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BARTOLOMEJ LEŠKO* — AUGUSTÍN ŠUTORA* — MARIAN PUTIŠ**

GEOLOGY OF THE POVAŽSKÝ INOVEC HORST BASED ON GEOPHYSICAL INVESTIGATION

(Figs. 10)

A b s t r a c t : The paper deals with the knowledge obtained by the analysis of geological and geophysical data from the Považský Inovec horst and its immediate surrounding. Attention is paid to the relation of the horst to the deep structure of the Earth's crust and to the tectonic-lithological features of the crystalline complex, Paleozoic and Mesozoic complexes from which the development of geological units and their position in the nappe structure of the West Carpathians is derived. The vertical uplift of the Považský Inovec horst is approx. 9—12 km. Owing to the uplift the units of the Carpathian Penninic are discovered in the form of a tectonic window situated in the area of Austro-Alpine nappes. The relation of the horst to the adjacent Neogene and Quaternary is solved marginally.

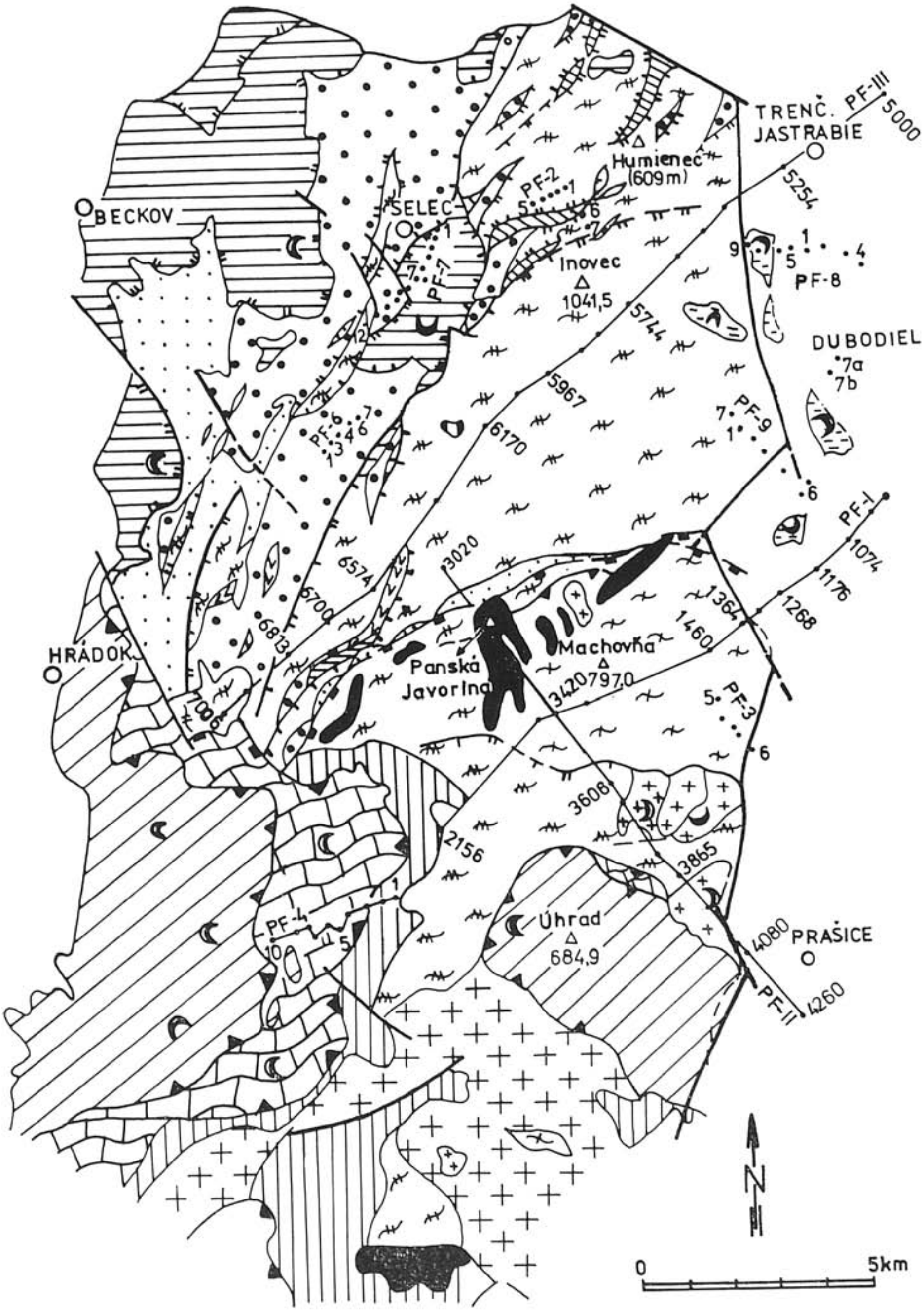
Р е з ю м е : В статье рассматриваются знания, полученные анализом геологическо-геофизических данных из горста Поважского Иновца и его близкой среды. Внимание уделяется отношению горста к глубинной структуре земной коры и тектоническо-литологическим чертам кристаллического комплекса, палеозойских и мезозойских комплексов, из которых мы делаем заключения о развитии геологических единиц и их месте в покровной структуре Западных Карпат. Вертикальный подъем горста Поважского Иновца 9—12 км, таким образом он открывает единицы карпатского пенниника в форме тектонического окна в районе австро-альпийских покровов. Второстепенно занимаемся отношением горста к прилегающим неогеново-четвертичных впадинам.

The systematic geophysical research of the West Carpathian crust carried out during last years resulted in the new knowledge on its physical nature making possible a more detailed insight into its geological composition and structure. Many orogenic processes of its development are embraced and fixed in the present physical picture of the crust which makes the physical data one of basic limits and directions when analysing geological conditions in a studied area.

Following the gravimetric research of F u s á n — I b r m a j e r et al. (1971) and T o m e k (1976) as well as the seismological research on regional profiles of the series "K" (B e r á n e k et al., 1979; M a y e r o v á et al. 1983, 1985) a wider area of the flysch and klippen zone as well as of Central Carpathian units of West Slovakia have been included into the comprehensive interpretation of detailed gravimetric measurements (Š u t o r a et al., 1982). A detailed areal geomagnetic, microgravimetric, micromagnetic, and geolectric in-

* RNDr. B. L e š k o, DrSc., RNDr. A. Š u t o r a, CSc., Geofyzika nat. ent., Podebradova 102, 612 00 Brno.

** RNDr. M. P u t i š, CSc., Department of Mineralogy and Petrology, Natural Sci. Fac., University of Comenius, Mlynská dolina, 842 15 Bratislava.



TRENČ. JASTRABIE
PF-III
5000
5254
Humienec
(609 m)
BECKOV
SELEC
PF-2
PF-7
Inovec
1041,5
5744
PF-8
DUBODIEL
7a
7b
5967
PF-9
PF-6
6170
PF-1
1074
1176
1268
1364
1460
3020
6574
6700
6813
HRÁDOK
Panská Javorina
Machovňa
797,0
3420
PF-3
3608
2156
3865
PF-4
Úhrad
684,9
4080
PRAŠICE
PF-II
4260
N
0
5km

vestigation along several profiles (Fig. 1) was carried out for the purpose of better knowledge of physical properties of surface crust layers of the Považský Inovec Mts. (Š u t o r a et al., 1985). The application of these geophysical methods made possible to obtain a knowledge which considerably enlarge our possibilities to decipher the geological structure of this mountain range.

A seismic wave pattern of subsurface and deeper parts of the crust in the wider area of the Považský Inovec Mts. was obtained by DDS along the profiles running across or parallel with the Carpathian arc. Particularly the transverse profiles KI, KII, KIII properly depict a seismic wave pattern of the West Carpathian crust in marginal and inner-central parts of West Carpathian tectonic units. Very important data making our knowledge on deeper crust structure and its physical differentiation more accurate have been obtained in the profile 100R/76, 78 (Fig. 2) running in the SW-NE direction along the Váh river valley and the Oravské Beskydy Mts. from Stará Turá to Poland, i. e. in longitudinal direction with respect to the Carpathian arc of the West Slovakia.

