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Geodynamic analysis of the Nízke Tatry Mountains based on geophysical and remote sensed data

Geodynamická analýza Nízkych Tatier na základe DPZ a geofyziky

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Geophysical data
Interpretation

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Abstract: Satellite images revealed an extensive deformation on the southern slopes of the Nízke Tatry Mts. range. This deformation can be ascribed to a group of gravity nappes. Geological survey, however, neither confirmed nor negated its existence. Therefore, a detailed analysis of aerial images was carried out on the scale of 1:35,000. Analytical interpretation led to the construction of a special morphotectonic and geodynamic scheme of the area, supported by the various geophysical data.

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Introduction

The complex analysis showed that during the Tertiary the southwestern part of the Nízke Tatry Mts. presumably had the character of a horst whose relative fast uplifts had been caused by active deformations within the fundament (Fig. 1). Complicated faults or fracture systems of great diversity were found, many of them of the strike-slip character. Also expressive dissection of the relief, the chaotic arrangement of levelled surfaces and numerous geodynamic features outline the intricate geological environment and complicated Late Alpine development of the whole structure.

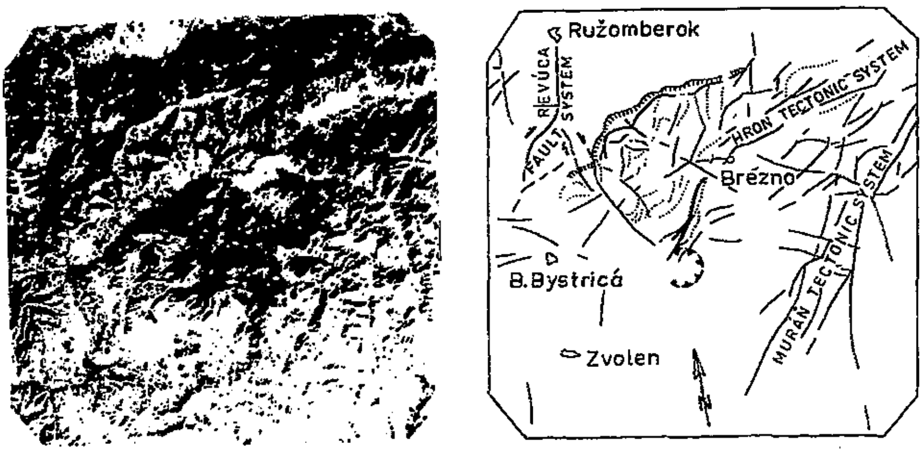
Methodology

In the interpretation of images we proceeded in the following methodological steps:
- evaluation of the tectonics of the area, with regard to orders of faults, fault zones, fracture zones, etc. and to the analysis of the drainage system,
- analysis of the morphological features, reflecting the peculiarities of the geotectonical development of the area (the relief forms, levelled surfaces, etc.),
- distinction of geodynamic processes and other geodynamic phenomena,
- re-evaluation of the previous and recent findings concerning the geological-tectonic development,
- evaluation of the latest geophysical and structural-geological data, correlation of data yielded by the individual research methods applied, and
- compilation of data, construction of maps and cross-sections.

The purpose of the chosen methodological process was to realize a complex analysis of the geological environment with emphasis on its properties and behaviour. Results of analytical processing of stereoscopic models, regional geological and geophysical surveys and other studies were synthetized into an organic set of information on the study area.

Analysis of morphological features

Geomorphological research in the area (Škvarček 1973, Škvarček pers. com., Košťálik 1971) showed the heterogenous nature of the relief leading to expressive difference in elevations of levelled surfaces in midmontaneous and river systems. The morphological analysis realized on the stereoscopical model confirmed this relief destruction into various individualized blocks and strips, their heights extraordinarily differentiated. As



1. Area of the southern slopes of the Nízke Tatry Mts. (part of the LANDSAT image and its interpretation).

it is indicated by contemporary investigations these are results of various, not yet strictly distinguished movements and of the selective exogenetic destruction of rocks. Neither the extensive gravity movement on the southern slopes of the Nízke Tatry Mts. can be excluded. This assumption is supported by the height differentiation of the midmontaneous levelled surfaces (in absolute values from 850 to 1,400 m a.s.l.) and of the river terrace system (100 to 300 m relatively above the Hron River valley). Due to the extreme morphological conditions it was possible only to range following groups of levelled surfaces:

1. less than 700 m a.s.l.,
2. 700 to 1,000 m a.s.l.,
3. 1,000 to 1,300 m a.s.l., and
4. more than 1,300 m a.s.l.

Analysis of fault and fracture systems of the rock mass

Three basic stages of the Alpine cycle are decisiv in the tectonic development of the Nízke Tatry Mts. (Andrusov 1958, Maheľ 1986).

