váh sequence, which is cropping out in accompaniment of the Zliechov unit (in its overlier) in Bzince pod Javorinou. Here together with members of the Rohatá skala sequence (Jurassic — Lower Cretaceous) they are part of frontal digitations of the Choč nappe thrust over the younger members of the Zliechov unit (Fig. 9).

It may be concluded from distribution of the members of the Krížna nappe in the Biele Karpaty and Malé Karpaty Mts. that in direction to the Alps spatial distribution of the members is changing. In the frontal part of the nappe, besides the Zliechov sequence (with members beginning from the Liassic) gradually also Triassic members occur with approaching the Alps. We stress that the accompanying marginal slice of the Frankenfels nappe or Kieselkalkzone is nothing other than the Bošáca sequence of the Manín nappe, the unit which has also thick Upper Triassic members, in the section Bzince pod Javorinou — Drietoma the Carpathian Keuper and Fatra formation and is linked with the classical area of the nappe (Maheľ, 1978), known from Budkov in the Strážovské vrchy Mts.

Clearing up of relations between the Krížna nappe and its structural analogues from the Alps implies strengthening of the opinion:

— spatial connection of the Krížna and Frankenfels nappe (Maheľ, 1964; Prey, 1965;1978). They differ mainly in the position in the structural plan; they reflect most distinctly the differences of the Alpine and Carpathian structural plan. The Frankenfels nappe forms the marginal frontal element of the Obero-

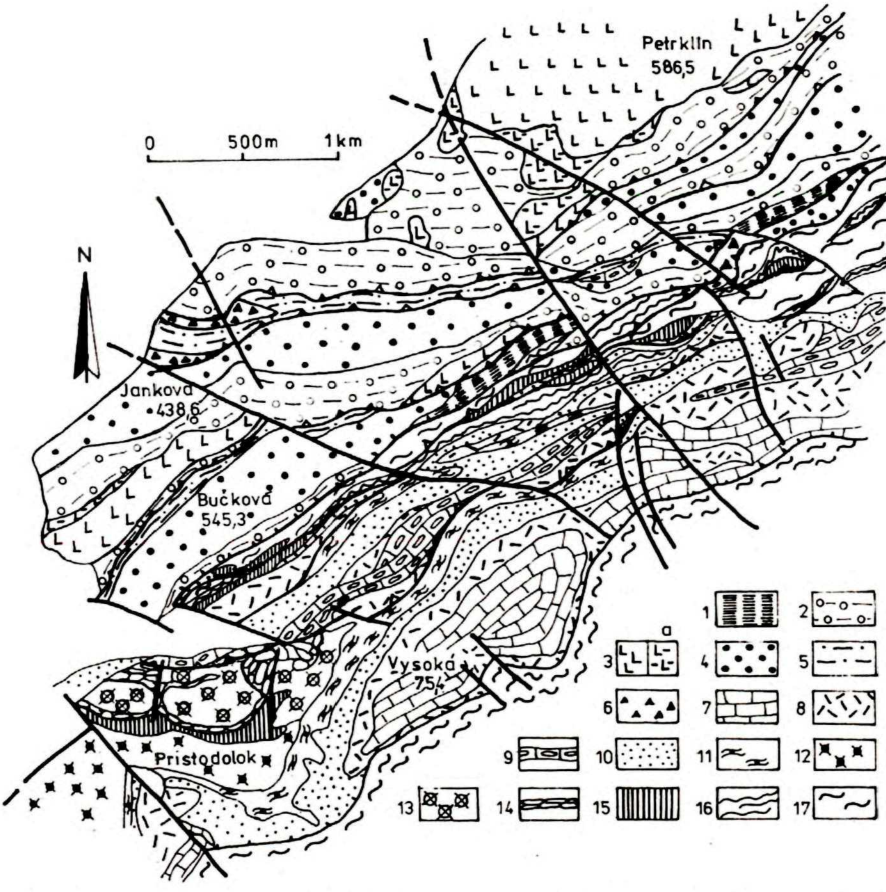

Fig. 10. Geological map of the Vysoká nappe and Melaphyre series north of Mt. Vysoká in the Pezinské Karpaty Mts. 1 — 6 — Choč nappe: 1 — Lower Permian-dark shales, intercalations of limestones, 2 — Upper Permian-variegated shales, intercalations of conglomerates, 3 — melaphyres, a — tuffs, 4 — Lower Triassic-sandstones, quartzites, 5 — Spathian-shales, intercalation of limestones, 6 — Middle Triassic-cellular limestones, 7 — 17 — Krížna nappe: 7 — Middle Triassic-limestones, 8 — Middle Triassic-dolomites, 9 — Carnian organogenic and cellular limestones, 10 — Norian-Lower Rhaetian — Carpathian Keuper, 11 — Rhaetian-Fatra formation, 12 — Liassic-spongolite-crinoidal limestones, 13 — Lower Dogger — Upper Liassic — crinoidal limestones, 14 — Malm-limestones, partly nodular, 15 — Lower Malm-Dogger-cherty limestones, 16 — Lower Cretaceous-limestones with cherts, partly marly, 17 — Albian-Lower Cenomanian-flysch and flyschoid

stalpin nappes, the Krížna nappe the substratum of the Choč nappe with piling up mainly of younger members in the frontal, but also in the rear part of the Subtatric nappes. The Malé Karpaty Mts., but mainly the substratum of the Vienna basin are an area of transition of these two structural plans. From the viewpoint of perspectives for deposits of natural bitumens it is particularly to know spatial regrouping of dolomite masses into the frontal part of the Krížna nappe, increasing in direction to the Alps,

— of genetic linking of the Semmering sliced system with the Frankenfels nappe and so with the Mittelostalpin (Clar, 1965). This is evident from spatial connection of the Vysoká nappe with the Semmering sliced system proved by boreholes into the substratum of the Vienna basin in the area of Weigelsdorf, Götzendorf, Maria Elend (Wessely, 1975). Whereas the Vysoká nappe is an inseparable element (subordinate nappe of the Krížna nappe, the Semmering slices are the rear part of the Paleoalpine Frankenfels nappe,

— of structural, only genetic linking of the Manín nappe with the Krížna nappe, which is clearer in the SW corner of the Carpathians closer than in the Váh valley; at the eastern margin of the Alps the Kieselkalkzone — SW corner of the Manín nappe — is only a marginal, frontal appendix of the Frankenfels nappe.