Relation of the Považský Inovec horst to the deep structure

From the viewpoint of Neoid arrangement of main crust blocks in the western part of Carpathians (F u s á n et al., 1971) the Považský Inovec horst is located in the north-western part of the Danubian block (Fig. 10). In neotectonic structural scheme (F u s á n et al., 1979) the horst is a part of the Nedzov — Inovec partial block. The understanding of its relation to deep geological structure has been possible only when an analysis of structural-tectonic elements recorded in the wave seismic pattern was performed in the profile 100R/76, 78. In the sence of this analysis a space of the central part of the profile can be cha-

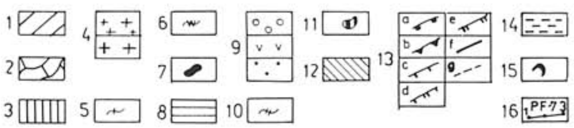


Fig. 1. Geological map of the Považský Inovec horst.

Explanations: C a r p a t h i a n A u s t r o - A l p i n e u n i t s: 1 —Choč unit; 2 — Krížna unit; 3—7; T a t r i c u n i t, 3 — Mesozoic as a whole; 4a — aplitic-pegmatitic granites; 4b — granites and inhomogeneous granitoids; 5 — migmatites; 6 — paragneisses; 7 — amphibolites; C a r p a t h i a n P e n n i n i c u n i t s: 8 — Mesozoic of the Selec unit; 9–11: I n o v e c u n i t; 9a — Permian sediments; 9b — Permian volcanics; 9c — Carboniferous; 10 — crystalline complex as a whole, (mica schist gneisses); 11 — amphibolites; 12 — Mesozoic of the Humienec unit; 13a — tectonic overthrust plane of Austro-Alpine units over Penninic units, 13b — line of the overthrust plane of subsidiary Carpathian Austro-Alpine units, 13c — overthrust planes of partial Penninic tectonic units exhibiting the tectonic style of recumbent folds, 13d — thrust planes of the "klippen" tectonic style superimposed on the tectonic style of recumbent folds, 13e — subsidiary thrust planes, 13f — faults, 13g — assumed tectonic lines; 14–15 — geological rock groups influenced by gravity movements; 16 — situation of profiles with depicted wedge caulking (Pk) and spacing of VES points for AB to 2000 m.

racterized as a zone of Earth's crust collision contact which has occured between Danubian and Fatric-Tatric blocks. In the sence of works by Leško — Beránek — Varga (1980) and Šutora — Janoštík — Leško (1982) we suppose the blocks as block elements of the Northeuropean platform.

The lower crustal layer along with the upper part of the Danubian block mantle which underlies the Považský Inovec horst just in the north-northeastern direction. It is clearly documented by the M-discontinuity rising from the depth of 32 km, at the Pk 70 km, up to the level of 28 km. To the north-east from the Pk 107 km the seismic wave pattern as well as gravity conditions change markedly. The M-discontinuity breaks there and further to the north-east it dips from

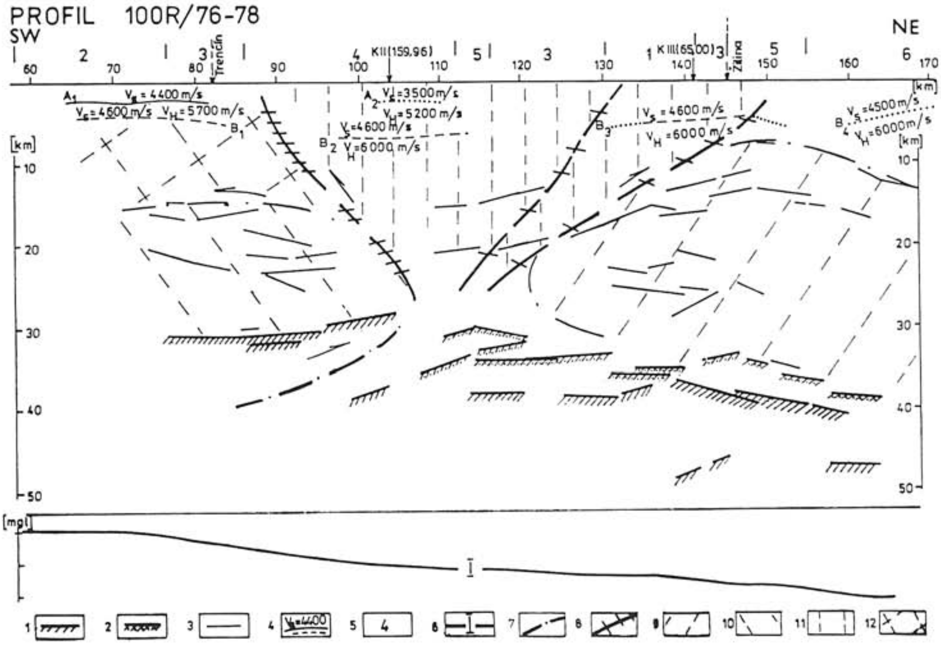


Fig. 2. Seismic profile 100 R(76, 78): interpretive section.

Explanations: 1 — distribution of refractory elements with presumed relation to the M-discontinuity; 2 — distribution of refractory elements with presumed relation to reworked complexes of the lower crust and upper mantle; 3 — distribution of refractory elements with presumed relation to the complexes of the middle and lower crust; 4 — refractory boundaries; 5 — designation of geological situation on the surface: 1. Inner Carpathian Paleogene; 2. Mesozoic as a whole; 3. Mesozoic of the Manín unit; 4. Neogene of the Ilava and Trenčín basins; 5. Pieniny klippen belt; 6 — flysch belt of the Magura nappe; Δg anomalies (i. e. gravity map of the inner part of the West Carpathians) at the level of Pre-Tertiary surface, according to Šefara — Šutora — Pospíšil — Bielik — Bodnár — Velich et. al. (1985): 7 — Danubian block overthrust plane; 8 — significant fault zones affecting the upper to middle part of the crust; 9 — crust of the platform type; 10 — crust of the platform type with Carpathian crust elements in its upper part; 11 — neotectonic Strážov block; 12 — northern part of the Nedzov — Inovec neotectonic block.

the depth of 30 km up to 40 km. At a depth of 34–36 km (Pk 115 km–Pk 165 km) a layer 3—4 km thick, transitional, probably reworked by melting is being formed from rock complexes of the lower crust and upper mantle, in the basement of the Fatric-Tatric block (Fig. 2).

It documents, in fact, that a collision — shortening — of crustal layers and the M-dicontinuity between Danubian and Fatric-Tatric blocks takes place by means of their mutual penetration with subsequent remelting of crustal rocks. A spacial segment between particular blocks of the European continent where the mentioned processes take place, we denote as a collision zone. Its present width is 20—30 km at the Earth's crust — upper mantle level, in subsurface conditions and in the configuration of geological units its observable widths reaches 40—50 km.

Based on the study of differentiation and of quantitative features of gravity data and differences in functions and rock lithologies of particular crustal blocks we consider the collision zone an expression of the deep boundary. The mentioned difference consists in a different thickness of rock complexes of the crust's middle part and in a character of rock environment of the collision contact at the crust-mantle level. The thickness of lithological complexes, inhomogeneous in velocity, in the collision zone does not exceed 16 km in a part of the Danubian block, the crust-mantle boundary being without a transitional lithological layer and displaying physically very markedly. On the other hand, crustal lithological units, inhomogeneous in velocity in the collision zone reach the thickness up to 26 km, and 4—5 km thick layer of transitional complexes (crust-mantle) being formed in its basement.

An analogically different seismic wave pattern and gravity field distribution occur also in upper crustal layers. In that way, the presence of marked velocity boundaries with Vh 5700—6000 m. sec^{-1} is indicated in the surrounding of Trenčín and in the highest elevated part of the Danubian block in subsurface crustal layers. From here downward to the basement up to the 15 km level the rock environment is physically indifferent without seismic waves registration. On the contrary, a richer seimic wave pattern can be observed in the segment of the collision zone from the Pk 90 km to Pk 130 km (profile 100 R 76, 78) up to the depth of 10 km and consequently also a thinning of rock environment homogeneous in velocity.

In the northern part of the profile 100R/76, 78 from the Pk 130 to Pk 160 km, i. e. in a rear segment of the Fatric-Tatric block the seismic wave pattern differs from two preceding ones having subsurface velocity boundaries with Vh 4600—6000 m . sec^{-1} in depths of 5—6 km. The homogeneous lithological layer in the middle part of the crust ceases and refractory velocity boundaries reach up to the depth of transitional crustal layers: crust-mantle.