1. Upper Permian to Middle Cretaceous (Paleo Alpine), closed by the folding of the central West Carpathians and by thrusting of the Mesozoic nappes in the Upper Cretaceous.
2. Lower Cretaceous to Miocene (Meso Alpine) closed by folding of the outer Flysch Belt and thrusting of flysch nappes in the Lower Miocene.
3. Lower Miocene (Badenian) to Quaternary (Late Alpine) – neotectonic, with volcanic activity, horizontal and vertical movements leading to the contemporary mosaic configuration of the West Carpathians to ridges and depressions. The movements have been taking place up to the present time and have manifested themselves by seismic activity (Pospíšil et al. 1985, Schenk et al. 1979).

The late Alpine movements resulted in the general uplift of the West Carpathians with expressive differentiation of movements of individual blocks along transcurrent faults, mainly of the NE-SW direction. This movement in the principal direction of horizontal stresses from the south resulted in the motion of the eastern part of the West Carpathians to the north and northeast.

Two areas with different uplifting-subsiding tendencies were distinguished in the study region:

1. The subsiding Hron River valley from the ENE to WSW following the post-Paleogene megasynclinal depression and the adjoining depressions. The Mesozoic folds have the character of subhorizontal thrusts making sharp angles with post-Paleogene faults causing the subsidence of the Hron River valley.

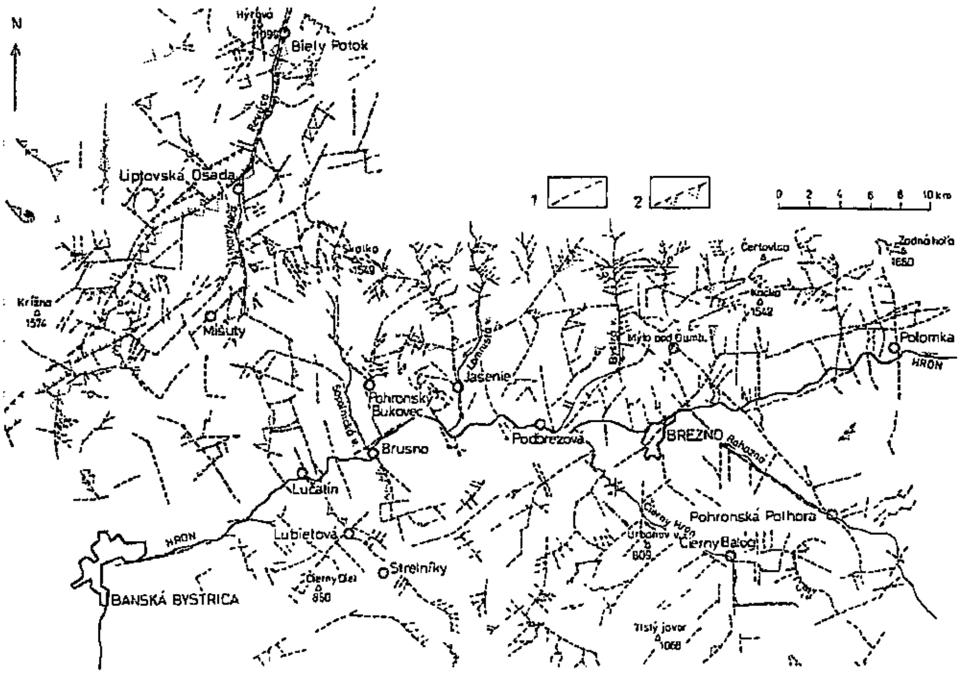
2. The elevation area of the Nízke Tatry and Veľká Fatra Mts. and the northern part of the Vepor Mts. with an uplifting tendency where the key role in forming the fracture tectonics was played by recent differential movements at the Late Alpine evolution stage.

It was impossible to find out on the satellite images which linear elements belong to older evolution stages and which to the Late Alpine development stage. According to the development and diversity of the geomorphological features it can be assumed that the majority of fault and structural-tectonic features are from the latest evolution stage or are results of several stages. For instance, the linear Hron River valley is presumably based on one ancient fault in partial segments documented by linear, steep and sporadically facetted slopes. The facets in valleys were taken as a criterion for interpretation of faults (e.g. numerous facets along the northern part of the Korytnice River valley indicating the Revúca fault line).

The fault and fracture zones are best characterized by the configuration of the drainage system. It can be assumed that the river follows the lines or zones of tectonic or lithological "weakening". In this way the principal directions of prevailingly linear tectonic zones, dislocations and shorter fault-fracture elements were distinguished (Fig. 2):

1. NE-SW, ENE-WSW systems (western branch of the Revúca fault zone, the Hron River valley and the system of lines in the east of the area). In this direction runs the Hron lineament (Pospíšil et al. 1986) interpreted as a transcurrent fault with a large dextral strike-slip.

2. NW-SE, NNW-SSE (the eastern branch of the Revúca fault zone and transverse faults between Lučatín and Brusno, in the East the Rohozná and Čierny Hron River fault).



2. Tectonic analysis of the southern slopes of the Nízké Tatry Mts. from aerial images. 1 – fault fractures, 2 – faceted slopes.