Mutual connection of the „higher" nappes of the Malé Karpaty Mts. with the Lunz and Ötscher system

Unclear points in relation of tectonic units of the SW corner of the West Carpathians higher than the Krížna nappe to the nappes of the Alps are reflected in terminological non-uniformity. Terms typically West Carpathian (Choč nappe, Melaphyre series), particular (Veterník, Havranica, Jablonica, Nedzov nappes, Lakšáre sliced zone), but also typically East Alpine (Ötscher, Lunz nappes, Frankenfels-Lunz sliced zone) are used. The units in the substratum of the Neogene of the Vienna basin with proved connection with the nappes of the eastern margin of the Alps are more often assigned to the Alpine units, those in the Malé Karpaty Mts. to the Carpathian units. As in the latter the essential part contains the light-coloured Wetterstein, partly Steinalm limestones, they are usually ranged as higher nappes identified with the Strážov nappe (Andrusov, 1936; 1967), even with the Gemericum (Andrusov — Bystrický — Fusán, 1973; Biely — Bystrický — Mello et al., 1980). When regarding the units of the Alps as Paleoalpine — Mesoalpine and the Carpathian units as Paleoalpine, it results logically that in the SW corner of the West Carpathians in the substratum of the Neogene of the Vienna basin the Alpine units wedge out and the Carpathian units set on (Jiříček, 1981). A different situation, however, appears with mutual connection of geometric bodies, thus of tectonic Alpine and Carpathian units and after proving of Mesoalpine overthrusts in the Periklippen zone (Maheľ, 1973; 1978).

The vast Melaphyre series in the Malé Karpaty Mts., equally as in other core mountains, builds up the basal part of the Choč nappe. In the SW part it is more distinctly sliced, in the Alps it is, however, unknown to a greater extent. The Melaphyre series is linked in direction with the sliced zone of the Permian and Werfen situated at the boundary of the pre-Permian Grauwackenzone members and limestone-dolomite complexes of the

Northern Limestone Alps (Fig. 10). The considerable portion of the „black" formation in the Melaphyre series of the Malé Karpaty Mts. weakens the idea of continuation of the Grauwackenzone to the substratum of the ~~Neogene~~ of the Vienna basin. The Grauwackenzone does not reach our territory as if it were re-

