Acta Geodyn. Geomater.Vol.1, No.3 (135), 97-109, 2004

GRAVITATIONAL SPREADING OF THE ELEVATED MOUNTAIN RIDGES IN THE MORAVIAN-SILESIAN BESKIDS

Oldřich KREJČÍ [1] *, František HUBATKA [2] and Jan ŠVANCARA [3]

[1] *Czech Geological Survey, Branch Brno, Leitnerova 22, 658 69, Brno, Czech Republic, 420543263, FAX 543212370*
[2] *KOLEJCONSULT& servis, spol. s r. o., Křenová 131/35, 602 00, Brno, 420543254286*
[3] *Institute of Physics of the Earth, Faculty of Science, Masaryk University, Tvrdého 12, 602 00, Brno, Czech Republic, Phone 420543423118, FAX 420543245927*
**Corresponding author's e-mail:* okrejci@cgu.cz

(*Received* February2004*, accepted* May 2004)

ABSTRACT
According to geomorphologic, seismic and gravimetric analyses carried out in the area between Frenštát pod Radhoštěm and Vsetín, today, the mountain regions of Kněhyně and their wider neighbourhood are not in balance with the platform basement and the processes of erosion. This is caused by the fact that, due to the accumulation of light masses of Lower Miocene rocks of the Carpathian Foredeep in footwall of the Godula nappe and frontal parts of the Magura nappe, mountain peaks arrived to higher altitudes than one would expect from simple overthrusting of the Silesian and Subsilesian units over the underlying foreland. Consequently, the whole mountain massifs experience gravitational spreading and break-up, which is well documented by development of deep and widespread deformations – predomininantly by pseudokarst phenomena. Concept of gravitational break-up of whole mountain complexes by mechanism of gravitational spreading is presented. The mechanism of gravitational spreading may in specific instances generate gravitational nappes but, for the most part, it is effective on continental slopes of the present-day oceans. More recently, however, the gravitational spreading is often considered in explanations of extension of mountain regions during final stages of orogenic cycles when the tectonic uplift exceeds topographic reduction due to denudation and erosion, which is the case of the Western Carpathians flysch.

KEYWORDS: Carpathians, Beskids, flysch, geomorphology, gravity, pseudokarst

1. INTRODUCTION

Silesian unit forms a dominant structure within the nappe system of the Outer Western Carpathians. This unit, which is highly differentiated in terms of facies distribution, is exposed mainly in the Moravian-Silesian Beskids. In the N, it is thrusted over the Subsilesian unit and Miocene deposits of the Carpathian Foredeep whereas in SE it dips under nappes of the Magura flysch. Different erosional-denudational properties of the unit are markedly reflected in the morphology of the Moravian-Silesian Beskids and their foothills. Major mountain massifs are composed mainly of Upper Cretaceous sandstone complexes whereas morphological depressions are composed of units with higher representation of mudstones of Upper Cretaceous and Palaeogene age.

2. GEOLOGICAL SETTING

The Silesian unit represents one of the most vivid examples of flysch basins in the Outer Western Carpathians. Sedimentation in a relatively long time interval from the Malmian (Oxfordian) to the late Oligocene can be traced in this unit. Deposits of the Silesian unit are well differentiated both vertically and horizontally, offering good examples of possible facies relationships within a flysch basin.

The Silesian unit is a block nappe, which is thrusted on top of the Subsilesian nappe and the autochthonous foreland. The nappes were folded and thrusted far on the platform foreland during the lower to middle Miocene phases of the Alpine orogeny. The original area of deposition of the units is well known and, as indicated by the presence of blocks of Devonian limestones and Carboniferous coal-bearing sediments in conglomerate sections, it was underlain by crystalline rocks of the Brunovistulicum and its sedimentary cover. Horizontal distance of overthrusting is estimated to be more than 50 km.

The Godula partial nappe is represented mainly by lithostratigraphic units of Upper Cretaceous age – the Godula and Istebňa Formations. Thickness of the core part of the nappe with the formations slightly interfolded is up to 3 km, which is documented by Staré Hamry-1 borehole (more than 2705 m, Roth 1969). This compact part of the nappe is underlain by Lower Cretaceous sediments – Těšín-Hradiště, Veřovice and Lhotka Formations. Overlying units represented by the Sub-Menilite, Menilite and Krosno Formations are preserved only in a marginal fringe of the core nappe. Evidence from seismic profiling indicates that the Silesian nappe is rootless and it quickly wedges out over a small distance from the Magura nappe.

