Neotectonics of the Inner Western Carpathians: Liptovský Ján area, case study northern slopes of the Nízke Tatry Mts., Slovakia)

Juraj Littva & Jozef Hók
Department of Geology and Palaeontology, Faculty of Natural Sciences, Comenius University in Bratislava, Mlynská dolina G, 842 15 Bratislava, Slovakia; littva@gmail.sk

AGEOS

Neotektonika vnútorných Západných Karpát: oblasť Liptovského Jána (severné svahy Nízkych Tatier, Slovensko)

Abstract: The neotectonic study results of the Liptovský Ján area and its implications for neotectonic development of the Inner Western Carpathians are presented. A broad spectrum of methods was used e.g., geological mapping, structural analysis, boreholes log data, morphotectonic analyses, transverse valley profiles, and orientation of cave passages. Three groups of normal faults active during the Quaternary were identified. The youngest faults are oriented generally in the N–S direction. The older fault groups are represented by the WNW–ESE and NE–SW directions as well. The successive arrangement of faults suggests change of the stress field from the N–S to the E–W oriented extensional axes under the tension condition in the study area during the Pleistocene. Comparison of obtained results with other studies revealed that stress field within the Inner Western Carpathians realm was changed during the Quaternary, from tension oriented generally in N–S direction to orogen-parallel extension i.e. parallel to the Inner Western Carpathian arc.
Key words: Inner Western Carpathians, Nízke Tatry Mts., neotectonics, stress field

1. INTRODUCTION

The area of interest is located on the northern slopes of the Nízke Tatry Mts., in the vicinity of Liptovský Ján village (Fig. 1). Its northern part partially extends to the Liptovská kotlina Basin. The area is bordered by Závažná Poruba village from the west, Liptovský Ján village from the east, Podtureň and Uhorská Ves villages from the north, and Okrúhla hill (1085m asl.) from the south. The most distinctive landforms of the study area include the Jánska dolina and Suchá dolina valleys. The area is drained by the Váh river with the Štiavnička river being its most significant tributary. According to the geomorphological division of the Western Carpathians the area is assigned to the Tatra-Fatra geomorphological area (Mazúr & Lukniš, 1986). The main part is situated on the Ďumbierske Tatry Mts. geomorphological subunit while northern part of the area extends into the Liptovská kotlina Basin geomorphological subunit. According to regional-geological division, the study area is located on homonymous geological subunits (Vass et al., 1988).

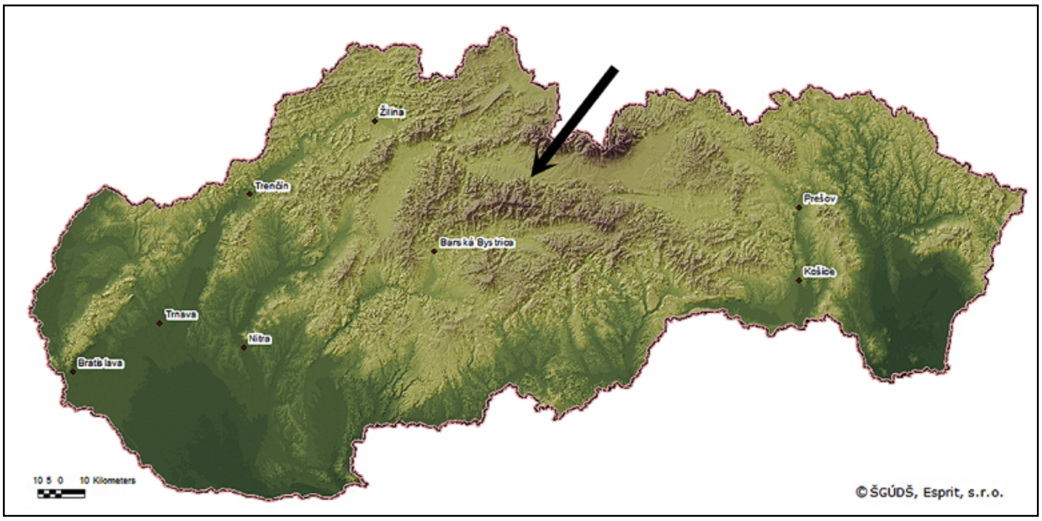


Fig. 1. Localization of the area of interest marked on map of the digital terrain model of Slovakia (adopted from the ŠGÚDŠ site).
Obr. 1. Lokalizácia predmetného územia vyznačená na mape digitálneho modelu reliéfu (prevzatého zo stánky ŠGÚDŠ).