3. N-S faults forming important valleys in this direction on southern slopes of the Nízke Tatry Mts. as well as the northern part of Revúca fault system.

All the tectono-structural features are indicated by the forms of valleys, abrupt changes of drainage system, spring lines, erosional features, morphological structures, etc.

Analysis of geodynamic processes

Important secondary factors, demonstrating the dynamics of the geological environment, and of all exogenetic processes, are geodynamic phenomens.

The following factors were in the focus of the interest:

1. slope deformations (creep, slide and fall gravity deformations, taluses, block disintegration and block fields),
2. erosion elements (gully and sheet erosion, erosion edges),
3. surface karst phenomena (sinkholes, areal and linear surface karst elements),
4. forming of proluvia (young alluvial cones), and
5. weathering.

Slope deformations. The relatively new results of tectonics, engineering-geological and geophysical investigations show that numerous structures at the Earth's surface so far related to the dynamics and mechanism of tectonic (plicative and disjunctive) movements are actually connected with gravitational tectonics. In the Veľká Fatra Mts. such deformations are represented on top ridges in the vicinity of elevation points Zvolen Mt. (1,402 m a.s.l.), Chabenec Mt. (1,955 m a.s.l.), Krížna Mt. (1,574 m a.s.l.), etc. (Nemčok 1982).

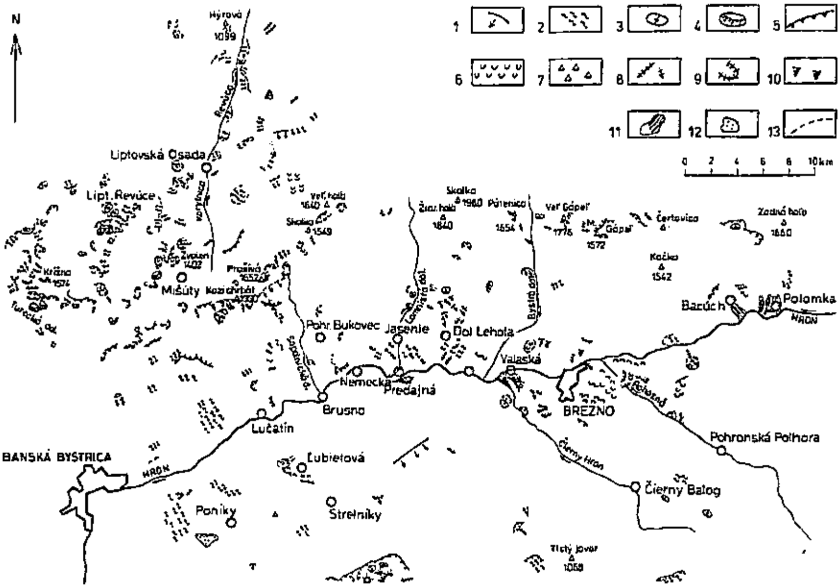
Along the mountain ridges they form a linear succession and may represent a boundary of the active root area of an extensive gravity deformation.

The slides could be well identified on the Veľká Fatra Mts. slopes (Turecká valley), on the Nízke Tatry Mts. slopes (S of the village Dolná Lehota, Prašivá Mts., Kozí chrbát Mt, etc.), but namely on the slopes of intramontanous basins, e.g. near Lubietová village (Fig. 3). Their direct connection with the significant tectonic Revúca zone cannot be excluded.

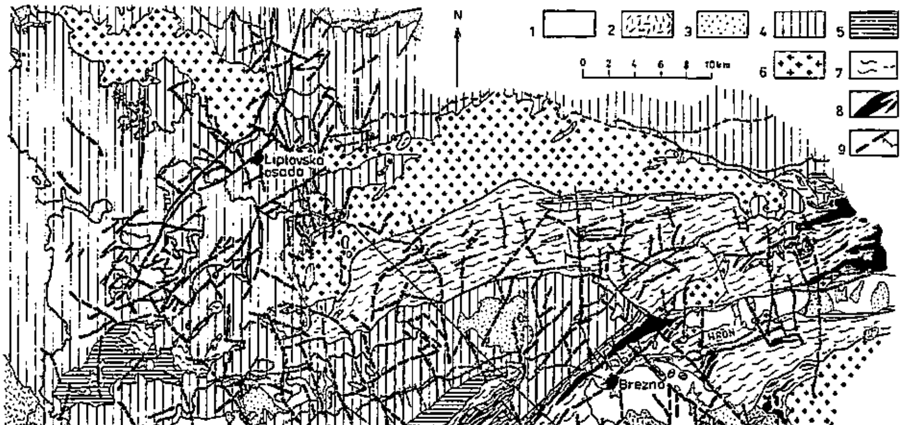
Erosion phenomena. Two types of erosion can by encountered in the area of interest: gully erosion and sheet erosion. Due to a large uplift of the mountain, an intensive drowncutting of water flows took place and created a variable erosion relief with various types of the water system. At the present time the size of the erosion downcutting and its extension depend on the gradual disintegration of the rocks and on climatic changes.