Buday — Dudek — Ibrmajer (1969) have already found out the presence of a gravity phenomenon at the line Přerov — Gottwaldov — Banská Štiavnica and they interpreted it in relation to the subsidence which, according to the authors, has conditioned the geological structure of the West Carpathians at the level of 15—36 km during the Pre-Alpine period. Similarly, Beránek — Zounková (1979) assume that in this physically anomalous zone a marked depression of the gravity field and the M-discontinuity occur. In accord with the mentioned authors we can state that the deep fault system can be registered only in the lower part of the crust in the interval of 15—36 km whereas it is not manifested physically in subsurface crustal layers. It is probably a result of dispersed fault planes of NW-SE and N-S or even SW-NE directions. The Jastrabie fault plane is one of them (Maheľ, 1967). However, the function of a paleogeographic factor (in the sence of the mentioned author) cannot be attributed to the fault plane because the whole collision phenomenon is of Miocene to Pliocene age the traces of which survive up to the Recent (Figs. 9, 10).

Dynamic crustal processes fixed in the seismic wave pattern and in the gravity distribution of lithological masses can be connected with orogenic processes of the Middle to Upper Miocene age when, in a substantial form, the Carpathian tectonic arc has been formed. The dynamic processes surviving from the Pliocene up to the Recent have not been less important having completed vertically the structural picture of the upper crustal layers of the West Carpathians.

As a result of all these events the Považský Inovec horst has been uplifted by 9—12 km related to the granite layer of the crust which subsequently caused the present morphological cut to expose the geological units characterizing Earth's crust at the level of 6—8 km. In such a way, the geological units with lithological-stratigraphical sequences and tectonic features (the "klippen style") affected by the Alpine dynamometamorphosis, i.e. the units of the Carpathian Penninic as the basement of nappes of Austro-Alpine provenance are outcropped in the erosion cut of the horst in the area of the Pk 65—90 km (profile 100R/76. 78).

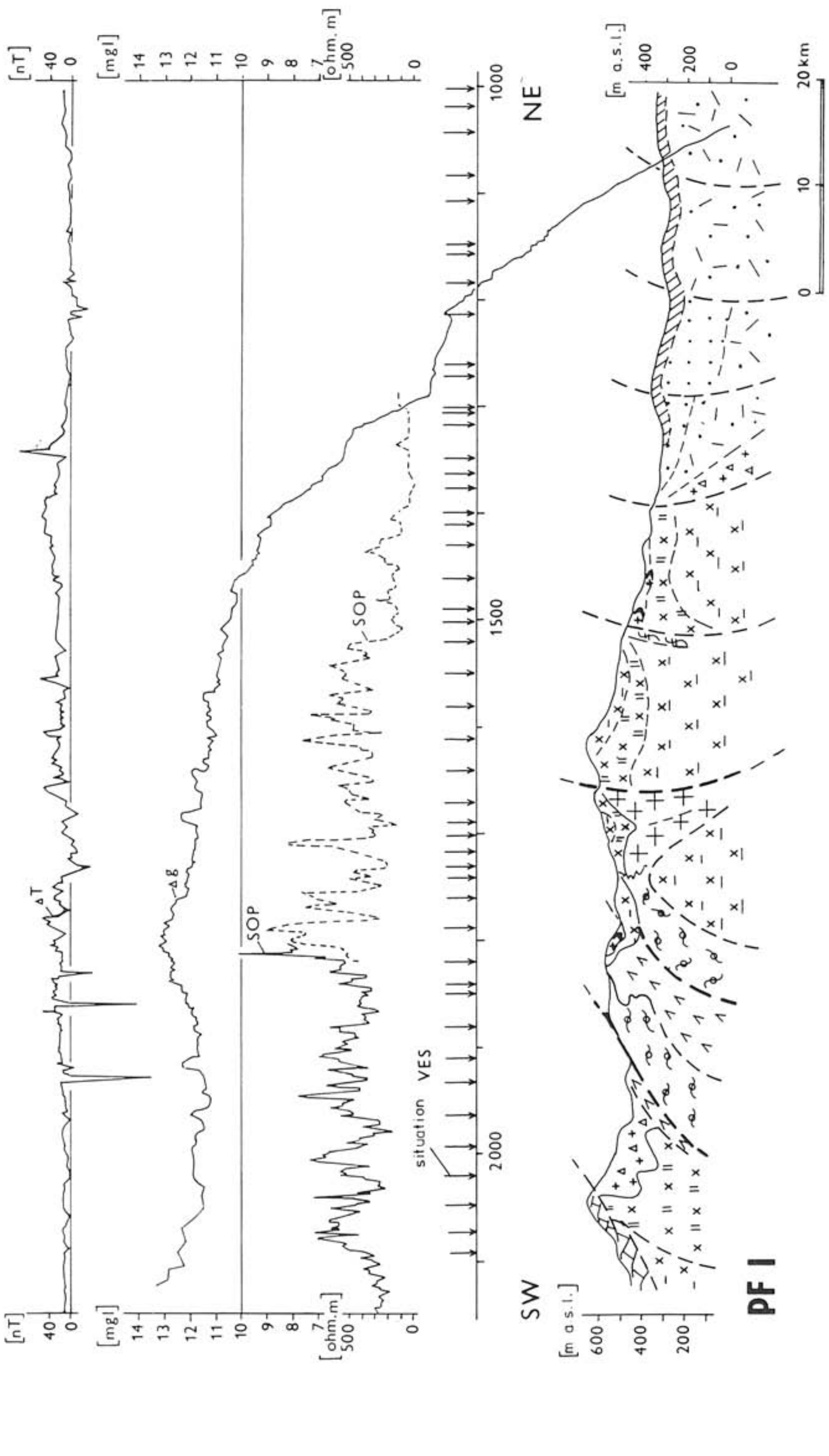
Geological structure and composition of the Považský Inovec Mts.

Application of geophysical methods

When studying the lithological composition of the Považský Inovec horst we started from the detailed geophysical works carried out areally and in several profiles which run both longitudinally and diagonally to the direction of surface tectonic units. As a starting material we have used geological maps from the last decade by the authors Zimáň (1979), Plašienka (1976), Havrila (1983), Putiš (1981). We have also used the geological information on results of drilling works in the Považský Inovec Mts. and surroundings carried out by various geological survey companies (Štimmel, in press).

In order to find a correlation between lithological and geophysical knowledge we have superimposed the geophysical sections over the rock environment. We have taken into account all knowledge on physical properties of rocks obtained by the application of geoelectrical, gravimetric and geomagnetic methods. Further information was obtained from parametrical geoelectrical measurements from several boreholes as well as from surface outcrops of the rocks building up the Považský Inovec Mts. We have used also the results of the qualitative and quantitative interpretation of the SOP measurement, microgravimetry and microgeomagnetics. In this way we have tried to minimize a subjective approach when evaluating the lithological environment which was interpreted from the geophysical knowledge.