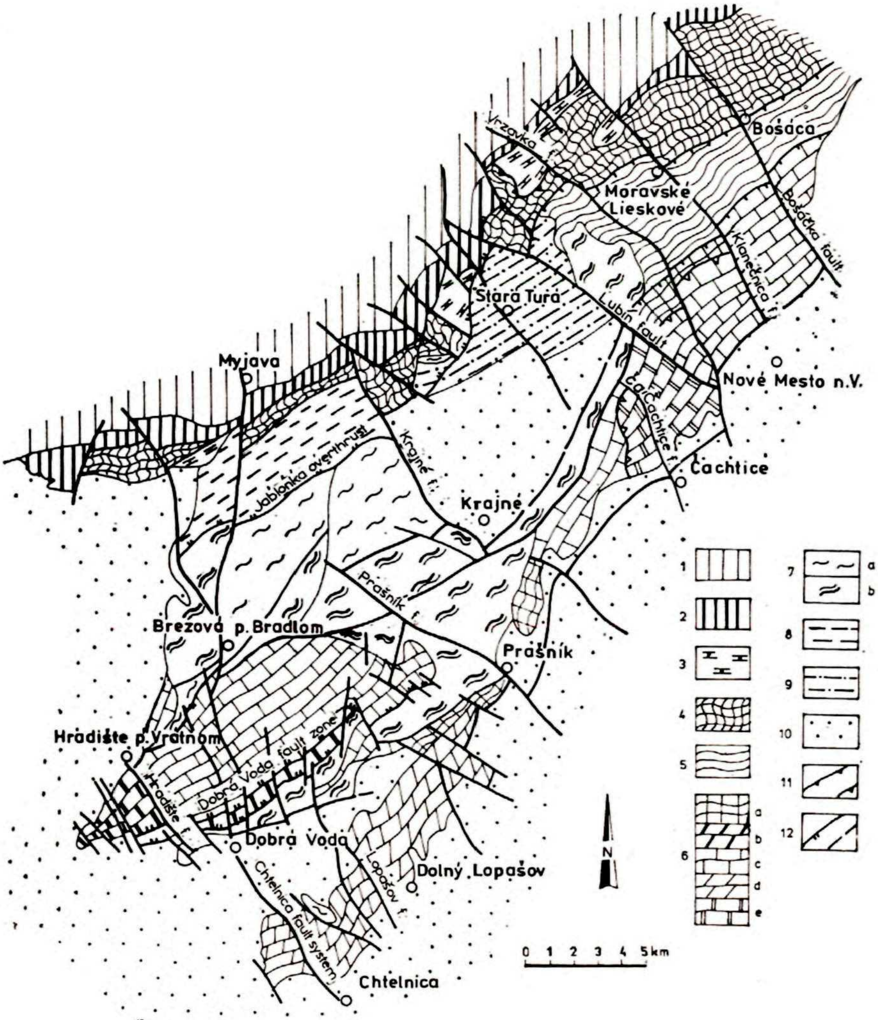

Fig. 11. Tectonic sketch-map of the Brezovské Karpaty Mts. and Myjavská pahorkatina Upland (according to geological map of Began — Salaj, 1974). 1 — Flysch Belt, 2 — Klippen Belt, 3 — Upper Cretaceous sequence of the Klape or Manín nappe, 4 — Manín nappe, 5 — Krížna nappe,, 6 — higher nappes: a — Rhaetian-Neocomian and dolomites of the Choč nappe, b — Biely Váh type, c — Jablonica nappe, d — Veterník (partly Bebrava?) nappe, e — Nedzov nappe, 7 — Brezová unit: a — Upper Cretaceous sequence, b — Paleogene sequence, 8 — Surovín of II. order, 12 — upthrust, faults

placed structurally by the Melaphyre series.

The Čierny Váh sequence, immediately overlying the Melaphyre series in many core mountains, is missing in the Pezinské Malé Karpaty Mts. We, however, range the dolomites accompanying the Rohatá skala sequence (Rhaetian to Hauterivian), building up the frontal slices of the Choč nappe near Bzince pod Javorinou, to it. Some of the slices with thick Hauptdolomit in the substratum of the Neogene of the Vienna basin at the inner margin of the Klippen Belt (known as the Frankenfels-Lunz system) also belong to this unit as a consequence of manifestation of the features of approaching the model of the Alps.

Neither the Biely Váh sequence, represented by the Reifling limestones and thicker Lunz beds, forms a more distinct nappe unit in the Malé Karpaty Mts. It emerges from beneath the Jablonica unit in the Brezovské Karpaty Mts. in smaller inliers (Hradište pod Vrátnom) and in the Dobrá Voda sliced zone. The borehole DB-1 near Dobrá Voda encountered the Biely Váh unit in its typical development (with thick Lunz beds and Reifling limestones). In the Biele pohorie Mts. the Biely Váh unit is laterally replaced by the Veterník unit, characterized by the Reifling, Pseudoreifling, but also Wetterstein limestones. An analogous sequence in the substratum of the Neogene of the Vienna basin and in the eastern part of the Alps is mainly characteristic of the southern, inner structures of the Lunz nappe. The Veterník unit situated in the rear part of the Choč nappe displays features of approaching the Alps in content in the overlier of the Melaphyre series, its distribution is, however, given by the Carpathian structural plan.

The Havranica and Jablonica units, both with a high portion of light-coloured limestones Anisian-Cordevolian in age, resemble the units of the Ötscher (Göller) nappe; the first its northern structures with the Reifling limestones, the second the southern. Their equivalent in the other core mountains is the Bebrava unit with thick Wetterstein dolomites (Maheľ, 1981). Spatial linking of typically Carpathian, transitional and Alpine units is more or less proved.

With mutual connection of the tectonic units of the Alps and Carpathians we have the not easy task where to place the boundary between them, expressed by other names. The more it is difficult because the areas of transition from the Alpine structural plan to the Carpathian or of gradual transition of the lower units from „juxtaposition" to the position below one another are covered with thick Neogene sediments, but also because the geometric bodies are mostly connected with one another from the Alps to the Carpathians. As we consider the differences in spatial distribution of the tectonic units in the structural plan of the Alps and West Carpathians as a consequence of less intesity of post-Upper Cretaceous overthrusts in the innermost zones of the West Carpathians, the Malé Karpaty Mts. and adjacent Myjavská pahorkatina Upland represent a transitional segment with the late-tectonic Paleogene Buková depression, but also with thick Upper Cretaceous — Paleogene complexes close to the Gosau type. We also considered the latter from the Myjavská pahorkatina Upland as elements more or less post-tectonic, the filling of a brachysynclinal depression. In this regard, however, a change of the view in favour of their structural approaching analogous to the Gosau complexes of the Alps, incorporated in the structure of nappes affected by intense horizontal post-Paleogene overthrusts, is necessary.