Manuscript received 14 October 2013
Revised version accepted 3 March 2014

The region is widely known for occurrence of travertine mounds and mineral springs. Abundance of such phenomena points out the recent neotectonic activity which has been studied by numerous geologists as well as geomorphologists (e.g., Kettner & Šťastný in Matějka & Andrusov, 1931; Porubský et al., 1959; Biely, 1960, 1965, 1976; Ložek, 1961; Droppa, 1963, 1964; Porubský, 1968; Čajka et al., 1969; Kovanda, 1971; Vaškovský & Ložek, 1972; Hanzel & Gazda, 1973; Hanzel, 1973, 1974, 1977; Klinec, 1976; Peterka et al., 1976; Gross et al., 1979, 1980; Šalaga et al. 1985; Biely et al., 1992, 1997). However a modern neotectonic study of the area is still lacking. Therefore, the aim of this paper is to provide results of neotectonic study and discuss them within context of the Western Carpathians.

2. GEOLOGICAL SETTING

Most of the rock formations (Gutenstein Fm., Ramsau Dolomite, Reifling Fm., Lunz Fm., Hauptdolomite) cropping out in the area, can be assigned to the Biely Váh Middle Triassic facies belonging to the Strážov partial nappe of the Hronic Unit (sensu Havrilla, 2011). Exception to this are the Borové and Huty Fms. (Priabonian) which belong to the Central Carpathian Paleogene Basin (Gross et al., 1980), as well as Quaternary tufa, travertine, and alluvial, to debris flow sediments. From those, tufa, travertine, and fluvial deposits are of particular interest for the neotectonic analysis. Their specific arrangement, combined with other distinctive geomorphological features allows neotectonic interpretation with good measure of certainty.

3. METHODS

A wide spectrum of methods, including geological mapping, morphotectonic analysis and structural research, was applied. In addition to that, data obtained from boreholes drilled in the study area (Porubský et al., 1959; Čajka et al., 1969; Peterka et al., 1976; Šalaga et al., 1985) were studied, analyzed, interpreted, and/or reinterpreted. The brittle structural data were processed using StereoNET software (Allmendinger et al., 2012). Landforms were also studied from historical maps (ÚAZK site, years 1870–1880). Raster maps were converted to vector maps using R2V software, and digital terrain model was created in the Grass GIS (GRASS Development Team, 2012) software. Morphotectonic analysis included landform analysis, lineament analysis, analysis of the drainage system, analysis of transverse river valley profiles and analysis of cave corridors orientation.

4. RESULTS

4.1. Geological mapping

Detailed geological mapping (Fig. 2) shows that faults are far more abundant than previously thought (Kettner & Šťastný in Matějka & Andrusov, 1931; Biely, 1976, Gross et al., 1979; Biely et al., 1992).

The key feature of the new geological map is the Jánska dolina valley. There are significant differences between rock sequences cropping out at the left side and the right side of the valley. While Lunz Fm., and Hauptodolomite is prevalent on the left side, Gutenstein Fm., Ramsau Dolomite, Reifling Fm., and Lunz Fm., crop out on the right side. These differences are further underlined by significant disproportion in the occurrence of Quaternary deposits on the right side and the left side of the valley. Presence of delluvial sediments, terrace-mound travertine (classification according to Hancock et al., 1999), and several fluvial terraces on the left side of the valley contrasts with occurrence of landslide, delluvial sediments, and single fluvial terrace on the right side. Those features are indicative of presence of the Quaternary-active normal fault, yet only one of the existing maps (Gross et al., 1979) acknowledged its existence. Furthermore, this fault bisects alluvial fan of right tributary of the Štiavnička river and is parallel to another synthetic fault that is probably responsible for asymmetry of fluvial terraces on the left and the right side, as well as altitude discrepancies between them. Both normal faults have the NNE–SSW striking with the westward dipping.

Other significant fault system is observable in vicinity of the Suchá dolina valley. Rather than one distinctive fault line, a fault zone was mapped here, being of various length, orientation, dipping, and kinematics. General orientation of the zone is in the N–S direction and a normal movement seems to be prevalent. A variegated mosaic of the geological structure comprising several lithological rock types near Hrádok and Okrúhla hills presents direct consequence of activity of the Suchá dolina valley fault zone. This zone most probably represents a result of the activity of single, eastward dipping, deeper rooted fault that is antithetic to the Jánska dolina valley faults. Area between the two valleys thus forms a pseudo-graben structure.