In spite of these physical limits the constructed geological sections (Figs. 3–8) may in some cases represent alternative solutions, particularly in the situations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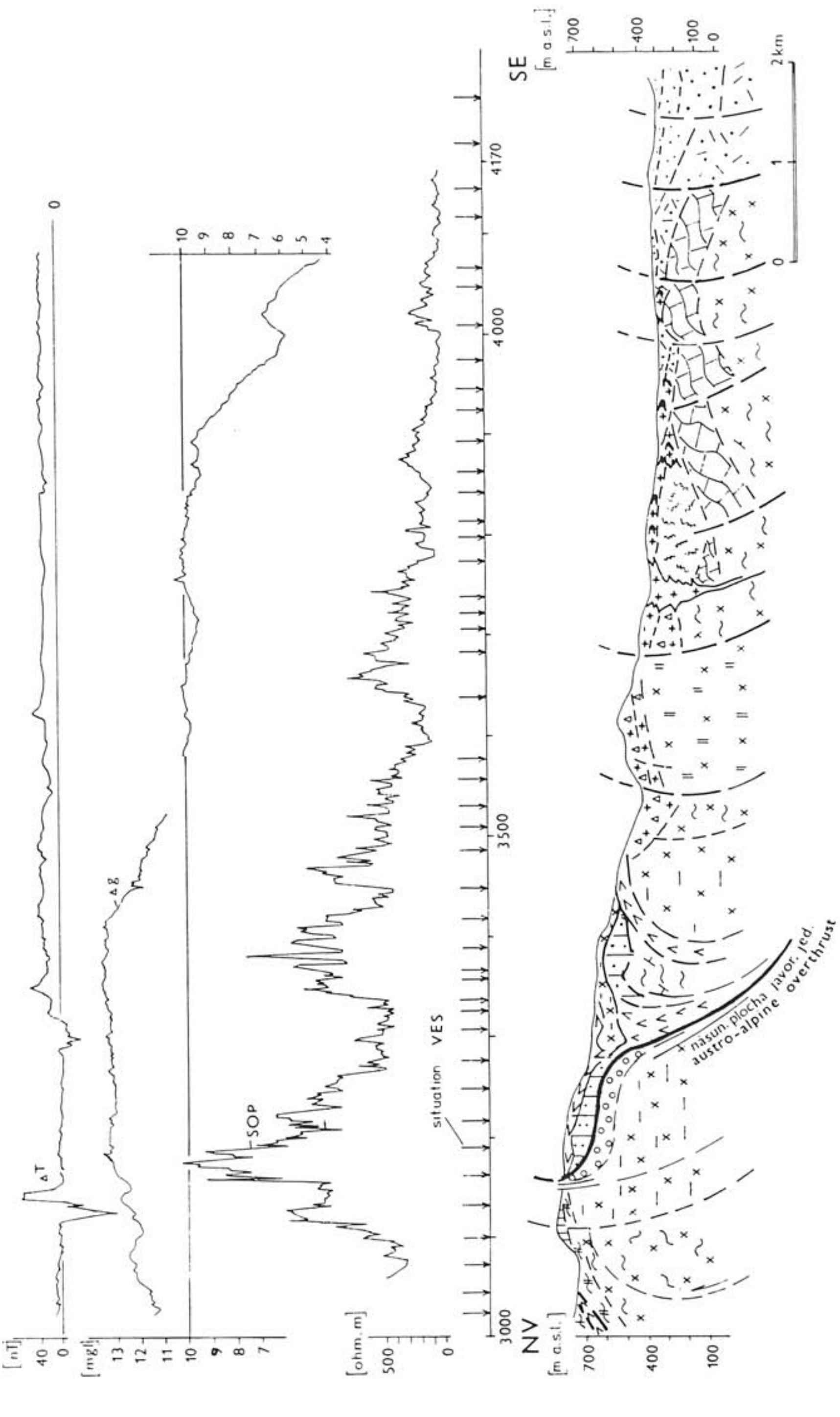

NV
SE
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situation
násun. plocha javor. jed.
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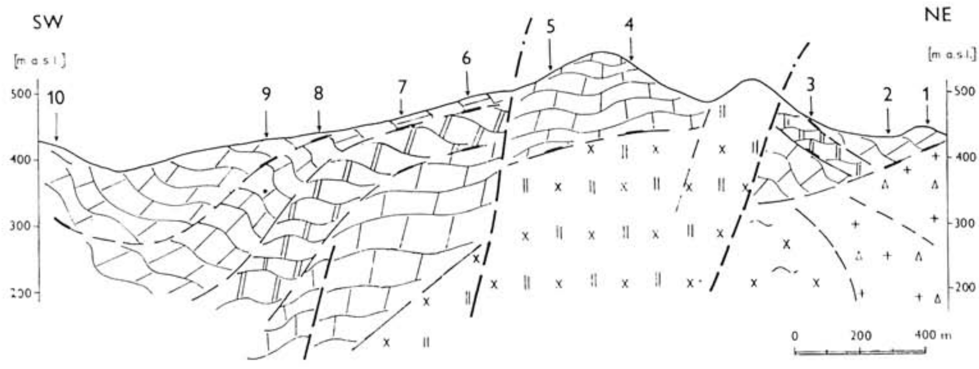
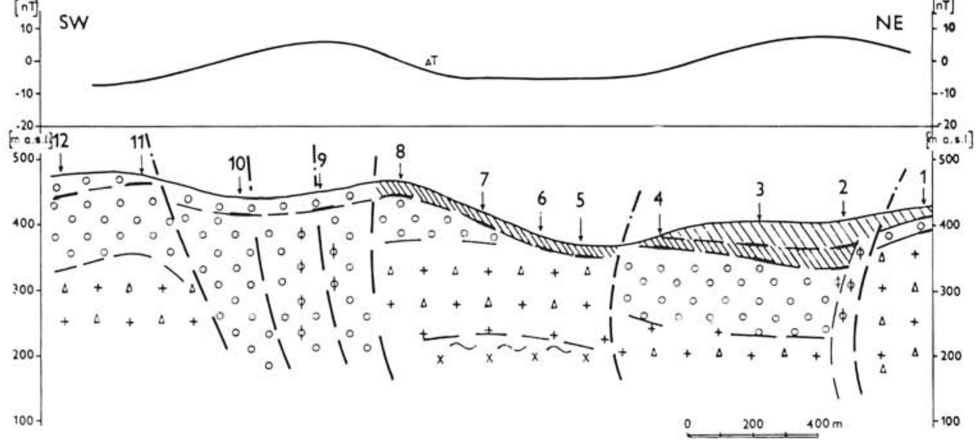
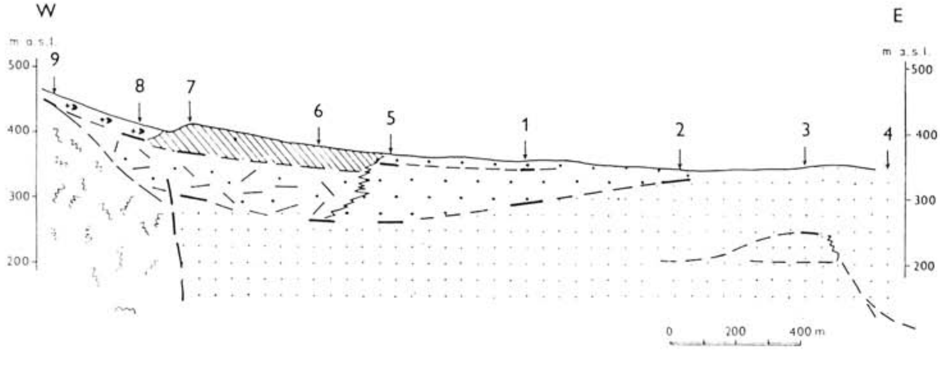
PF-4 (N. LEHOTA)



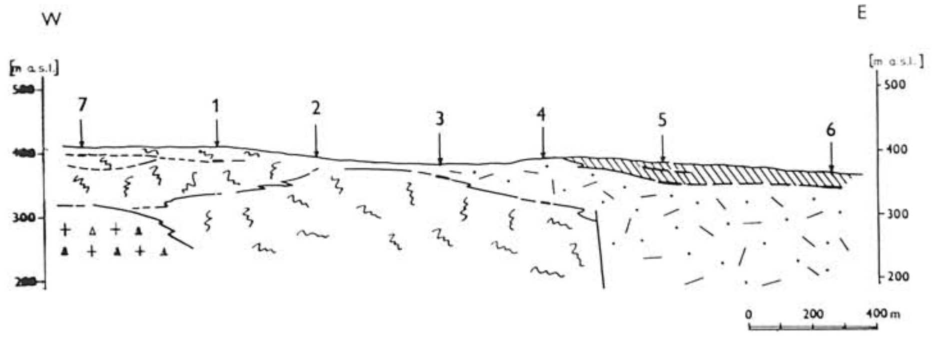
PF-7 (SELEC)

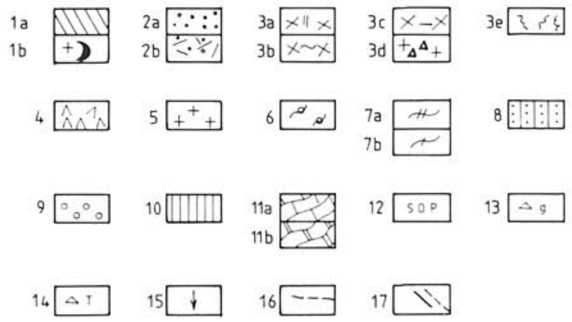


PF-8 (PATROVEC)



PF-9 (STARÁ HORA)





Figs. 3–8. Geological sections PFI, II, PF 4, 7, 8, 9.