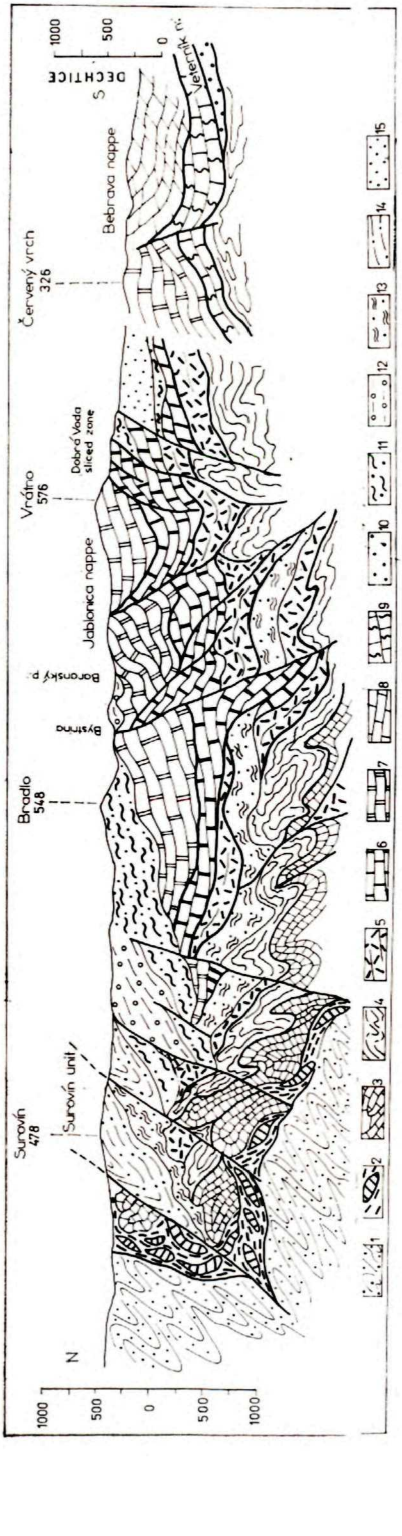

Fig. 12. Geological profile through the Myjavská pahorkatina Upland and the Brezovské Karpaty Mts. 1 — Magura unit, 2 — Klippen Belt, 3 — Manín nappe, 4 — Križna nappe, 5 — Choč nappe, Čierny Váh type — dolomites and Rohatá skala sequence, 6 — Choč nappe, Biely Váh type, 7 — Jablonica nappe, 8 — Bebrava (Havranica?) nappe, 9 — Veterník nappe, 10 — Melaphyre series, 11 — 12 — Brezová unit: 11 — Upper Cretaceous sequence, 12 — Paleogene sequence, 13 — 14 Surovín unit: 13 — Upper Cretaceous sequence, 14 — Paleogene sequence, 15 — Neogene

Incorporation of the Upper Cretaceous sequences in the nappe structure

For more detailed knowledge of the inner structure of the Upper Cretaceous-Paleogene complexes of the Myjavská pahorkatina Upland many open essential questions remain to be solved. Two pieces of knowledge may be considered as a basis of the new view of their position:

— distinguishing of the particular Surovín periklippen development with a continuous Upper Cretaceous-Eocene sequence different from the Brezová sequence (Salaj — Began, 1983). Their present-day juxtapostion is a consequence of distinct tectonic approaching and probable overlapping of the connecting elements, perhaps an analogue of the Gieshübler sequence,

— proving of the presence of Upper Cretaceous and Paleogene members amidst erected slices built up of the Choč nappe in the substratum of the Neogene in the northeastern part of the Vienna basin, south of the inner margin of the flat structure formed by the Upper Cretaceous complexes. The tectonic style of the substratum of the Slovak part of the Vienna basin is obviously equal as on the Austrian territory with two structural stages. The lower stage shows erected structures, mainly built up of the Lunz or Choč nappe, but also of Upper Cretaceous-Paleogene members and the upper stage has flatter structures built up of the Ötscher or Jablonica nappe but also of the Choč nappe with Upper Cretaceous-Paleogene complexes, which are probably laterally connected with the Brezová sequence of the Myjavská pahorkatina Upland (Němec — Kocák, 1976; Kysela, 1984).

The Brezová sequence (group of Bradlo and Myjava group sensu Samuel — Salaj

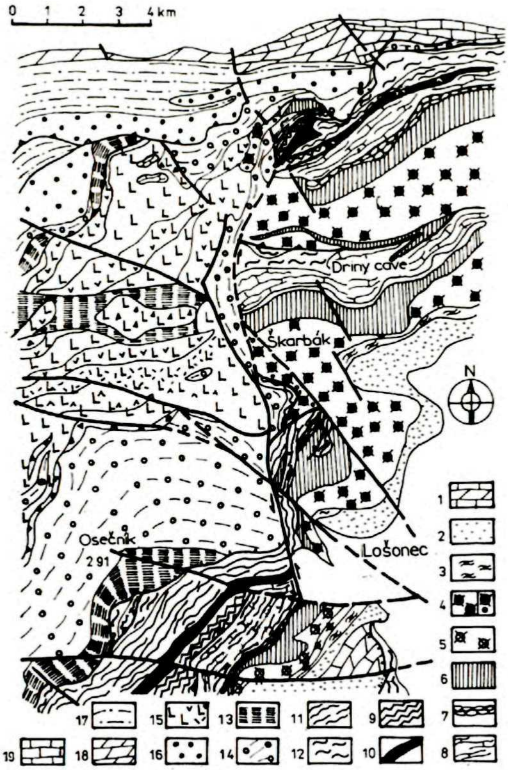

Fig. 13. Geological map of the Vysoká unit and Melaphyre series is the area of Smolenice, Lošonec strike slip. 1 — 12 — Krížna nappe: 1 — Upper Triassic — dolomites, 2 — Carpathian Keuper, 3 — Rhaetian-Fatra formation, 4 — Liassic-sandy-crinoidal limestones and shales: a — coarse-grained crinoidal-spongolite limestones, 5 — Upper Liassic-crinoidal limestones, 6 — Dogger-cherty limestones, silicites, 7 — Malm nodular limestones, 8 — Tithonian-Barremian-limestones with nodules of cherts (1 — 8 — Vysoká type), 9 — Upper Liassic-Fleckenmergel, 10 — Dogger-Malm-radiolarian limestones and radiolarites, 11 — Tithonian-Barremian-marly limestones (9 — 11 — Zliechov type), 12 — Albian marly shales, sandstones, 13 — 19 — Choč nappe: 13 — Lower Permian-dark-grey shales, sandstones, 14 — reddish-violet shales, sandstones, conglomerates, 15 — basalts of melaphyre type, 16 — Lower Triassic-sandstones, quartzites, 17 — Spathian-marly shales and limestones (13—16 — Melaphyre series), 18 — Hydaspian-dolomites, 19 — Lower Anisian-dark-grey limestones

— Began, 1980) obviously neither represents a late-tectonic member, as it was considered until lately, nor the continuation of the Gieshübler structure. It was thrust together with the underlying Jablonica or other nappes over the outer Upper Cretaceous-Paleocene or Lower Eocene (Surovín, Gieshübel; Fig. 12) sequences. We consider the presence of thick Eocene to Lower Oligocene members in the Brezová sequence as a Carpathian feature, approaching the Central-Carpathian Paleogene.