The amount of internal shortening of the Silesian unit calculated by Němčok and others (1998) is 10.3 km (47%), which gives 11.7 km from the total width of 22 km. However, in case of the Silesian nappe the covering partial nappes with different trajectory of movement became detached due to different rheologies of the body of the Godula nappe and the underlying and overlying units. The Upper Jurassic and Lower Cretaceous members with higher proportion of mudstones and rhythmical, fine-grained flysch successions were disintegrated forming tectonic breccias that, together with the Subsilesian nappe, acted as a lubricant for the Godula nappe core. Today, huge rigid bodies of the Godula nappe core constituting the Kněhyně, Lysá hora and several other massifs separated by erosion rest on these unstable sediments. Upper parts of the Palaeocene to Oligocene sediments were detached during the transport and remained buried under the Magura thrust, where they generate gravity minima.

According to our own geomorphologic, seismic and gravimetric analyses carried out in the area between Frenštát pod Radhoštěm and Vsetín, today, the mountain regions of Kněhyně and their wider neighbourhood are not in balance with the platform basement and the processes of erosion. This is caused by the fact that, due to the accumulation of light masses of Lower Miocene rocks of the Carpathian Foredeep in footwall of the Godula nappe and frontal parts of the Magura nappe, mountain peaks arrived to higher altitudes than one would expect from simple overthrusting of the Silesian and Subsilesian units over the underlying foreland (see cross-section in Fig. 3). Consequently, the whole mountain massifs experience gravitational spreading and break-up, which is well documented by development of deep and widespread deformations. According to Wagner and others (1990), the accessible depth of the Kněhyně abyss is 57.5 m (Fig. 5) and demonstrable depths of several open fissures are more than 100 m. A similar situation can be seen on top of the mount Lysá hora, where the fissures, completely filled with detritus, were exposed during construction of television transceiver (see e.g. unpublished report by Novosad et al. 1984, Fig. 6)

Němčok et al. (1998) addressed the issues of erosion of the mountain peak regions estimating the erosion to be 1 to 2 km. Since sediments younger than the Istebna Formation are absent in the peak parts of mount Kněhyně and mount Lysá hora, we believe this estimate to be correct, although tectonic erosion during the material displacement within duplex nappe slices might also have been partly involved (it can be assumed that this area has been partially overlapped by the frontal part of the Magura nappe. Despite the estimated loss of material, the denudation processes and degradation are not sufficient and balanced, resulting in gravitational break-up of whole mountain massifs.

3. GEOPHYSICAL DATA PROCESSING

A gravimetric and a derived gravity map of the wider area of Rožnov pod Radhoštěm have been compiled in order to analyse the geology of the Silesian nappe, and reflection seismic profiles 221/77, 221A/80, 221B/79 and 221C/80 have been used to refine the interpretations.

Data from detailed gravimetric mapping 1:25 000 with density of 4 to 5 gravimetric points per square km were used as input information for compilation of the gravimetric and derived gravimetric maps. Total Bouguer anomalies were calculated according to the new definition of gravimetric anomaly in the Czech Republic (Švancara 1995). In this definition of Bouguer anomaly the normal gravimetric field is calculated according to the parameters of WGS-84 system of references, utilizing the S-Gr95 gravimetric system. Field topography correction up to the distance of 166.7 km and the Bullard term were included in all gravimetric measurements. Values of gravimetric anomalies are given in mGal units, where 1mGal = 10 $\mu m/s^2$.

The gravimetric maps were calculated for 2550 kg/m^3 reduction density, which approximates the values of natural density of the Magura flysch. Values of total Bouguer anomalies were interpolated into 250m x 250m rectangular grid in the S-42 co-ordinate system, using the minimum curvature method. A colour map of Bouguer gravity anomalies at 1:100 000 scale with 1mGal contour interval is shown in Fig. 1. Included in the map, there are the lines of reflection seismic profiles and the borehole locations. The residual gravity field (see Fig. 2) in this area delimits an extensive gravity minimum at the midpoint of a line connecting the towns of Rožnov pod Radhoštěm and Valašská Bystřice. This gravity minimum is intersected by the seismic profile 220/79, which shows enlarged thickness of low density Karpatian sediments beneath the front of the Magura thrust. Another pronounced negative anomaly is situated 6 km NE of Kněhyně near Ostravice. In the residual gravity map there is an indication of interconnection between these two negative anomalies near the top of Kněhyně. Interpretation of the joint seismic profile 221 reveals beneath Kněhyně more than 1000 m of Karpatian sediments – Fig. 3.