In places of tectonic or lithological weakening mainly on the steep slopes a considerable progress of back erosion can be observed (Fig. 3). Scours, deep ravines and gorges, and also flat closures of mountain valleys in the top parts of the ridges are formed. In the greater part of the area, back erosion has modelled the top parts into sharply-cut shapes and thus disintegrated ancient structural planes.

Karst phenomena. Karstification is scarce in the area of interest due to the relatively rare occurrence of soluble karst carbonate rocks. Its surface elements can be encountered only in the south-western part near the village Poníky and Nemecká where the sinkholes



3. Analysis of geodynamical phenomena. 1 – slope deformations generally, 2 – talus creep, 3 – block rifts, block fields, 4 – individual blocks, 5 – scarps, 6 – landslides, 7 – alluvial fan, 8 – gully erosion, 9 – erosion edge, 10 – sheet erosion, 11 – proluvial cones, 12 – sinkholes, 13 – karst valleys (after Varga - Lada 1988).



4. Geological scheme of main fault and fracture systems. 1 – neogene, 2 – neovolcanic products, 3 – Paleogene, 4 – Mesozoic complexes, 5 – Paleozoic and crystalline complexes, 6 – granitoids, 7 – metamorphites, 8 – amphibolites, 9 – known and interpreted faults.

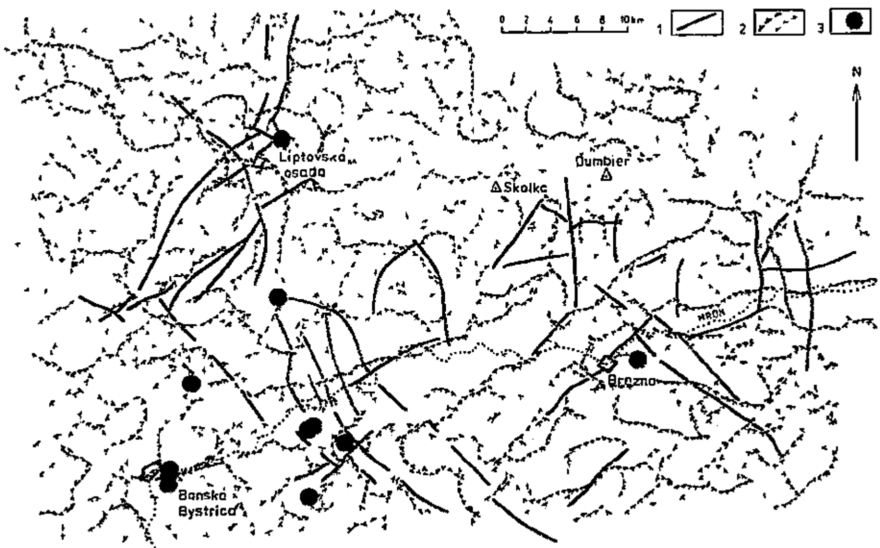
form small groups of greater or smaller depressions. Linear arrangement indicating occurrences and systems of tectonic lines cannot be observed (Fig. 3).

Other phenomena. Among the best identified phenomena belong proluvial cones. On images they are clearly visible by the tributaries of the Hron River.

The most intensive products of weathering in the diversified relief remodelled by erosion and denudation activity were transported away.

Correlation of remote sensing, regional geological and geophysical data

The position of fault zones, fault lines and other structural features manifested by means of remote sensing, corresponds to regional geological and geophysical data in the study area is in a good agreement. First of all, the stereoscopic interpretation of various images produces much more continuous picture (and complex results) than geological or other maps on different scales. Evidently, the interpretation criteria allow an identification of faults also in the places where they have not been the corfirmed by field mapping. All the identified faults are mostly wide zones of the highest inhomogenity rate in terms of secondary lithological changes, fragmentation or blockiness. They are all very expressive in the morphology. In this connection of greatest significance is the confirmation of extraordinarily manifested tectonic zone, corresponding partly to the Revúca fault system. First of all the interpreted branching into the two separate systems (Fig. 4) was of significance. One of them, N-S or NNE-SSW system, progresses along the Revúca River valley and indicates the continuation of important regional tectonic