Summary

1. The occurrence of Paleozoic sequences different lithologicaly, in metamorphism and structure, more or less synchronous in the same Alpine tectonic unit, the Bratislava nappe, is the consequence of their tectonic unification by Neohercynian overthrusts. It is necessary to take into consideration the significant role of the Hercynian nappes in the structure not only of the Malé Karpaty, but also in a considerable part of the Tatric crystalline complex of the West Carpathians. The pre-Alpine nappes are, however, obscurred by Alpine tectonics, but also by Hercynian metamorphism younger than the principal Hercynian tectogenesis.

2. In the frame of the West Carpathians the anomalous composition of the Tatricum in the Malé Karpaty Mts. (abundant Paleozoic sequences and particular types of Mesozoic sequences) is also evident from the occurrence of its lowermost units at the northwestern margin of the system of inliers, distributed in the segment transitional between the Alps and Carpathians. There are the frontal parts of the nappe units more deeply rooted in the substratum of the Neogene of the Danube lowland.

3. The Mesoalpine folding affected the whole Malé Karpaty Mts. and Myjavská pahorkatina Upland. The geological bodies-Carpathian tectonic units are spatially linked with the Alpine ones there. Wedging out of some units at transition from the Alps to the Carpathians, e. g. of the Grauwackenzone on the Alpine side or the body of the Melaphyre series on the Carpathian side are a phenomenon common along the Alpine-Carpathian system, frequent at transition from one segment of the Alpides to other.

4. Lateral strike slips are more distinct in the Malé Karpaty Mts. but also in the transitional segment between the Alps and Carpathians (even already at the eastern margin of the Alps), manifested by: a) the change of the East Alpine direction of structures (W — E direction) into the West Carpathian SW — NE and in the Penninicum of the Rechnitz inlier even the effect of structures of N — S direction (Pahr, 1977); b) the bend of the western margin of Jurassic members of the platform envelope to NE — SW (Wessely, 1975); c) abundant fault zones of N — S direction in the Malé Karpaty Mts. with several local strike slips of 1—5 km (Fig. 2 and Fig. 13).

5. The mutual transition from the Carpathian building plan to the Alpine is shown in the Malé Karpaty Mts.: a) in content — increasing Wetterstein limestones; a typical representative of the transitional type is the Veterník subordinate nappe, which represents the southern part of the primary Choč nappe; b) increasing Upper Cretaceous sequences and lower-grade metamorphosed metamorphites in the crystalline rocks; c) structurally-regrouping of units with gradual transition from juxtaposition according to the Alpine model to the position above one another-characteristic of the Carpathian model. Accompaniment of the Choč nappe by the Melaphyre series situated only at the inner margin is an example of the Alpine model, equally also the presence of Triassic members in the near-frontal and frontal part of the Krížna nappe and the occurrence of lower units of the Choč-nappe — the Čierny Váh (?), Biely Váh units in the frontal and near-frontal part of the nappe. The occurrence of lower nappes in the substratum and in the hinterland of higher nappes (of the Krížna nappe as one whole in relation to higher nappes) is an example of the Carpathian plan.

6. Structural and genetic linking of the Manín nappe with the Krížna nappe, much closer in the Biele Karpaty Mts. than in the Váh valley, is shown particularly distinctly in the substratum of the Neogene of the Vienna basin and mainly at the eastern margin of the Alps. In the substratum of the Vienna basin both nappes are a part of the Periklippen sliced zone together with the frontal part of the Choč nappe. In the eastern part of the Northern Limestone Alps the analogue of the Manín unit (its southwestern corner), the so called Kieselkalkzone, forms the marginal slice of the Frankenfels nappe.

7. Post-Upper Cretaceous and post-Eocene horizontal strike slips of greater extent, in other places of the Central Carpathians put into connection with the Periklippen zone, probably affect the whole Malé Karpaty Mts.

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Malé Karpaty — súčasť prechodného segmentu medzi Karpatmi a Alpami; významné tektonické okno alpíd

Malé Karpaty sa ako okrajové pohorie susediace s Východnými Alpami vyznačujú prítomnosťou všetkých základných západokarpatských jednotiek. Každá jednotka však vykazuje celý rad obsahových i štruktúrnych odchýlok, ktoré sa z karpatského pohľadu javia ako špecifiká. Väčšina týchto osobitostí je dôsledkom priblíženia k stavbe Álp. Popri „miešaní sa“, karpatských a alpských prvkov sa v stavbe Malých Karpát stretávame s fenoménmi, ktoré považujeme za charakteristické pre prechodný segment medzi Alpami a Karpatmi, za endemity tzv. Devínskych Karpát (Maheľ, 1983), geneticky podmienenými priečnym prelomom prepájajúcim Český a Maďarský masív. K takým endemitom treba priradiť i zdvih hlbokého podložia v Malých Karpatoch, výstup spodných štruktúrnych elementov tatrika, ktoré inde na povrch nevystupujú, a pravdepodobne i výstup penninika. V takom poňatí predstavuje malokarpatské tatrikum súčasť sústavy tektonických okien známych z východných okrajov Álp (obr. 1).

Pri takomto prístupe vystupuje do popredia rad dôležitých otázok, týkajúcich sa vzťahu Álp a Karpát, stavby podložia neogénu viedenskej panvy, ako aj perspektívnosti ložísk ropy a zemného plynu.