4. GEOLOGICAL CONDITIONS IN THE KNĚHYNĚ – ČERTŮV MLÝN AREA, DESCRIPTION OF GEODYNAMIC PHENOMENA (PSEUDOKARST, LANDSLIDE-PRONE AREAS)

Middle parts of the Godula Formation with thickly rhythmical flysch and thick-bedded glauconitic sandstones are exposed in landslide-prone areas on the hill slopes of Kněhyně and Čertův mlýn Mts. (Figs. 4, 5). Individual layers reach thickness of several metres. Sedimentary bed contacts between individual turbidite rhythms are visible in the

Kněhyně abyss. Bed strikes and dips in the Kněhyně abyss vary from 216/20º and 270/10º near the entrance to 49/10º in the "Dóm objevitelů" (Hall of discoverers). Variations in bed strikes and dips are caused by tilting of huge blocks of sandstone layers, whose original dip was relatively very low – 20º or less. Field survey has revealed variations in bed dips on regional scale, due to the tendency of sandstone layers with low dip values to align conformably with the slope as a consequence of mass movements.

A feature which is totally predominant in the central area of the Godula nappe is represented by fault systems. Major faults revealed from geological mapping have N-S, E-W and SW-NE directions. All of the fault systems intersect in the apical area of the mount Čertův mlýn. Fissures of the N-S fault system on the top of the mount Čertův mlýn, widened by erosion, form a several-metres deep morphological depression with presence of pseudokarst features. A root edge of a bulky sheet slide extended for many hundred metres down to the valley was found at about 100 m distance SW from axis of a ridge outspreading from the top of the mount Čertův mlýn towards SSE.

Also the Kněhyně cave was formed on intersection of tectonic lines. Predominant system is represented by vertical, E-W (280-110º) trending fissures, on which also the "Dóm objevitelů" (Hall of discoverers) has been formed. Of the same direction is also a pronounced field depression or even gorge located uphill from the cave entrance, where a huge block of bedrock was tilted along a tectonic line providing a precondition for development of an abyss-cave system. Directions of another significant system of joints are 105/80º and 296/85º, i.e. approximately N – S. In concurrence with rockfalls and settling of rock blocks, this joint system combined with the E-W directions played a significant role in shaping of the Kněhyně abyss. Directions of additional joint systems found in the cave labyrinth are 48/85º (entrance fissure), 8-188/90º and 95-275/90º, which correspond to directions of the main systems.

To sum up, this abyss developed on intersection of joint systems, which belong to important regional systems of faults. Exogenous processes of settling and sagging of sandstone blocks and flushes of rainwater and waters from snow melting resulted in continuous expansion and deepening of the cave areas. The exogenous processes continue to shape the cave system up to the present day.

Similar situation was found on the highest mountain peak of the Moravian-Silesian Beskids, again composed of the Godula nappe – the mount Lysá hora. A geotechnical and geological investigation within the framework of television transceiver construction was carried out here in the first half of 70s. A dense network of open fissures filled with debris and clays was discovered after removal of stony and clayey talus sediments. The appropriate documentation was prepared by Novosad (1984). He presented a simple geotechnical model assuming that the whole mountain massif was disintegrating along slide planes extending down to the base of the Silesian nappe.

5. CONCLUSIONS

We have compiled gravimetric maps and derived gravimetric maps of the broader vicinity of Rožnov pod Radhoštěm that allowed us to refine the interpretation of reflection seismic profiles 221/77, 221A/80, 221B/79 and 221C/80. Results from the wave image analysis suggest that the lower formations of the Silesian unit together with the autochthonous Karpatian sediments have been overthrusted by the Magura unit. On the contrary, upper complexes of the Silesian unit form a minor, bowl-shaped depression in front of the Magura thrust. The enlarged thickness of lower density masses of outer flysch thrusts and/or autochthonous Karpatian sediments is manifested by residual gravity disturbances minima. The underthrusted lower density masses of Miocene age, off-scraped from the ramp of Palaeozoic sediments, produced a higher topography of the Silesian nappe than one would expect from its simple stratigraphic thickness including tectonic repetition.