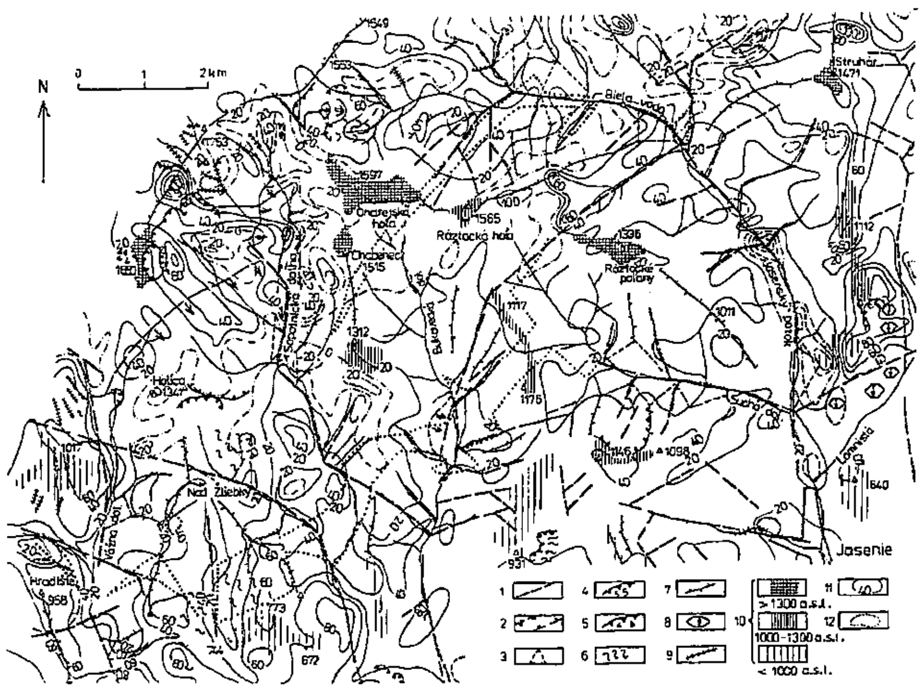


5. Map of vertical density boundaries and earthquake foci. 1 – interpreted fault, 2 – vertical density boundary, 3 – earthquake focus.

boundary – so called Považansko-Ihráčsky fault system. The second branch in the direction NNW-SSW could mark the indication of the west border of the Nízke Tatry Mts. gravity deformation. The analysis of satellite, aerial and radar images confirmed a great relief diversity, frequent changes in its morphological forms, development of gravity elements on slopes, etc. within the entire Revúca system.

The map of vertical density boundary (Fig. 5) was based on the gravity data which demonstrate the diversity and frequent tectonic delimination of structural blocks. the interpreted tectonic lines often coincide with density boundaries or with places of discrupted correlation. The loss of correlation can be observed along the entire lenght of the Revúca fault zone, Hron lineament etc. Geophysical data focussed our interest to the disruption of the NW-SE branch of the Revúca system. This not exactly limited wide zone is deformed there and along about 5 km it is bending to the WNW-ESE direction. It may be the crossing point of several tectonic faults with variable orientations.

The tectonic predisposition of the Hron River between Banská Bystrica and Brezno where two distinct NW-SE and NE-SW striking faults have been interpreted, can be supported by an intensive gravity gradient. Many of interpreted structural and tectonical boundaries, e.g. Mýto-Tisovec fault zone, Čertovica line have been confirmed by geoelectric, magnetometric and gravity data.

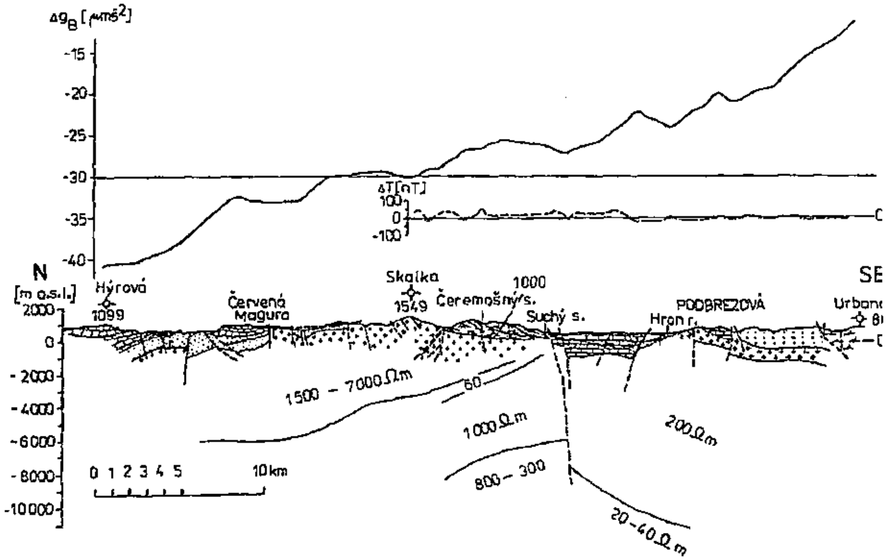


6. Relationship between the zone of the induced polarization anomalies and interpreted faults. 1 – faults and fractures, 2 – zones of interpreted faults, 3 – faces, 4 – creep deformations, 5 – alluvial fan, 6 – slope deformation generally, 7 – horsts, 8 – block rifts, block fields, 9 – erosion edges, 10 – midmountaneous leveled surfaces (850–1,400 m a.s.l.), 11 – magnetic anomaly (+40 nt), 12 – induced polarization anomaly.