Rad závažných poznatkov sa získal pri riešení nasledujúcich problémov:

— alochtónnosť tatrika Malých Karpát s viacerými príkrovovými šupinami — protiklad predstavy o autochtónnom postavení kryštalinika Malých Karpát a jeho negatívnom vplyve na perspektívnosť ložísk živíc vo východnej časti viedenskej panvy,

— nehlboká pozícia (sčasti výstup) podložného penninika a zdvih autochtónneho podložia (Český masív), prípadne aj jeho mezozoického obalu,

— nadväznosť tylových častí krížňanského príkrovu (vysockej jednotky) na semmerinský šupinový systém, ako aj nadväznosť čelových častí príkrovu prevrásnených manínskou jednotkou na frankenfelsko-lunzský šupinový systém včítane Kieselkalkzóny, ktoré sú v podloží viedenskej panvy nositeľmi viacerých ložísk prírodných živíc,

— prepojenie veterníckeho, havranického, jablonického príkrovu, ale i malokarpatských šupín čiernovážskeho a bielovážskeho typu na alpské príkrovy lunzskej a ötscherskej skupiny,

— včlenenie vrchnokriedovo-paleogénnych sekvencií Myjavskej pahorkatiny do stavby príkrovov (vyšší štruktúrny stupeň).

Pri riešení alochtónnosti malokarpatského kryštalinika a jeho vzťahu k alpským jednotkám sa stretávajú dve zdanlivo nezlučiteľné koncepcie. Na jednej strane sa prehlbujú poznatky, ktoré doteraz slúžili ako silné argumenty v prospech názoru o autochtónnosti malokarpatského kryštalinika. Je to periplutonická metamorfóza, a to i v bratislavskom a modranskom masíve, prítomnosť v podstate analogických, pre Malé Karpaty špecifických slabšie metamorfovaných staropaleozoických komplexov v oboch masívoch (Korikovskij — Cambel et al., 1985) a prejavy priečne orientovaných štruktúr (obr. 2). Na druhej strane sa ukazujú rozdiely vo veku bratislavských (388 ± 38 mil. r.) a modranských (347 ± 4 mil. r.; Cambel et al., 1977) granitoidov a v zložení oboch typov granitoidov. Odlišný je aj bezprostredný obal granitoidov. Bratislavské granitoidy sprevádza pararulový komplex analogický väčšine metamorfitov jadrových pohorí (pezinská sekvencia). Až v ich nadloží sú slabšie metamorfované komplexy (pernecká sekvencia, harmónske súvrstvie) analogické bezprostrednému obalu modranských granitoidov. Výraznejšie rozdiely sú i medzi slabšie metamorfovanými komplexmi v jednotlivých areáloch — telesách malokarpatského kryštalinika.

Zoradenie vekove približne rovnakých, ale metamorfne, štruktúrne i obsahovo odlišných sekvencií v bratislavskej tektonickej jednotke môže byť len dôsledkom hercýnskej tektoniky.

Aj sprievodné sekvencie obalového mezozoika (predtým považované za vývíny malokarpatskej jednotky: devínsky, borinský, kadlubský a orešiansky; Maheľ, 1961; 1967) vykazujú také paleotektonické rozdiely jurských členov, že názor na ich alpínske tektonické zblíženie je oprávnený (obr. 3). Navyše každá zo sekvencií vytvára „obal" iného kryštalinika.

Devínska sekvencia s mocnejšími triasovými vápencami a dolomitmi a brekciovitými liasovými vápencami tvorí obal bratislavského telesa — bratislavský príkrov, sekvencia Kadlubek s tenkými plytkovodnými a svahovými členmi tvorí obal príkrovovej šupiny Baďurky, orešianska sekvencia s hlbšievodnými jurskými a spodnokriedovými členmi tvorí obal modranského príkrovu. Borinská sekvencia so svahovými litotypmi (borinské vápence, zlepence Somára), zvlášť špecifická v rámci tatrika, je nahrnutá v okrajovej časti kryštalinika. Nadväzuje na ňu flyšoidné liasové súvrstvie s väčšími i menšími olistolitmi (Plašienka) a marianske vrstvy s bridlicami. Mocný komplex vápnitých bridlíc a slieňovcov so šošovkami mangánových bridlíc je zrejme súčasťou najspodnejšieho príkrovu. Mocné masy marianskych vrstiev, pravdepodobne širšieho stratigrafického súvrstvia (vrchný lias — spodný malm?), rozložené v samostatnej okrajovej štruktúre v úseku Stupava — Lozorno, sú analogické známemu alpskému litotypu — Bünderschiefer — reprezentantovi penninika. Navyše i vrchný neokóm a alb sú vývinom blízke. Na základe toho predpokladáme, že okrajová štruktúra patrí k váhiku, ktoré je pokračovaním penninika do Západných Karpát (Maheľ, 1981). Zaujímavá je aj faciálna blízkosť marianskych vrstiev k posidoniovým vrstvám charakteristickým pre bradlové pásmo, naznačujúcim začiatok výraznejšej oceanizácie.

Rozloženie rozdielnych paleozoických i mezozoických sekvencií vedľa seba i nad sebou je zrejme výsledkom ich tektonického hercýnskeho a alpínskeho zblíženia. Alpínske tektonické procesy nezotreli hercýnske prvky asi vďaka plytšej pozícii. Nápadné sú odlišnosti hercýnskych štruktúrnych prvkov, prejavujúce sa tým, že v rulovom komplexe (perneckom) osi B vrás prebiehajú paralelne s priebehom hercýnskej metamorfnej bridličnatosti, t. j. v smere SJ — JV (Klukan, v tlači), a tým, že v slabšie metamorfovaných členoch kryštalinika s ojedinelými mikro a mezovrásami sa popri smeroch SZ — JV výraznejšie prejavujú i smery JZ — SV.