Explanations: 1a – slides of Mesozoic rocks (ρ_z 80–160 ohm.m); 1b – slides of crystalline and magmatic rocks (ρ_z 50–300 ohm.m); 2a – Neogene sediments – clays, sandy clays (ρ_z 10–40 ohm.m); 2b – sands to conglomerates (ρ_z 40–80 ohm.m); 3a – crystalline schists, metamorphites mostly gneisses compact (ρ_z 600 ohm.m); 3b – crystalline complex as a whole tectonically affected (ρ_z 600 ohm.m); 3c – gneisses with interbedded amphibolites (ρ_z 700–1500 ohm.m); 3d – intensively damaged crystalline complex (ρ_z 140–300 ohm.m); 3e – crystalline complex hydrothermally altered or strongly tectonically damaged or weathered (ρ_z 56–120 ohm.m); 4 amphibolites (ρ_z 480–800 ohm.m); 5 aplite-pegmatite to two-mica granite, homogeneous (ρ_z 240–320 ohm.m); 6 – migmatites (ρ_z 200–320 ohm.m); 7a – strongly muscovitic gneisses of the mica schist type (ρ_z 900–1700 ohm.m); 7b – muscovite pegmatite (ρ_z 360–400 ohm.m); 8 – phyllonites, crystalline schists, strongly quartzose with the thickness of 50–150 m (ρ_z 900–1700 ohm.m); 9 – Permian sediments with interbedded basalt (ρ_z 1200–1700 ohm.m); 10 – Upper Carboniferous; 11a – Mesozoic as a whole, damaged (ρ_z 70–100 ohm.m), the more compact one (ρ_z 320–750 ohm.m); 12 – results of symmetrical resistance profiling (with AB to 200 m, MN 20 m); 13 – Bouguer anomaly for the density parameter $\sigma = 2670\ \mathrm{kg\,.\,m^{-3}}$; 14 – total magnetic intensity curve; 15 – vertical geoelectric sounding (spacing of points for AB to 2000 m, with probe designation); 16 – weathering and/or lithological boundaries; 17 – fault zones found out, or assumed.

when a physical response of various rocks or their lithological associations is similar or even identical in parameters. Under such conditions the knowledge from the qualitative and quantitative analysis of gravimetric and geoelectrical measurements was a decisive criterion.

As we can judge from the phenomena recorded in geophysical sections Pf I, II, III and Pf 4–7 (Figs. 3–8) the layered sedimentary rocks of the Mesozoic as well as relics of the Tertiary occur in upper parts of the profiles. However, a similar "layering" of the physical picture occurs also in the crystalline complex. The physical differentiation, i.e. the apparent layering occurs in two basic directions: ENE-WSW and NNE-SSW in the Považský Inovec horst.

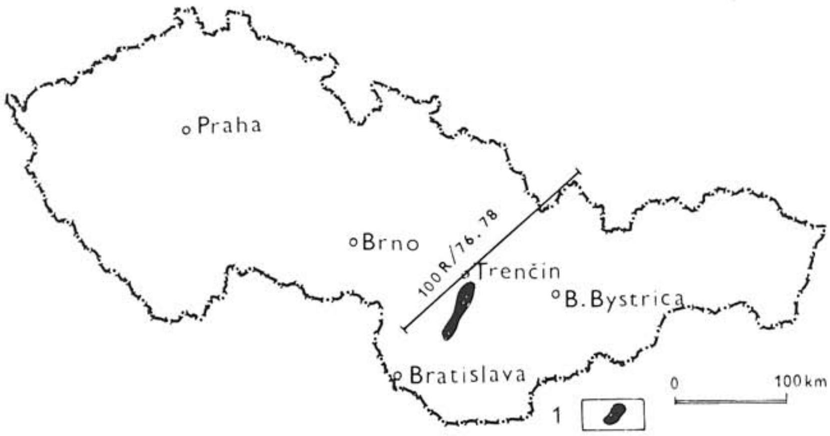


Fig. 9. a Territory of Czechoslovakia with designation of seismic profile 100 R (76, 78).
Explanation: 1 — The Považský Inovec Mts.

We are convinced that such a physical picture represents in the crystalline environment a transfer of particular partial masses during the Paleogene and Miocene orogenetic movements to form a slice structure as well as the degree of their tectonic and dynamometamorphic reworking. We also suppose that the proces of weathering directly proportional to the intensity of tectonic events plays here a significant role.

Thus, we can state, that geophysical data obtained by the methods of microgravimetry, geoelectricity, geomagnetism make possible to distinguish reliable a spatial distribution of crystalline schists, volcanic bodies and sediments of the Paleozoic and Mesozoic each to other and in covered areas below Pliocene and Quaternary sediments. The obtained data help in this way to get an idea of the youngest development stage of the horst.

Geological characterization and the tectonic style of the horst

On the basis of the analysis of lithological-stratigraphical sequences and application of geophysical data we have arrived at the decision that two fundamental geological elements of the different paleogeographic provenance must be distinguished in the Považský Inovec horst. It is the group of geological units of Penninic provenance and the group of geological units of Austro-Alpine provenance. The difference is exhibited already in crystalline rock masses consisting of two individual pre-metamorphic sequences with a different metamorphic development, a degree of granitization, and a tectonic style.

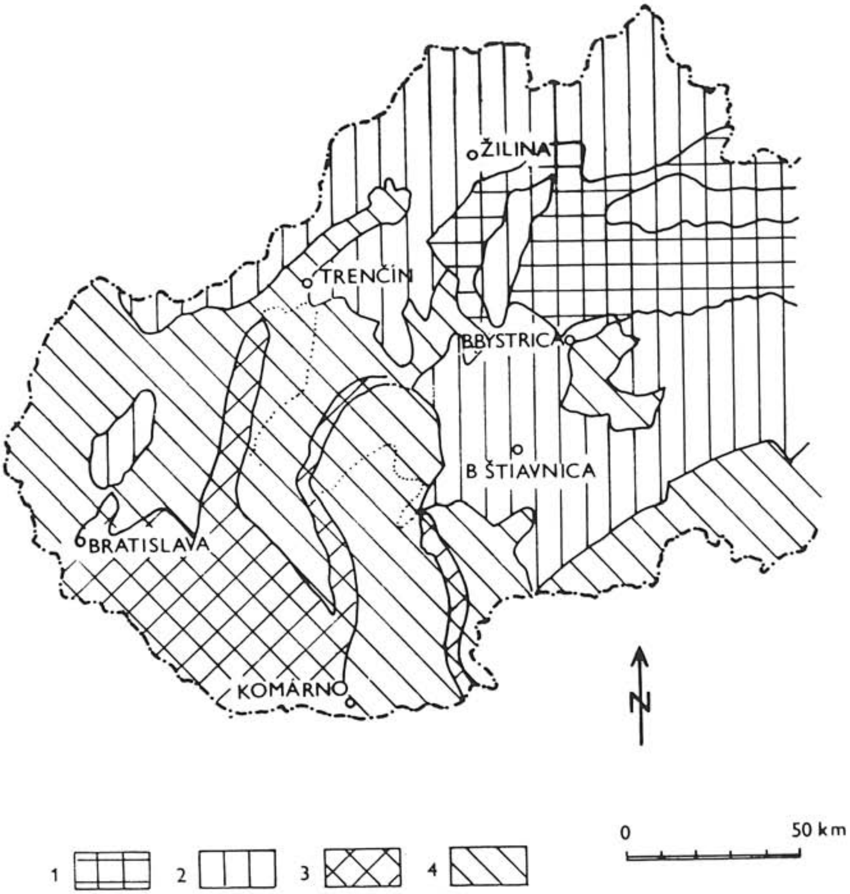


Fig. 9b Territory of West Slovakia with designation of areas with various recent vertical movements rates (according to K v i t k o v i č-P l a n č á r, 1979).
Explanation: 1 — area of positive vertical movements +0.5 to +1.0, or to 2.0 mm . yr^{-1}; 2 — area of vertical movements 0.0 to +0.5, or to 1.5 mm . yr^{-1}; 3 — area of negative vertical movements —1.0 to —3.0 mm . yr^{-1}; 4 — area of negative vertical movements 0.0 to —1.0 mm . yr^{-1}.