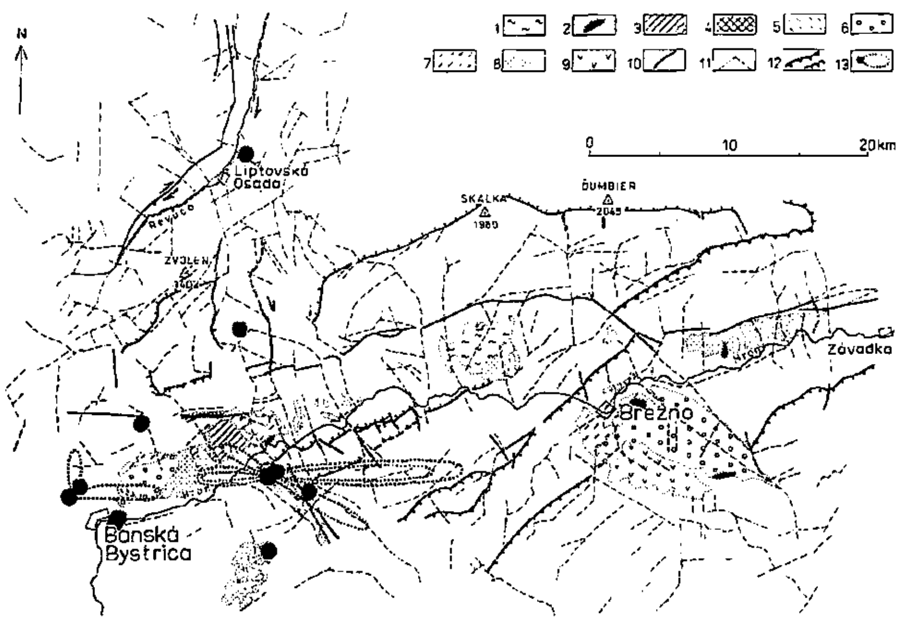
The broader surroundings of the south slopes in the middle-west part of the mountain has been the focus of investigations for ore prospecting. Geophysical measurements and aerial photographs yielded a detail picture of the tectonics of the area. Mapping of the so called "productive zone" showed equal values of resistivity and polarizability to those of the immediate surroundings of the existing deposit (Vybíral et al. 1986). The zone of the anomalous induced polarization values strikes from the NE to SW and it is evidently bounded by fault zones (Fig. 6). Tectonic lines interpreted on the images disturb this zone in form of shifts and disruptions so that it proves the particular interest from the viewpoint of tectonics, geological structure and mineralization in this area.

Obtained geophysical data from various methodological stages cannot be fully illustrated in the geological cross-sections, but only in a schematic section (Fig. 7). It is because of an unclarity in the geological interpretation of the Nízke Tatry Mts. structure itself. Moreover, new seismic and magnetoteluric data on transcarpathian profile 21 (Tomek et al. 1989; Varga - Lada 1988) provide a picture completely different from the one so far assumed. In that way the new proofs and criteria for verification of the so called "gravity nàppe" and the Hron lineament (Klinec et al. 1985, Pospíšil et al. 1986) do not exclude the influence of Late Alpine tectonics.

In geomagnetic data, the most expressive anomaly is the Mýto-Tisovec fault zone accompanied with Tertiary volcanites and the Revúca fault zone which probably served as the cahnnel way for volcanic products.



7. Geological cross section over the Nízke Tatry Mts. with results of geophysical investigations. Δg_B – gravity curve, ΔT – magnetic anomalies curve, resistivity values interpreted from the magnetotelluric curves.



8. Dynamics of the Revúca fault system. 1 – the Vajsková conglomerates, 2 – sediments of mottled series (pre-Lutetian), 3 – dolomitic conglomerate facies, 4 – sediments of the Podkonice series, 5 – sandstone - conglomerate facies, 6 – claystone lithofacies, 7 – regressive facies of Oligocene, 8 – gravel (Pliocene), 9 – neovolcanics, 10 – known faults, 11 – interpreted faults and fractures, 12 – overthrusts, 13 – earthquake epicenters.

Seismotectonics of the area

The data on the occurrence of strong earthquakes (Brouček 1987; Procházková - Kárník 1978; Schenková - Kárník 1988) in Central Slovakia (Fig. 8) mostly come from an earlier period so that the positions of some shock epicentres around the Revúca fault system might be inaccurate. Nevertheless, it can be shown that except for the earthquakes confined to the Verona-Semmering-Váh lineament in the West Carpathians (Schenk et al. 1985; Buday et al: 1986), great part of the earthquakes in Central Slovakia are confined to the surroundings of the Hron and Revúca fault systems.