Prejavom alpínskych vrásnení je rozsiahla mylonitizácia v bratislavskom i modranskom telese, zvlášť výrazná na styku s mezozoickými členmi.

Výraznejšie uplatnenie staroalpínskych horizontálnych pohybov v malokarpatskom tatriku dokladajú (obr. 4, 5):

— ležaté vrásy budované mezozoickými sekvenciami, ale aj paleozoickými členmi a granitoidmi; zvlášť výrazné v modranskom telese (Maheľ, 1979),

— násunová pozícia bratislavských granitoidov na borinských vápencoch a marianskych vrstvách pri západnom okraji bratislavského granitoidného telesa,

— alochtónna pozícia rúl a svorov bratislavského telesa preukázaní vrtmi pri jeho západnom okraji (Polák — Rak, 1981),

— výskyt mezozoických bázik s xenolitmi mezozoických vápencov uprostred metamorfného plášťa kryhy Baďurky (Hovorka — Spišiak, 1983),

— nové gravimetrické mapy a profily, podľa ktorých granitoidy v bratislavskom „masíve" nesiahajú hlbšie ako 1000 m (Bárta, 1985),

— seizmický hlbinný profil naprieč bratislavským masívom na spojnici Lozorno — Jur pri Bratislave s násunovou plochou granitoidov v hĺbke 1500 — 2000 m (Tomek, ústna informácia).

Viaceré osobitosti (v rámci tatrika) malokarpatského kryštalinika sú nesporne znakmi priblíženia k unterostalpinu, sčasti k penniniku. Pri porovnávaní podstatnej časti malokarpatského tatrika s alpskými jednotkami (Maheľ, 1980, 1981a, 1983) treba však mať na zreteli tieto základné znaky tatrika platné v Malých Karpatoch:

— pestrejší a kompletnejší vývin mezozoických sekvencií od spodného triasu po spodný cenoman s dvoma výraznými, paleotektonicky odlišnými typmi — na severe hlbokovodným a na juhu plytkovodným,

— v kryštaliniku podstatne väčší podiel granitoidných más, ktoré majú tendenciu vytvárať samostatné príkrovové šupiny,

— zachovanie predalpínskych štruktúr, menej výraznú penetratívnu alpínsku tektonizáciu viazanú hlavne na presunové línie.

V krížňanskom príkrove Malých Karpát je popri rozsiahlom zastúpení vysockej jednotky pozoruhodné priestorové rozloženie vysockého a zliechovského dielového príkrovu (obr. 6, 7, 8, 9).

Vysocký príkrov je rozložený v tylovej časti príkrovu v Pezinských Karpatoch. Jeho zošupinovatené digitácie (digitácia Prístodolku a digitácia Vývratu), tak ako inde v Západných Karpatoch základové digitácie krížňanského príkrovu, tvoria mocné triasové vápencovo-dolomitické komplexy, karpatský keuper a fatranské súvrstvie. Vysocký príkrov so svojimi základovými digitáciami nadväzuje na semmerinský šupinový systém, čo svedčí skôr v prospech názoru o príslušnosti týchto šupín k mittelostalpinu ako k unterostalpinu (Tollmann, 1963, 1967).

Krížňanský príkrov zliechovského typu, rozložený hlavne v čelovej časti príkrovu (pred čelami chočského príkrovu), je prevrásnený sprievodným manínskym príkrovom bošáckeho vývinu. Frankenfelský príkrov s okrajovou čelovou šupinou známou ako „Kieselkalkzone" je ich západným pokračovaním.

„Kieselkalkzóna", považovaná za okrajovú šupinu frankenfelského príkrovu, sa ani obsahovo, ani štruktúrne, ani priestorovým postavením nelíši od manínskeho príkrovu (bošácky vývin). A to považujeme za ďalší znak štruktúrnej i genetickej previazanosti manínskeho a krížňanského príkrovu.

Znakom priblíženia k Alpám je, že do čelovej časti krížňanského príkrovu sa dostávajú staršie členy, hlavne dolomity, ktoré sprevádzajú zliechovský sled v podloží neogénu viedenskej panvy. Ťažko ich však možno odlíšiť od dolomitových más čiernovážskej sekvencie.

Dávno známe osobitosti v stavbe príkrovov vyšších ako krížňanský v Malých Karpatoch, vyjadrené i osobitnými názvami (veternícky, havranický, jablonický), sú dôsledkom priberania niektorých alpských znakov (väčší podiel wettersteinských vápencov aj v chočskom príkrove, ako aj postupný prechod z karpatského do alpského modelu stavby — priestorové rozmiestnenie jednotiek). Typické karpatské jednotky bielovážska a čiernovážska v tylovej časti chočského príkrovu nevystupujú, ale podľa alpského modelu sú nakopené v čelovej časti prekrytej neogénom viedenskej panvy. Tylovú časť chočského príkrovu zastupuje veternícka jednotka „zmiešaného" typu s reiflinskými, ale i wettersteinskými vápencami. Ona vytvára najmohutnejší element v nadloží melafýrovej série (typický karpatský znak; obr. 10). Pre neogénne podložie viedenskej panvy nie je typické vyklíňovanie alpských a nasadzovanie karpatských jednotiek (Jiříček, 1981), ale vzájomné prepojovanie geometrických telies s postupnou prestavbou alpského a karpatského plánu s postupným premiestňovaním jednotiek z pozície vedľa seba (alpský model) do pozície nad sebou (karpatský model).