A. Units of the Carpathian Penninic

1. *The Humienec unit* (the name is according to the elevation point Humienec 609 m). In the highest elevated part of the Považský Inovec horst Middle and Upper Cretaceous sediments consisting of calcareous schists, detritic limestones,

sandstones and conglomerates outcrop at the surface. The schists are often variegated with intercalations of radiolarites. The petrographical composition of clasts (after Kullmanová–Gašpariková, 1982) suggests that they came from Upper Paleozoic and Mesozoic rocks as well as from the crystalline rocks (Putiš, 1986) outcropping at the surface in the northern part of the Považský Inovec. The detritical limestones have got rauhwacke-like, argillites and argillaceous schists have been affected by the marked cleavage with planes discordant to those of original bedding. The originally sandy cement of psammitic sediments is recrystallized with the association of new minerals — quartz, illite, sericite and chlorite.

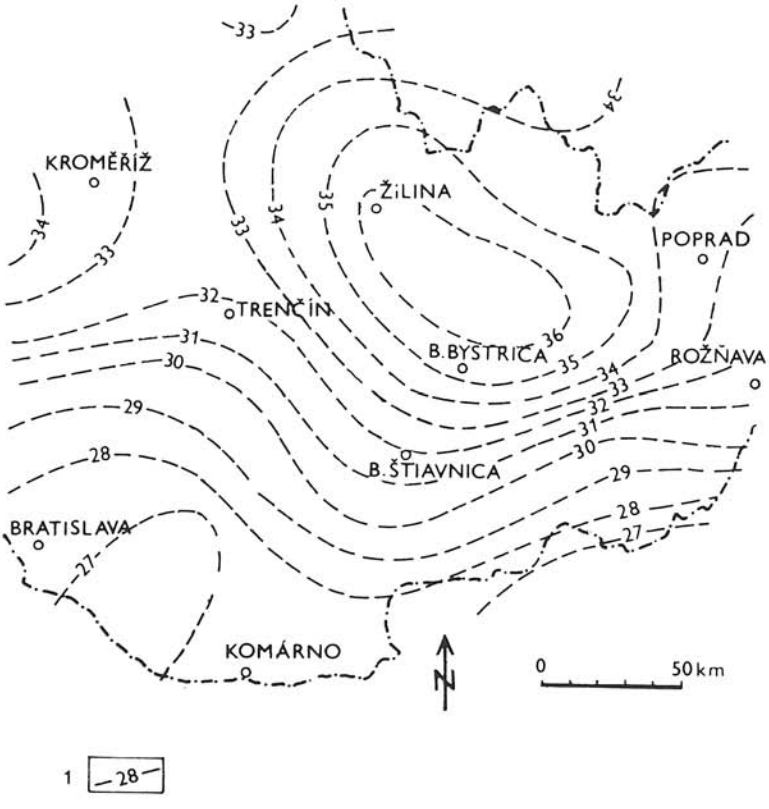


Fig. 10. Relief of the M-discontinuity in the area of the Danubian and Fatric-Tatric blocks adapted according to Fejfar et al. (1982) and Mayerová et al. (1985).

Explanation: 1 — M-discontinuity boundary depth (in km).

The surface occurence of the strata series (according to Kullmanová–Gašpariková, 1982, with recrystallized *Globotruncana* of the Coniac and with bioclasts o fthe Klapy facies Mesozoic) representing a thickness ranging from several tens to hundreds of meters in bound to thrust fault planes in crystalline schists. Together with the schists this dynamometamorphosed strata series takes part in the slice structure of the "klippen" style (P u t i š, 1981, 1983, 1986) of the Považský Inovec horst. According to present surface tectonic features we cannot judge its original tectonic relation to the crystalline complex and to the Upper Paleozoic complexes of the Inovec unit and to the Mesozoic complexes of the Selec unit during older, first of all, however, Paleogene orogenic stages. From the present geological configuration it is evident, however, that the Upper Cretaceous strata series affected by the dynamometamorphosis and outcropped at the surface in the elevation maximum of the Považský Inovec horst lies in the basement of higher units (the Inovec and Selec ones) of the Carpathian Penninic. In the Považský Inovec horst the strata series forms an individual tectonic unit which we refer to as the Humienec unit and we include it in the Pieniny sedimentary area as a dynamometamorphosed equivalent of the Klapy Upper Cretaceous sedimentation.

2. *The Inovec unit.* In the nappe system of the West Carpathians this unit represents a frontal part of the nappe of the southern group of Penninic units in the sence of L e š k o—V a r g a (1981). Crystalline schists consisting of mica schist gneisses, paragneisses, mica schists and metaquartzites reaching the thickness of decimeters, meters up to tens of meters, mica schist gneisses with high content of coarse-flake muscovite prevailing, are the basic rock types of the unit. The mica schist gneisses belong to the wide staurolite zone of the progressive regional metamorphosis (K o r i k o v s k y—P u t i š, 1986) where staurolite coexists with cyanite, andalusite and sillimanite. This is a characteristic feature of the crystalline schists of the Inovec unit only. Sericitization, chloritization, albitization and increased quartz content in biotite and two-mica gneisses and in mica schist gneisses are the main manifestation of the Pre-Alpine diaphtoresis. The increased coarse-flake muscovite content is a result of recrystallization of proper lithological members, mainly the pelites of an originally sedimentary sequence. It means that the alternating of biotite and two-mica paragneisses, mica schist gneisses, mica schists, and metaquartzites reflects first of all lithological changes of the original sediment and is not a result of the retrograde metamorphosis. After all, the muscovite has a relation to metamorphic foliation: it is, thus, not a result of a superimposed metamorphosis but the product of the original regional metamorphosis. The age classification of crystalline schists and their metamorphic cycles is dealt with in detail in papers by P u t i š (1981, 1986), that is why it is not a subject of this work.

The Upper Paleozoic complexes outcroping near the western margin of the horst are another feature of the lithological content of the Inovec unit. Their lithology and metamorphosis was recently dealt with in papers by P u t i š (1981, 1986) and K o r i k o v s k y–P u t i š (1986).

The Carboniferous sediments consist of claystones, greywacke-sandy schists, siltstones and sandstones with interbeds of polymict conglomerates. Black bituminous shales are a typical feature of the strata series. Conglomerate clasts came from the metamorphic and magmatic rocks of the basement and from sedimentary rocks of the strata series itself.

The Permian strata series overlying the Carboniferous complexes consist of arcose sandstones, sandy greywackes, variegated argillites, polymict conglomerates to quartzites, intercalations of sandy limestones and evaporites. The facial picture of the Permian strata series suggests a continental to lagunar environment of origin. The clast content of the conglomerates varies in rock composition and indicates a local source (Kamenický, 1958). Acid and basic volcanism is a characteristic feature of the Permian series of strata. Rhyolites, as a product of the acid volcanism, occur only in relics due to a deep morphological erosion level of the horst. On the other hand, products of the basic volcanism — basalts and their tuffs — occupy large areas in the Považský Inovec horst. Volcanics, particularly tuffs are affected by the hydrothermal metamorphosis, by the formation of chlorite schists in the places with hydrothermal veinlets with actinolite, albite, epidote, chlorite, quartz and calcite. The bi-modal volcanism of basalt-rhyolite association is one of the characteristic features by which they differ from the stratigraphically equivalent strata series of the Austroalpine provenance (Putiš, 1986).

The Carboniferous and Permian series of strata are both affected by low-grade Alpine metamorphosis which, however, is not of an identical intensity in the whole strata series. Yet, it is in the organic connection with deformation movements of the basement crystalline complex.

In these strata series we can distinguish: a) the Paleoalpine deformation stage (Paleogene) with a tectonic style of recumbent folds and charriage structures in the form of nappes (Inovec, Selec and Humienec units); b) the Mesoalpine deformation stage (Paleogene—Lower Miocene) with a tectonic style of assymmetrical folds and slices — "klippen" style; c) the Neoalpine deformation stage (Upper Miocene—Pliocene) with a block and slice tectonic style along fault and overthrust planes due to gravity movements.

The dynamometamorphosis has a zonal character of the NNE-SSW direction in the whole complex of the Inovec unit depending on direction of charriage and overthrust structures. The width of zones ranges from several meters to tens of meters, but the length reaches up several of kilometers. The most pronounced manifestation of the dynamometamorphosis occurs usually at the contact of Upper Paleozoic and Mesozoic sediments with basement crystalline schists (cf. Putiš, 1986).