Besides the above mentioned faults, the WNW–ESE and NE–SW striking faults are present. Those faults are less obvious as they are commonly bisected by the N–S striking faults to the point of making them untraceable at several places. Small travertine mounds (probably eroded-sheet travertine according to classification of Hancock et al., 1999) are located on several of those faults, meaning that the WNW–ESE and NE–SW normal faults were active during the Quaternary. It is not entirely clear whether those faults represent two successive generations of faults or conjugated faults. Situation in the western part of area, where the NE–SW fault seems to intersect the WNW–ESE fault, might suggest that the NE–SW faults are younger.

4.2. Interpreted data from boreholes

Borehole data, despite certain ambiguities, provide interesting results. Of particular interest are B-1, B-2, and "Rudolf" boreholes (Porubský et al., 1959; Čajka et al., 1969; Peterka et al., 1976; Šalaga et al., 1985). Those boreholes are situated in the mouth of the Jánska dolina valley (Fig. 3). In this place, Quaternary deposits of the Štiavnička river are almost twice as thick as in the other boreholes (Tab. 1), even when compared to the boreholes drilled in fluvial plane of the Váh river. Another anomaly directly tied to the boreholes is artesian groundwater

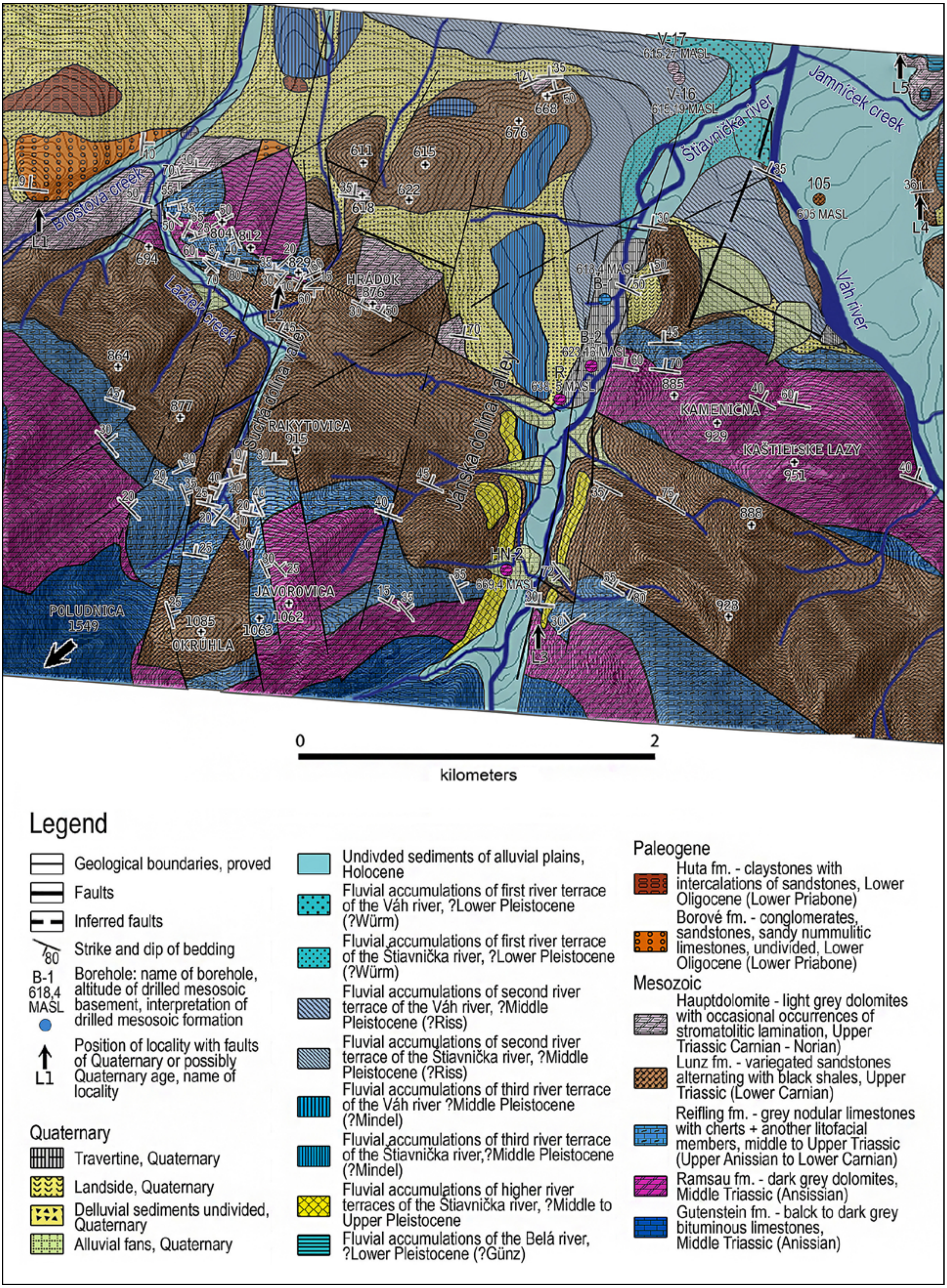


Fig. 2. Geological map of the study area.