The above-mentioned opinions are in accordance with our concept of gravitational break-up of whole mountain complexes by mechanism of gravitational spreading. The mechanism of gravitational spreading may in specific instances generate gravitational nappes (Merle 1998) but, for the most part, it is effective on continental slopes of the present-day oceans. More recently, however, the gravitational spreading is often considered in explanations of extension of mountain regions during final stages of orogenic cycles when the tectonic uplift exceeds topographic reduction due to denudation and erosion, which is the case of the Western Carpathians flysch. A typical present-day example of extensional break-up of main elevation ridge of an orogene is represented by the Apennines. In this mountain range, frequent transtensional, fault-bounded valleys are produced, which are rapidly deepened by erosion (Moores and Fairbridge, eds., 1997). Correctness of our hypothesis is evidenced by measurements of residual shear stress at the base of the Silesian nappe, which indicate directions from SE despite the fact that the thrusting ended already in the Badenian. This residual stress caused destruction of a newly-constructed shaft of the Frenštát pod Radhoštěm coal mine (Dopita et al., 1997).

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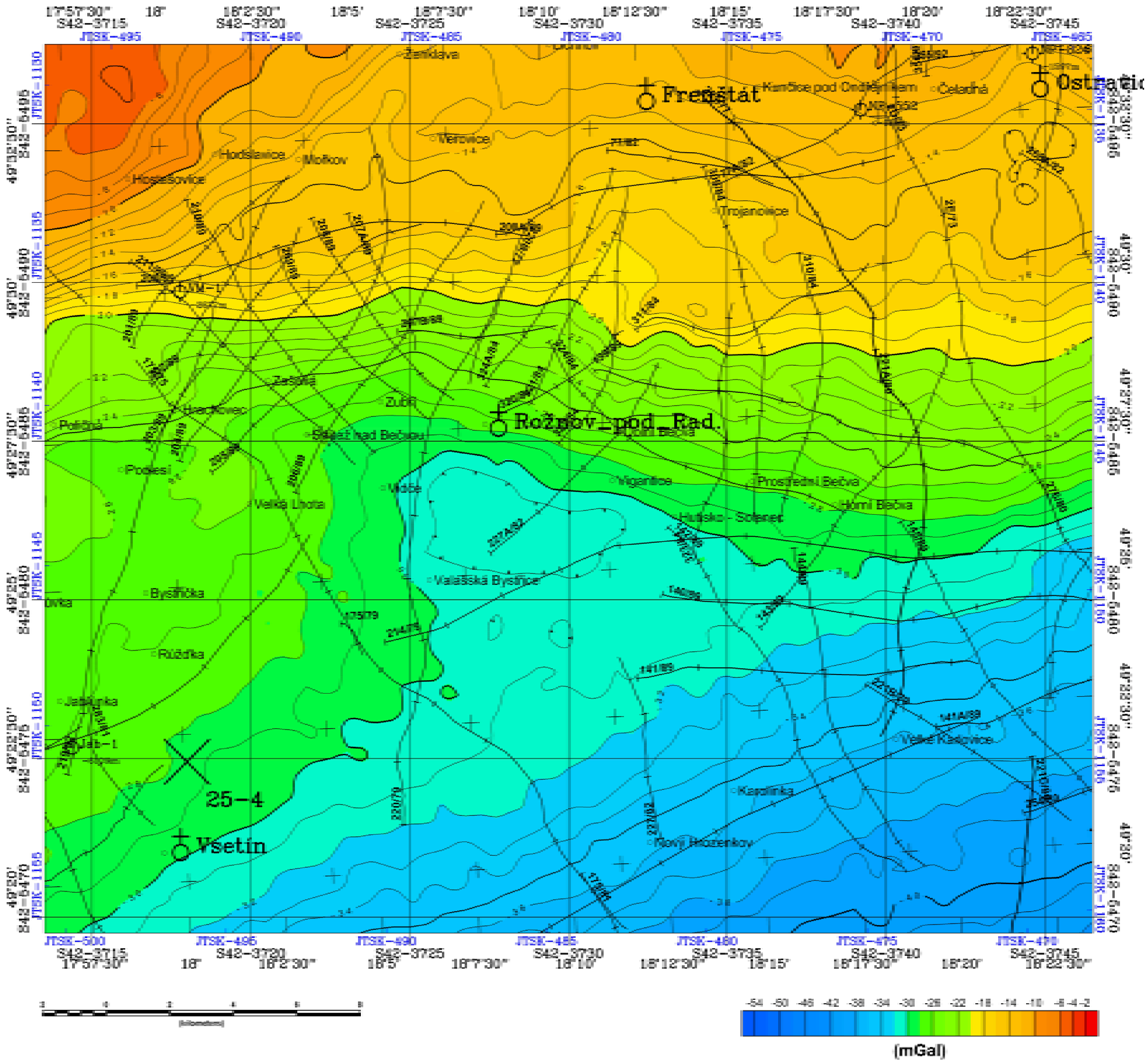