The Alpine metamorphosis has the isochemical character in the basement crystalline complex and it is limited to mylonitized and phyllonitized crystalline schists in the vicinity of charriage and overthrust planes. A brittle deformation and recrystallization predominates over neoblastesis in these rocks (quartz, sericite, chlorite).

3. *The Selec unit.* The Mesozoic formation outcropping at the NW margin and in the central part of the Inovec segment of the horst have been considered from the days of Uhlig (1903) till today, the so called cover of the crystalline complex. Mahel' (1959, 1967)described the northern part of this "cover" as the Beckov series ascribing to it considerable thicknesses in the Triassic members, especially in the Carpathian keuper and in the Lower Jurassic. But, Kullmanová—Gašparíková (1982) found out, on the basic of *Globotruncana* association, that the detritical strata series considered as the Liassic by the mentioned author represent the Upper Cretaceous period of sedimentation.

To the Selec unit we include: Lower Triassic quartzites, quartzose and arcose sandstones, conglomerates, variegated claystones with intercalations of dolomites (Z i m á ň, 1979). Further, superjacent Middle Triassic limestones with rauwackes and Jurassic members involving sandy oolitic limestones, crinoid and white limestones (M a h e ľ, 1967).

The dynamometamorphosis caused a schistosity in sediments of the Selec unit, by which a partial re-crystallization and orientation of quartz along schistosity planes took place with the formation of new sericite. The limestones and dolomite interbeds of the Middle Triassic were affected by schistosity and by formation of rauwacke interbeds and tectonic clay on the contact boundaries with the crystalline complex slices. The Jurassic white limestones are marmorized and oolitic white sandy limestones have got schistose. The schistosity is oriented oblique or perpendicular to the original sedimentary bedding and to the direction of tectonic transport of the Mesozoic masses.

The Paleogene and Miocene, even up to the Recent operating movements make it difficult to resolve the Mediterranean movements or to find traces, i.e. to make a decision on the "cover" position of the unit to Lower Paleozoic and older crystalline complexes of the Inovec unit. Some geological relations, however, may be deduced from geophysical indications, e.g. in the profile PF — 7 (Fig. 6). In this profile can be seen that the Mesozoic complexes of the Selec unit with the thick of 15—50 m and ρ_z 70—100 ohm.m lie on rocks with ρ_z = = 1200–1700 ohm.m belonging presumably to the Permian sediments. On the contrary, in the western part of the profile (Pk 5—8) below the depth of 10—50 m and in the eastern part of the profile (Pk 4—2) below the depth of 100—150 m the environment with very low ρ_z values of 140—300 ohm.m occurs. These geophysical indications suggest that the rock environment consists of crystalline schists strongly damaged and affected erosion.

Consequently, according to surface distribution, the Selec Mesozoic complex would seem to lie in "normal" stratigraphic sequence above the Upper Paleozoic and crystalline basement. But considering the fact, that some Mesozoic members of the Selec unit with a thick bed of plastic rauwackes in the base lie on a strongly weathered and tectonically affected crystalline complex as well as the fact, that in the northern part of the village Selec the Mesozoic members were detected also in the basement of the Permian sediments (Š t i m m e l, in press) we suppose that gravity movements have occurred there, and thus slide bodies from the Miocene period to the Recent are concerned there. The occurrence of two springs with their quantity, chemical composition and temperature would also support this idea (K u l l m a n, oral communication).

Thus, we can accept the alternative according to which the Mesozoic complexes of the Selec unit achieved their tectonic individuality during the Paleogene movements which was affected during later Upper Paleogene. Mesozoic complexes together with the Lower Paleozoic and older crystalline members were unified into "klippen" style. Eventually, the Upper Miocene to Quaternary movements during the horst formation have even more complicated the structural situation of the Mesozoic "cover" by displacing of instable rock masses from originally erected or recumbent and to the south-east and east overturned slices to the lower levels on a structurally heterogeneous basement (Figs. 4–8).

B. Carpathian Austro-Alpine units

1. *The Panská Javorina unit (943m).* The unit outcroppes at the Earth's surface in the southern part of the horst having lithological-stratigraphical sequences different from those in the Inovec and Selec units. Crystalline schists show only the low degree of Alpine reworking and unlike to the Inovec crystalline unit a Pre-Alpine tectonic style predominates in them. The style is marked by open macro-folds of metamorphic foliation in paragneisses and migmatites. The phyllonitization of a basal part of overthrust unit members as well as the mylonitization along north-south faults belong to the most marked signs of Alpine tectonics.

A large part of crystalline schists belongs to the staurolite zone of progressive metamorphosis, but as opposed to the Inovec unit crystalline with kyanite lacking. The staurolite zone changes in direction to granitoids to higher temperature sillimanite zone with biotite and muscovite.

The Panská Javorina geological unit as a lower nappe of Carpathian Austro-Alpine group is displaced at a 35° angle northward on the Inovec unit (Fig. 4). The charriage plane often consists of phyllonites with thickness of some tens of meters which differ strikingly in physical picture with their values of ρ_z 1400 ohm.m and $\triangle$ T = 0. Triassic to Lower Cretaceous carbonatic and pelitic-psammitic members (with the Upper Paleozoic lacking) lie in an immediately adjacent rocks superposing the crystalline schists and volcanic bodies more or less detached from the basement built up usually by rauwacke beds.

According to Havrila (in Havrila—Vaškovský, 1983) Mesozoic series of strata of the Panská Javorina unit begins in the Lower Triassic by Lužná beds and ends by a flysch strata series in the Albian with hiatus in the Upper Triassic. Southward this strata series, together with crystalline basement, dips below particular blocks of Mesozoic rocks of higher Austro-Alpine nappes which are, however, not dealt with in the present work.

Particular lithological-stratigraphical members of the Panská Javorina unit as well as the complexes of the Carpathian Austro-Alpine higher nappes (Krížna and Choč nappes) continually disappear as the Považský Inovec horst dips southward into Bánovce and Danubian basins from surface levels. It is necessary to note here, that the tectonic style and tectonic activity of the members differ markedly from the tectonic nature of basement units (the Humienec, Inovec and Selec ones) of the Carpathian Penninic. As stated above, at least three stages of tectonic development with dominant "klippen" style may be observed in the latter. On the contrary, Austro-Alpine units, i.e. the Panská Javorina, Krížna and Choč ones behave passively during the Paleogene and Lower Miocene orogenic movements, as masses laid on a tectonicaly activated Penninic basement. Finally, blocks have been formed of particular complexes of mentioned units due to vertical crust movements and subsequent gravity forces accompanied by transport to heterogeneous rock environment from the Upper Miocene early to the Recent.

Blocks of Jurassic and Cretaceous rocks occuring isolated at the eastern margin of the horst and lying on Pliocene to Quaternary sediments are an example. They were considered the tectonic outliers of the Manín nappe by Mahel' (1986). If the statement is valid, than we may approximate to the determination of paleogeographic and tectonic positions of the Manín unit-nappe in the West

Carpathian fold-nappe system on the basis of geological relations in the Považský Inovec horst as well as on the basis of knowledge of Mišik (1975) and Mišik—Sýkora (1981) obtained from the wider region of the Váh river.

The Manín nappe is considered an independent unit by Rakús (1975) displaced on Upper Cretaceous sediments of Púchov facies ("couches rouges") of the klippen belt. Its sedimentation area is searched by the author southward to south-eastward, beyond the southermost part of the original Pieniny basin, but before the basin where Mesozoic members of the Tatric zone have originated. A similar opinion was expressed by Mišík—Sýkora (1981) who locate the origin of this unit to the foreland of Tatric sedimentary space on the basis of sedimentary criteria.

Geological relations in the Považský Inovec horst together with knowledge of the mentioned authors regarding a wider back-land of the horst allow us to consider the Manín unit-nappe to be an external-marginal element of Austro-Alpine provenance, and consequently the lowest basal tectonic nappe of the West Carpathian Austro-Alpine group. It differs from the Tatric and Austro-Alpine higher nappes besides lithological and stratigraphical content and facial nature also by its lithological sequences participating in Mediterranean orogens as well as in Paleogene and Miocene orogenic movements at least partially together with units of the klippen belt, i.e. with the Carpathian Penninic units. The Manín nappe is overthrust on an immediate flysch strata series of the Middle Eocene Magura nappe (Kullmanová, in Leško et al. 1982) in surroundings of Stará Turá, but it is overthrusted on Cretaceous sequences of the Kysuca unit of the klippen belt (Rakús, 1975) in the valley of the Váh river and around the borehole Soblahov (Kullmanová, 1978; Mahel', 1985).