I keď v postavení vrchnokriedovo-paleogénnych komplexov Myjavskej pahorkatiny ostáva vyriešiť veľa zásadných otázok, pre nový pohľad na vzťah Álp a Karpát považujeme za východiskové dva poznatky: Vrchnokriedovo-paleogénnu sekvenciu, označovanú ako vývin, resp. brezovskú sekvenciu, nepovažujeme ani za neskorotektonický člen, ani za pokračovanie gieshübelskej štruktúry. Predstavuje vyššiu štruktúrnu etáž v nadloží jablonického, v severnej časti azda i chočského príkrovu bielovážskeho typu, presunutú cez vrchnokriedovo-paleogénny komplex jednotky Surovín. Táto sekvencia s neprerušeným vrchnokriedovo-eocénnym sledom (Began — Salaj, 1983) sprevádza v podloží vztýčené štruktúry krížňanského príkrovu (spolu s manínskym) i príkrovu chočského čiernovážskeho a bielovážskeho typu. Vnútornejšie časti sekvencie Surovín, prekryté plochejšími štruktúrami jablonického príkrovu, by mohli byť ekvivalentom gieshübelskej priehlbne (obr. 11, 12).

Poznatky širšieho významu

1. Vystupovanie litologicky, metamorfne i štruktúrne odlišných paleozoických sledov, vekove viac-menej synchrónnych v tej istej alpínskej tektonickej jednotke (bratislavský príkrov), je dôsledkom ich tektonického zjednotenia neohercýnskymi presunmi. Hercýnske príkrovy mali význačnú úlohu nielen v stavbe malokarpatského, ale i v značnej časti tatrického kryštalinika Západných Karpát. Predalpínske príkrovy však zastiera alpínska tektonika, ale tiež hercýnska metamorfóza mladšia ako hlavná hercýnska tektogenéza.

2. V rámci Západných Karpát anomálna skladba malokarpatského tatrika (hojnosť paleozoických sekvencií a osobitné typy mezozoických sekvencií) vyplýva i z výstupu jeho najspodnejších jednotiek pri severozápadnom okraji sústavy tektonických okien, rozložených v prechodnom segmente medzi Alpami a Karpatmi. Pritom sa jedná o čelové časti v podloží neogénu Podunajskej nížiny hlbšie zakorenených príkrovových jednotiek. S obdobnou stavbou treba počítať i v hlbších etážach ostatných, hlavne severných jadrových pohorí.

3. Mezoalpínske vrásnenie postihlo celé Malé Karpaty a Myjavskú pahorkatinu. Pritom karpatské tektonické jednotky priestorove nadviazali na alpské. Vyklinovanie niektorých jednotiek na prechode z Álp do Karpát, napr. Grauvackenzóna na alpskej, príp. telesá melafýrovej série na karpatskej strane, je pozdĺž alpsko-karpatskej sústavy bežným javom, zvlášť častým na prechode z jedného segmentu alpíd do druhého.

4. V Malých Karpatoch, ale i v celom prechodnom segmente medzi Alpami a Karpatmi (i pri východnom okraji Álp) sa laterálne posuny, výraznejšie než kdekoľvek inde, prejavujú:

— v zmene východoalpského smeru štruktúr (smer Z — V) na západokarpatský (JZ — SV) a v penniniku rechnitského tektonického okna dokonca v uplatnení sa štruktúr smeru S — J (Pahr, 1977).

— v ohybe západného okraja jurských členov platformného obalu do smeru SV — JZ (Wessely, 1975),

— v hojnosti zlomových zón smeru S — J v Malých Karpatoch s viacerými lokálnymi posunmi 1 — 5 km (obr. 2 a 13).

5. Vzájomný prechod z karpatského stavebného plánu do alpského sa v Malých Karpatoch prejavuje:

— obsahovo — nárastom wettersteinských vápencov; typickým reprezentantom prechodného typu je veternícky čiastkový príkrov, ktorý predstavuje južnú časť kmeňového chočského príkrovu, ako aj nárastom vrchnokriedových sekvencií a v kryštaliniku nárastom slabšie metamorfovaných metamorfitov;

— štruktúrne — preskupovaním jednotiek s postupným prechodom z pozície vedľa seba (podľa alpského modelu) do pozície nad sebou — charakteristickej pre karpatský model. Sprevádzanie chočského príkrovu melafýrovou sériou rozloženou len pri vnútornom okraji, prítomnosť triasových členov v pričelovej a čelovej časti krížňanského príkrovu a vystúpenie spodnejších jednotiek chočského príkrovu (čiernovážskej ?, bielovážskej) v čelovej a pričelovej časti príkrovu je príkladom alpského modelu. Vystupovanie nižších príkrovov v podloží a v zázemí vyšších (krížňanského ako celku v pomere k vyšším) je príkladom karpatského plánu.

6. Štruktúrna a genetická zviazanosť manínskeho príkrovu s krížňanským, v Bielych Karpatoch ďaleko užšia ako na Považí, sa zvlášť výrazne prejavuje v podloží neogénu viedenskej panvy a hlavne pri východnom okraji Álp. V podloží viedenskej panvy sú obidva príkrovy spolu s čelovou časťou chočského príkrovu súčasťou pribradlovej šupinovej zóny. Vo východnej časti Severných Vápencových Álp vytvára tzv. Kieselkalkzóna — analóg manínskej jednotky (jej juhozápadný cíp) — okrajovú šupinu frankenfelského príkrovu.

7. Povrchnokriedové až poeocénne horizontálne presuny väčšieho rozsahu, inde v centrálnych Karpatoch spájané len s pribradlovou zónou, postihujú pravdepodobne celé Malé Karpaty.