Fig. 1 Bouguer anomaly contour map. The contour interval is 2 mGal = 20 μm/s^2. Gravity anomalies were computed for the density of 2550 kg/m^3 for the Bouguer reduction. Gravity system S-Gr95. Black lines show the positions of seismic profiles. Black circles mark positions of selected boreholes.

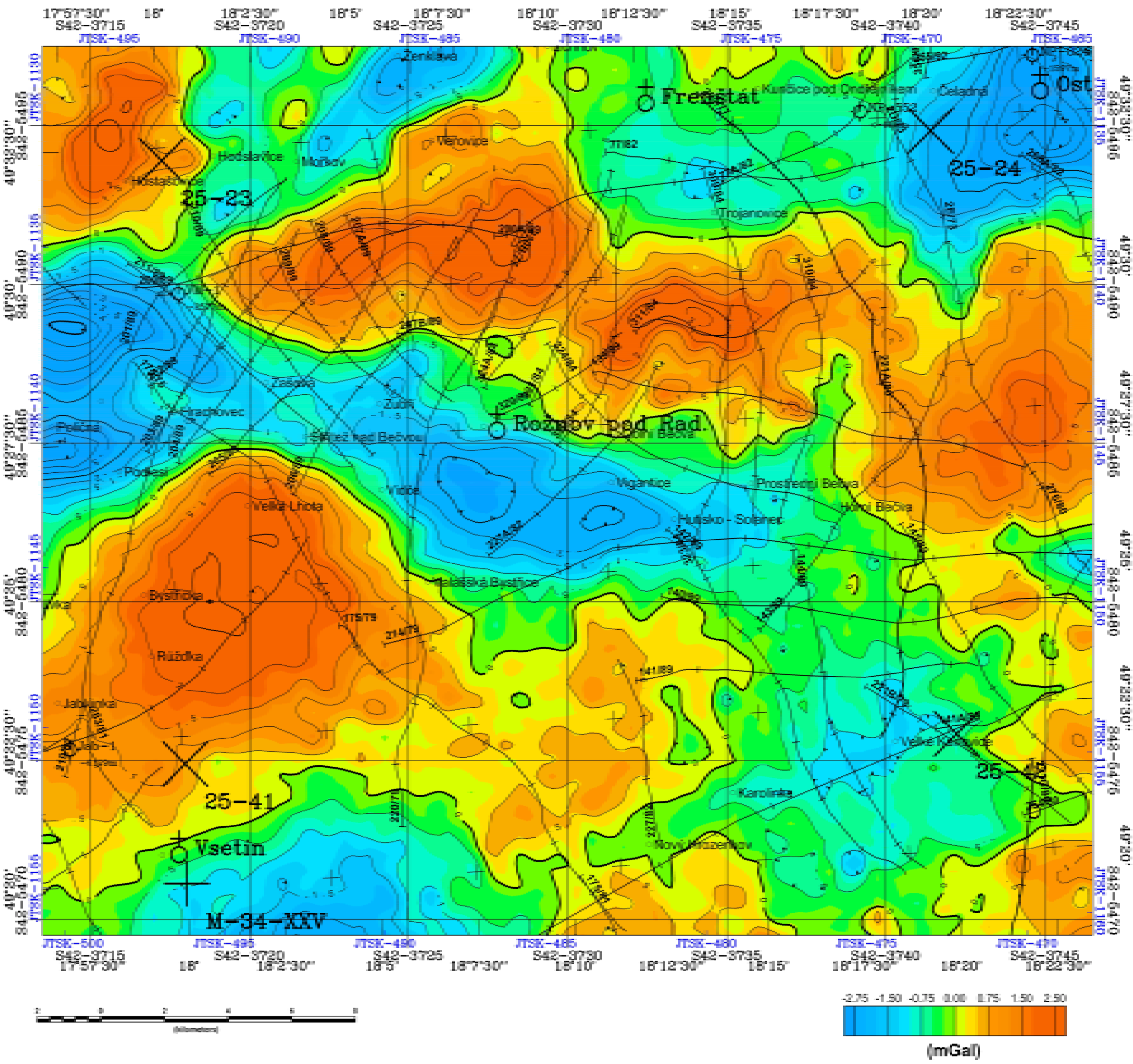

Fig. 2 Residual gravity contour map. The contour interval is 0,5 mGal = 5 μm/s^2. High-pass