Discussion

From the analysis of geological relations, especially from that of several superimposing evolution stages and the difference of metamorphic events, some regularities may be revealed which make possible to understand not only the structure of the Považský Inovec horst but its application to the geological development of the whole West Carpathians. It can be shown that the Mesozoic paleogeographic belts of the original Austro-Alpine continental crust together with an island belt in the South of geosyncline were affected by orogenic movements already before the Albian, the movements continuing up to the Upper Cretaceous. At that time, besides the Mesozoic carbonate plate as well as its crystalline and the Paleozoic basement was affected.

However, the orogenic movements have affected also sedimentation belts of the Southern Penninic containing oceanic crust, which resulted in subduction processes of the Carpathian geosyncline. It is evidenced by a clast association in Upper Cretaceous sediments from the Albian to the Upper Eocene described in the Pieniny klippen belt in the northern part of the Penninic (Marschalko et al., 1980). The Penninic has not yet been tectonically damaged at that time, at most folded into large radius folds (Leško et al., 1980). Owing to these movements the South-Penninic nappes (Vepor, Gemer and other groups) and the Austro-Alpine group nappes have been formed from the crystalline, Paleozoic and Mesozoic masses with the transport in direction to the northern foreland of the Carpathian Penninic.

As is suggested by the Upper Cretaceous and Paleocene sediments, the moving forward South Penninic and Austro-Alpine nappes have covered only partly the sedimentation areas of the original Pieniny basin, on the contrary, the movements initiated the origin of a longitudinal trough (Marschalko, 1973) at its northern, i.e. external part.

Orogenic movements during the Paleogene can be divided into two stages. The first one occurred in the Paleogene to the Lower Eocene, actually it was a continuation of Upper Cretaceous movements in the newly-formed trough (Marschalko, 1973; Leško et al., 1980). The distinctive sedimentation features especially that of wild-flysch strata series, and the petrographic composition of clast material in the trough along the Pieniny klippen belt suggest an intensive tectonic activity in this space. According to Marschalko (1973) the southern margin of the trough was rimmed by reef limestones the autochthonous equivalents of which are not known on the present surface, but they occur as a heterogeneous material in the form of olistoliths in the flysch formation. The mentioned author assumes that they hardly could have been formed at the external margin of the Austro-Alpine zone because nothing suggests a genesis of reefs there taking into account relations in the Austro-Alpine nappe system in inner basins of the West Carpathians.

A remarkable phenomenon is that the reef limestones as olistoliths in sediments of the Paleogene to the Lower Eocene occur together with zoophics suggesting bathyal sea depths. Moreover, Wetterstein and Guttenstein type limestones of the Austro-Alpine zone occur there in negligible amounts, the clasts of the Jurassic, Upper Cretaceous, Danian and Montian however, predominate coming from a periphery of the own devastated sedimentary basin (Leško et al., 1982).

Mingling of the clasts of the Penninic and Austro-Alpine provenance, breaking, i.e. "canibalism" of marginal parts of the North Penninic basin as well as a resedimentation of the clasts together with continental shelf reef olistoliths suggest the active tectonic events in those Carpathian Penninic belts which were not folded and incorporated in nappes during the Upper Cretaceous.

The second stage of Paleogene movements is well documented in the klippen belt and in the Magura flysch belt in East Slovakia (Książkiewicz—Leško, 1959). Pre-Upper Lutetian sediments are intensively folded there into anticlinal and synclinal forms with relatively small radii which are overlain by the Upper Eocene to the Oligocene sediments in the form of wide synclinal belts. Upper Paleogene movements occurred perhaps later in the western part of the Carpathians, i.e. in the Oligocene, because no their traces can be observed in the Magura flysch belt in East Slovakia in the boundary of the Upper Lutetian and the Priabonian.

Thus, the formation of nappes of Austro-Alpine and Penninic provenance was completed during the Paleogene orogenic movements. The forward motion and transport of nappe masses caused the destruction and the superimposed dynamic metamorphosis of the Penninic lithological sequences with an exception of a marginal part of the Pieniny klippen belt sediments. The part of the margin of original klippen sedimentation has "escaped" dynamometamorphosis only because as a plastic and incompetent rock mass, it was pushed away by the moving forward Austro-Alpine (the Tatric — Panská Javorina unit, and „Subtatric" — Krížna and Choč nappes) as well as South Penninic nappes (the Inovec and Selec units, Vepor and Gemer group nappes and others) and consequently it was not affected by their weight (L e š k o—V a r g a, 1981). It is confirmed by the Upper Cretaceous complexes not affected by the dynamometamorphosis and the whole sedimentary cycle of the Klapy unit on the surface of the Klippen belt and, on the contrary, by their dynamometamorphosed equivalents in the Inovec unit environment.

The final tectonic style of the Považský Inovec horst was imprinted only during Upper Miocene movements at the end of the Badenian and Sarmatian. The movements are well documented in the surrounding of the Vihorlat Mts. where, after the *Bulimina–Bolivina* zone has sedimented, a marked uplift of the flysch geosyncline and its compressing into tight folds occurred. The folds correspond with the tectonic forms of the Klippen belt and with sediments of the Lower Miocene in the Vihorlat surrouding (L e š k o—S l á v i k, 1969).

As far as the downstream of the Váh is concerned the Badenian orogene documented in East Slovakia occurred perhaps earlier in the Považský Inovec horst — during the older Styrian phase. This orogene completed the formation of blocks and slices of the "klippen" style in the direction NNE-SSW from the units of Humienec, Selec and Inovec differentiating them from the overlying Austro-Alpine nappes (the Panská Javorina, Krížna and Choč units). The extent and intensity of Miocene movements are derived from a shortening of crustal layers at the collision boundary crust/mantle detected on the line Přerov—Banská Štiavnica — ČSSR/Hungaria frontier (the profile 100R/76, 78) and at the Peri--Pieniny line (L e š k o et al., 1980) in the direction SE-NW documented in profiles of the "K" series.

K s i ą ż k i e w i c z (1972) starting from sedimentary phenomena in the flysch geosyncline assumes that the shortening of crust might have reached 140—170 km. Similarly, K r s — R o t h (1979) claim that the transport of rock masses in the West Carpathians reached after the Oligocene more than 100 km. Moreover, the deep boreholes Lubina 1 (3300 m) or Hanušovce 1 (6003 m) indicate gentle slopes of transport planes (25—35°) of the Klippen belt over the Magura nappe and of the latter over outer flysch zone units in contrast to the surface structures which are steeply erected or even overturned against the transport direction (e. g. in Orava region). That is why we assume that a crustal shortening over the distance of 100 km under the conditions of subhorizontal movements of masses in the direction to the outer margin of the Carpathians is a sufficient evidence of superimosing of the Magura flysch belt and Pieniny klippen belt by nappes of the southern Penninc and Austro-Alpine zones. Thus, not only the stratigraphical-lithological sequences of the Klippen belt but also the rear parts of the Magura belt may occur in the crystalline basement of the Inovec unit in the Paleocene and Miocene tectonic scheme, however, having been dynamometamorphosed.

After the Považský Inovec horst had formed during the Upper Miocene the tensional movements have occurred which continue almost up to the present. A cause of the movements is thought to be in the asthenospheric activity and in a phenomenon of the Pannonian diapir which has been formed in the South of the Carpathian arc. An atitude of the vertical uplift of the horst may be derived either from the thickness of lacking Miocene (?) to Quaternary sediments which reach 4500—5000 m in the South of the Danubian block or from the lacking lithological complexes of the Austro-Alpine nappe group denudated on the present surface, or from the lacking at present Paleogene cover of these units.

It follows that the Považský Inovec horst has been vertically uplifted 9—12 km in the peak of elevation and in such a way it represents a tectonic window of the Carpathian Penninic in the environment of Austro-Alpine nappes: the Tatric and "Sub-Tatric". Nevertheless, in the recent stage of development the horst exhibits a subsidence tendency in comparison with the adjacent relief. The movement is observable from levelling measurement (Kvitkovič—Plančár, 1979) (Fig. 9). In spite of this tendency the subsidence of the horst relative to the Pliocene and Quaternary is slower causing a continuing overthrusting of the units participating in the horst structure over Pliocene and Quaternary sediments of surrounding basins.

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