Obr. 2. Geologická mapa študovaného územia.

Tab. 1. Table of processed archive data from boreholes in the area of interest and its close vicinity.
Tab. 1. Tabuľka spracovaných archívnych vrtných dát z predmetnej oblasti a jej bezprostrednej blízkosti.

Name of the borehole	Altitude (m a.s.l.)	Thickness of Quaternary sediments (m)	Altitude of rock basement (m a.s.l.)	Level of drilled and stabilised groundwater (m)	Interpretation of drilled formation
B-1	637,6	19,2		3 above surface	Reifling Formation
B-2	645,66	22,5		10 above surface	Ramsau Dolomite
Rudolf	653	16,5		5 above surface	Ramsau Dolomite
20	605	9,5		1,5 drill., 2 stab.	Huta Formation
105	617	12		2,1 drill., 2,1 stab.	Lunz Formation
V-15	625,67	10,4		not drilled	Hauptdolomite
V-16	625,99	10,8		not drilled	Hauptdolomite
J-148	615	10		5,9 drill., 3,2 stab.	Hauptdolomite
J-150	613	10		1,8 drill., 1,6 stab.	Hauptdolomite
J-151	613	17		2,3 drill., 1,9 stab.	Hauptdolomite
HN-2	678,84	9,4		5,7 drill., 9,5 stab.	Ramsau Dolomite
19	605	11,1		1 m nar., 2 m vyst.	Huty Formation

being present in all three of them. Upon drilling the groundwater, it erupted several meters above ground level. Data suggest that the artesian groundwater in the B-1 and B-2 boreholes was drilled in the depth interval of 10 to 20 meters. Same depth interval is characteristic for transition from Quaternary deposits to the zone of intensively brecciated Mesozoic rocks.

Since the occurrence of the artesian groundwater is confined into a small area and depth in which the artesian groundwater occurs is relatively shallow, it cannot be ascribed to any specific strata. Abundance of brecciated rocks suggests that boreholes drilled into the fault zone. Therefore, rather than being related to any specific stratum, an abundance of the artesian groundwater in all likelihood linked to the occurrence of a fault zone. This data further support the claim of existence of the NNE–SSW oriented, westward dipping, Quaternary-active normal faults situated in the Jánska dolina valley.

4.3. Morphotectonic analysis

4.3.1. Drainage pattern

The study area shows a trellis to rectangular drainage pattern (Fig. 4) that can be divided into two parts. First one is located in the middle of the study area and presents the Štiavnička river drainage system. Latter is located in the western portion of the study area and is presented by the Brostová and Lažtek creeks and their respective tributaries. The watershed between these two areas runs through peaks of Okrúhla, Javorovica, Rakytovica, and Hrádok hills and crests located between them (Fig. 4).

Drainage pattern of the Štiavnička river presents obvious example of a trellis drainage pattern (Fig. 4), with the Štiavnička river flowing to the NNE and perpendicular tributaries striking in the WNW–ESE direction. At the mouth of the Jánska dolina valley, just before the Štiavnička river flows into the Váh river, the Štiavnička river changes its course to the NE. From historical maps is apparent that the river was branching out in this place, yet all branches flowed uniformly to the NE, being parallel to each other. This river course change might not seem anomalous at first, but when course of other rivers is taken into consideration, the anomaly is obvious. The Jamníček creek, the right tributary to the Váh river, flows generally to the SW and changes its course after entering the alluvial plain of the Váh river. That means the creek flows at obtuse angle to the general current direction of the Váh river, which presents a striking anomaly, especially when the setting of the Štiavnička river and the Jamníček creek to each other is considered.

Drainage pattern of the Brostová and Lažtek creeks is more complex (Fig. 4). The Lažtek creek catchment area shows rectangular drainage pattern with creeks flowing to the WNW–ESE and NNE–SSW, respectively. Creeks near the Brostová creek shows characteristics of parallel pattern, with general orientation to the NE–SW. Furthermore, this drainage pattern is parallel to the direction of the Iľanovka and Ploštínka creeks situated nearby. The NE striking of both creeks is at obtuse angle to the course of the Váh river. This situation is similar to the anomaly present at the mouth of the Jánska dolina valley and near the Jamníček creek.