Butterworth filter for the wavelength cut-off 20 km was applied in gravity anomalies computed using for the density of 2550 kg/m^3 for the Bouguer reduction. Black lines show the positions of seismic profiles. Black circles mark positions of selected boreholes.

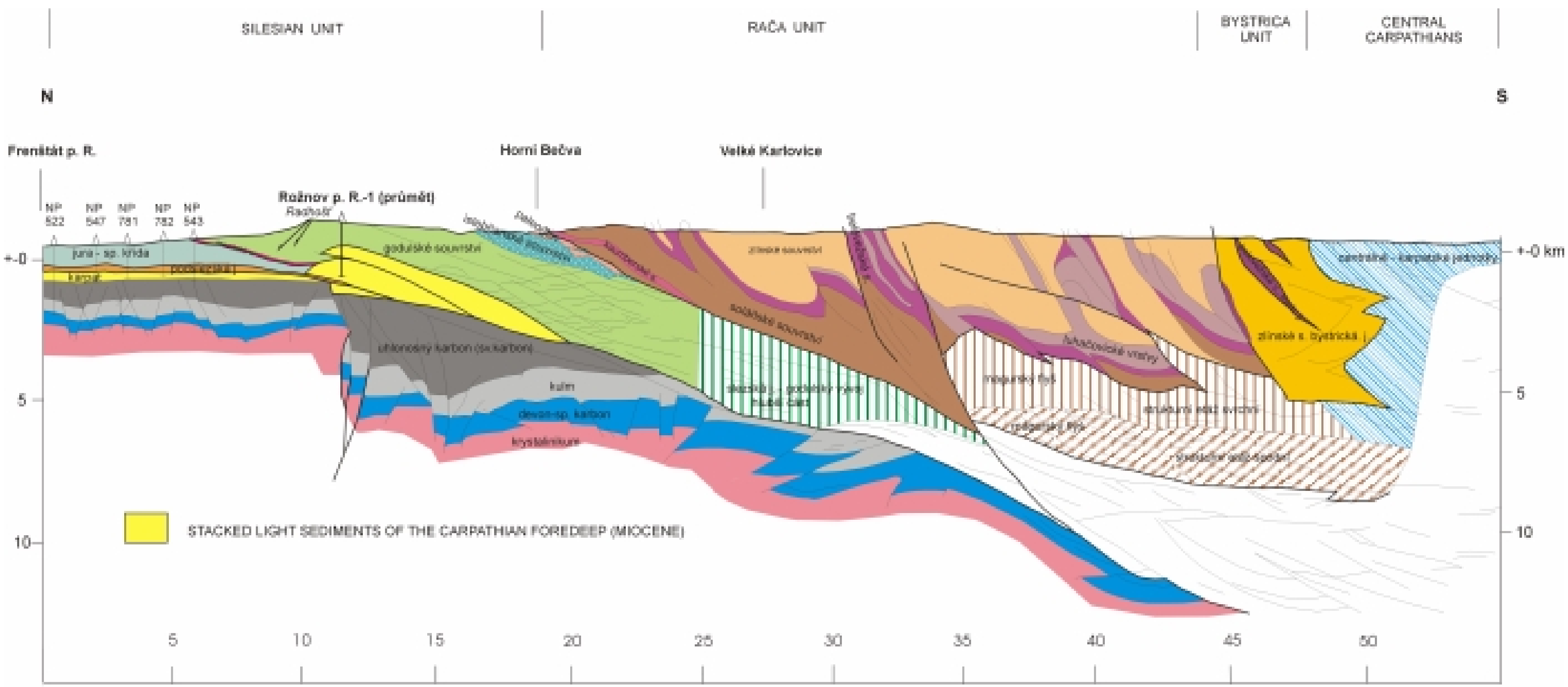

Fig. 3 Geological cross-section along the seismic profiles 221ABC/77-80 with marked Miocene sediments. Modified after Menčík (1983).