The earthquakes originating in Central Slovakia are bound to the area of broader surroundings of the town Banská Bystrica. To a certain extent, their occurrence can be correlated with the region of the intersection of the Revúca fault system and the Hron tectonic zone. The most interesting, and in fact unclarified, is the strong shock of June 5, 1443 (8°–9°MSK), which caused serious damage in a large area. In contemporary writings a shock felt in Hungary, Moravia, Poland, Bohemia and in Austria is mentioned. From the fragmentary information available, its position cannot be determined with sufficient accuracy, however: its location was most probably in the broader neighbourhood of Banská Bystrica (Kárník et al. 1948). The depth of this earthquake is estimated at 25 km. Its origin could be bound to the Hron tectonic zone, for even some other earthquakes (1855, 1862) of an intensity of 6°–6.5° MSK are found in this zone between Banská Bystrica and Ľubietová. The focal depths of the earthquakes of this region vary within a range of 4–12 km.

The earthquake occurrences (Figs. 5, 8) can be associated with the weakened places of the Hron and Myjava-subTatra tectonic zones, among which the Revúca fault system passes or rather parallel zone lying 20–30 km west of the Revúca zone.

Even though we know 18 earthquake shocks in the area under investigation, the paucity of direct recordings did not allow us to determine the fault plane solution for any of them.The latest earthquakes, from June and November 1989, have not been processed yet. Nevertheless, the available seismological material enabled us to determine the directions of decreased seismic energy (Fig. 8, Schenk et al. 1989). We made use of the isoseismal maps known for some of the mentioned shocks, all of them being in the south part of the area investigated. The radius differences of the isoseismals characterize a different degree of seismic energy attenuation with distance; positive values correspond to the direction of lower attenuation, i.e. to the direction of the structure-tectonic elements. The performed analysis shows that in the valley of the Hron river, EW or actually ENE-WSW directions prevail. Their coincidence with the hron tectonic zone direction is very good (Pospíšil et al. 1986).

In addition to the data on earthquake occurrence, we utilized the results of gravity and magnetic measurements of this area (Obernauer 1980) and the correlations of seismological data with the course of photolineations determined from satellite images (Pospíšil et al. 1985). It appears that contrary to the previous interpretations, we can include into the dextral transcurrent system evan its broader surroundings, i.e. even the tectonic zone that bounds the crystalline basement of the Veľká Fatra Mts. in the east side. According to gravity data, the zone continues to the southwest as far as the western margin of "the Staré Hory tectonic window" (Andrusov 1965). All the interpreted disturbances are manifest in the gravity field by sharp gradients, which segment them into a series of narrow elongated positive zones corresponding to incised mesozoic carbonate complexes (young grabens).

It is understandable that an analysis of the fault movement activity cannot account for the entire time-and-space development of the study area. The character of faults, hawever, suggests the probable force conditions that must have existed in a given area under the origin of the boundary system. A paleogeographic analysis of the Tertiary development of the area revealed an uplift tendency of the Low Tatra region with respect to its surroundings until the Pliocene period (Klinec et al. 1985). The cyclic character (pulsations) of the uplift seams to have had a rapid course in the last period, which was apparently evoked by the horizontal movements of the Carpathian blocks along the faults of NE-WS and ENE-WSW direction (Janků et al. 1984; Pospíšil et al. 1985, 1989). Those faults are buried and seated under Tertiary sediments in the crystalline basement. On the surface, only fragments of these faults can be seen (e.g. Strážovské vrchy Mts., the Vysoké Tatry, Vepor part of Slovenské Rudohorie Mts., Vienna basin etc.). The Revúca fault system, which has a dextral character of movement, connects Hron and Myjava-subTatra tectonic systems of a higher order and can thus be regarded as a second order system of wrench faults.

The configuration of the faults of Revúca disturbance system indicates that the origin of the 2nd-order faults must have been sided by a tectonic predisposition of the area that increased the depth reach of these boundaries. This is also evidenced by the rise of intermedial magmas along these faults to the surface (volcano Poľana). The liveness of these faults is also confirmed by the present knowledge of the earthquake occurrence in the area under study. Present earthquake activity is known from the Revúca reiver valley and its south continuation.

Conclusions

The purpose of contemporary studies on the southern and southwestern slopes of the Nízke Tatry Mts. and Veľká Fatra Mts. was to verify the important tectonic boundaries and deformation structures interpreted on satellite images.

The interpretation results of serial photographs and radar images were included in analytical maps of tectonic, geodynamic and morphostructural features on the scale of 1:50,000. This analysis showed their great heterogeneity rate in the area of interest. The relief diversity is most probably due to the movements of Late Alpine active blocks, but the theory of a large gravity deformation can by no means be excluded. The geodynamic phenomena analysis and their relation to the tectonic features confirmes the intensivedestruction of the "gravity nappe" area. Beside these conclusions also the continuity of the Revúca fault system, its branching, further the Mýto-Tisovec tectonic zone and the proof of the existence of the so called Hron lineament was of great significance.

Despite the analyzed data we cannot draw the final decisive conclusion of the development and destruction of the south slopes of the mountain. The explanation of that problem is closely connected with an analysis of the development of the broader area and with more detail analytical and complex data.