Fig. 4 Block desintegration and weathering of sandstones in the Čertův mlýn pseudokarst area.

Fig. 5 Entrance to Kněhyně cave system through the open fissure.

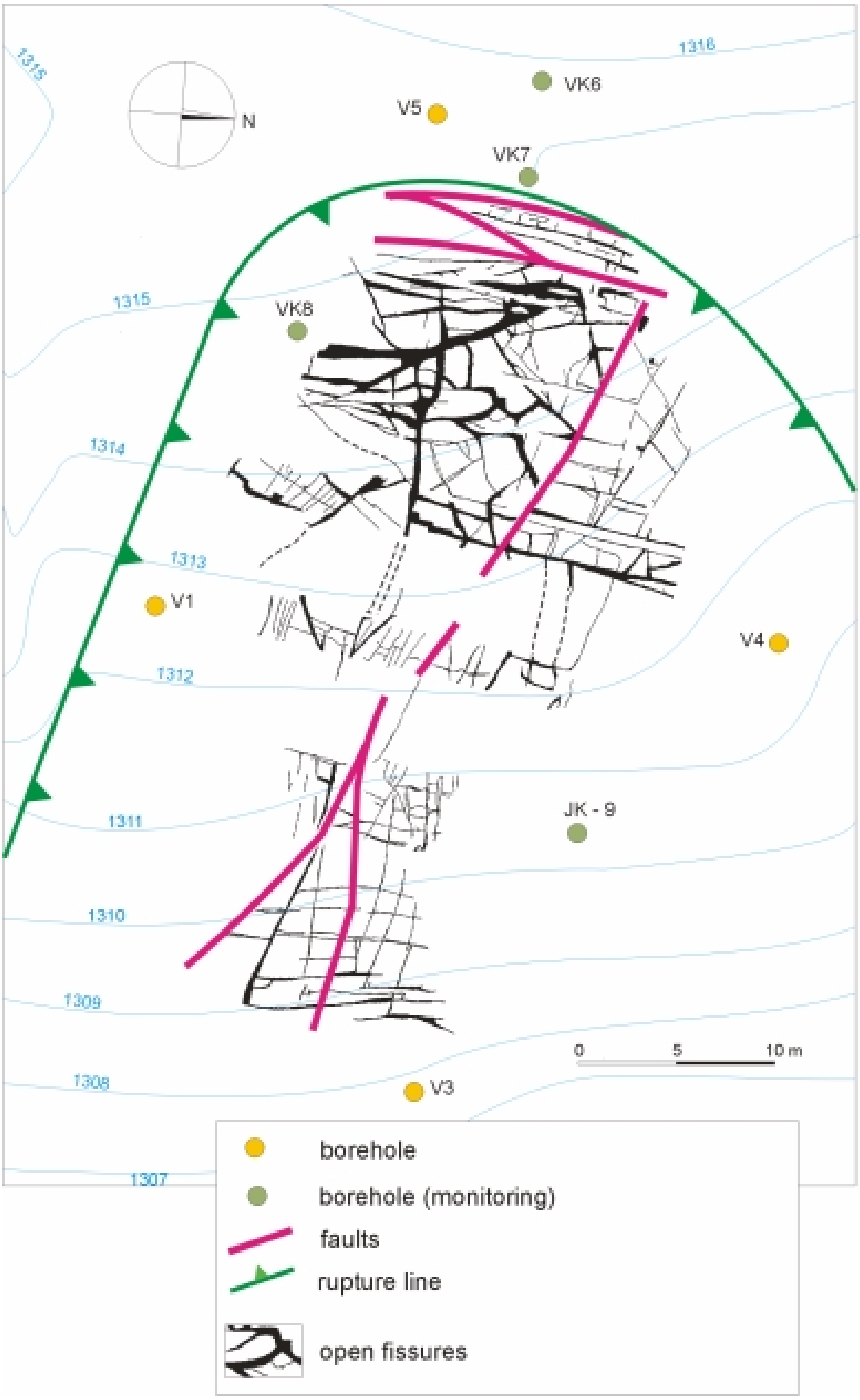

Fig. 6 Detail of scarp area on the top of Lysá hora Mt. After unpublished reports by (Novosad et al., 1984).