K tisku doporučil O. Fusán
Přeložil L. Pospíšil

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Geodynamická analýza Nízkych Tatier na základe DPZ a geofyziky

(Résumé anglického textu)

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Pohorie Nízkych Tatier patrí z hľadiska vývoja Centrálnych Západných Karpát ku kľúčovým územiam. Na základe štúdia kozmických snímok bola na južných svahoch Nízkych Tatier interpretovaná rozsiahla deformácia zatriedená do skupiny gravitačných príkrovov. Ďalšie výskumy však jej existenciu plne nepotvrdili. Preto sa prikročilo k podrobnej analýze leteckých snímok v mierke 1:35 000, predovšetkým s dôrazom na štruktúrno-tektonické, morfologické a geodynamické fenomény tohto hypotetického modelu, doplnenej o interpretáciu výsledkov geofyzikálneho prieskumu.

Komplexná analýza územia ukázala, že počas terciéru mala jz. strana Nízkych Tatier pravdepodobne povahu hráste, ktorej zdvihy boli podmieňované aktívnymi poruchami vo fundamente. Boli zistené komplikované a rádovo veľmi rôznorodé zlomové poruchy, zlomy alebo puklinové systémy, z ktorých mali mnohé charakter horizontálnych posunov. Rovnako aj mimoriadna disekcia reliéfu, chaotické usporiadanie úrovní zarovnávania a množstvo geodynamických javov načrtáva značnú komplikovanosť stavu geologického prostredia a neotektonického vývoja celej štruktúry.

Relatívne rýchly výzdvih pohoria dokázaný paleogeografickou analýzou bol pravdepodobne spôsobený pravostrannými pohybmi karpatských blokov pozdĺž zlomov I. rádu smeru VSV-ZJZ. Revúcky zlomový systém, ktorý vykazuje tiež pravostranný pohyb, je aktívny od hlavných fáz alpínskeho vrásnenia až podnes. Tento systém zlomov II. rádu (smer S-J) je považovaný za najdôležitejšie rozhranie pre vznik študovanej gravitačnej deformácie.

Ako ukazujú doterajšie výsledky diaľkového prieskumu a geologicko-geofyzikálneho výskumu, možno predpokladať úzku súvislosť medzi výskytom ložísk rúd (W, Au, Sb) a uvedenými hlboko zasahujúcimi tektonickými poruchami.

V nemenšej miere získané poznatky možno uplatniť tiež pri inžiniersko-geologickom hodnotení základných zložiek geologického prostredia a riešení seizmotektonických problémov.

Vysvetlivky k obrázkom

1. Južné svahy Nízkych Tatier (výrez zo snímku LANDSAT a interpretácia).
2. Tektonická analýza j. svahov Nízkych Tatier podľa družicových snímkov. 1 – zlomová štruktúra, 2 – facetový svah.
3. Analýza geodynamických javov. 1 – sklonové deformácie, 2 – osypový tok, 3 – blokové rifty, 4– individuálne bloky, 5 – príkre srázy, 6 – zosuvy, 7 – aluviálne kužele, 8 – erózna rokľa, 9 – erózna hranica, 10 – plošná erózia, 11 – proluviálny kužel, 12 – krasové javy (Varga - Lada 1988).
4. Schéma hlavných zlomových systémov. 1 – neogén, 2 – neovulkanity, 3 – paleogén, 4 – mezozoický

komplex, 5 – komplexy paleozoika a kryštalinika, 6 – granitoid, 7 – metamorfity, 8 – amfibolity, 9 – známe a interpretované zlomy.

5. Mapa vertikálnych hustotných rozhraní a zemetrasných ohnísk. 1 – interpretovaný zlom, 2 – vertikálne hustotné rozhranie, 3 – ohnísko zemetrasenia.

6. Vzťah medzi zónou anomálie vyzvanej polarizácie a interpretovanou tektonikou. 1 – zlomy, 2 – interpretované zlomy, 3 – svahy, 4 – suťové deformácie, 5 – aluviálne kužele, 6 – svahové deformácie, 7 – hráste, 8 – rifty a bloky, 9 – erózna hranica, 10 – medzihorie vo výške 850–1400 m n.m., 11 – magnetická anomália (+ 40 nT), 12 – anomália IP.

7. Geologický rez Nízkych Tatier a geofyzikálna data. Δg_B – Bouguerova tiažová anomália, ΔT – anomália totálneho vektoru geomagnetického poľa, odporové krívky z magnetotelurických meraní.

8. Dynamika revúckeho zlomového systému. 1 – konglomeráty Vajskovej, 2 – pestrá séria (pre–lutenian), 3 – fácia dolomitických konglomerátov, 4 – sedimentárna séria Podkonice, 5 – fácia piesčitých konglomerátov, 6 – ílovcová litofácia, 7 – transgresívny oligocén, 8 – pliocénny štrk, 9 – neovulkanity, 10 – zlomy, 11 – interpretované zlomy, 12 – príkrovy, 13 – ohnísko zemetrasenia.