4.3.2. Topolineament analysis

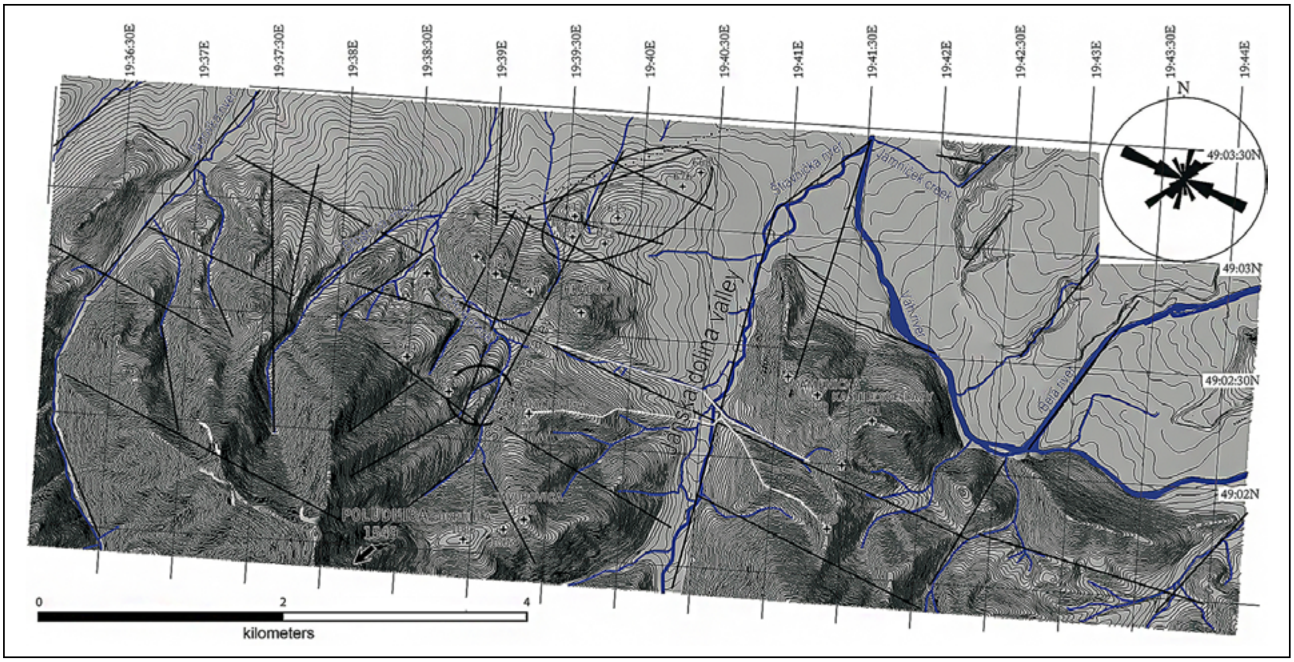
Using digital terrain model, a number of distinctive topolineaments was recognized in the study area (Fig. 4). Their orientation shows three preferred directions: WNW–ESE, NE–SW, and NNE–SSW. Not only these directions fit well with flow directions of local streams, but they also correlate with mapped faults (compare Figs. 2 and 4).

4.3.3. Analysis of terrain features

There are several distinctive terrain features present in the study area that are indicative of neotectonic activity. Abrupt broadening of the Váh river valley occurs near the mouth of the Jánska dolina valley. To this point the valley of the Váh river is narrower and erosion prevails over deposition. Downstream

Fig. 3. Location of boreholes displayed in orthophotomap (Google Earth, 2006).
Obr. 3. Rozmiestnenie vrtov zobrazené v ortofotomape (Google Earth, 2006).

Fig. 4. Digital terrain model of the surroundings of the study area. Topolineaments are distinguished by black lines. Rose diagram shows their orientation in stereographic projection. Dotted line represents boundary of the breakthrough-valley of the Váh river described by Droppa (1964). Two prominent terrain features mentioned in the text (offset in the river valley and the hillocks) are encircled in the map. White lines are the profile lines of profiles shown at fig. 5.
Obr. 4. Digitálny model reliéfu širšieho okolia študovanej oblasti. Topolineamenty sú zvýraznené čiernymi líniami. Ružicový diagram znázorňuje ich orientáciu v stereografickej projekcii. Bodkovaná čiara reprezentuje hranicu prelomového údolia Váhu popísanú Droppom (1964). Dve výrazné črty reliéfu spomínané v texte (offset v riečnom údolí a pahorky) sú v mape zakrúžkované. Biele línie sú línie profilov zobrazených na obr. 5.



from the mouth of the Jánska dolina valley, the valley of the Váh river rapidly broadens and deposition becomes prevalent over erosion. Droppa (1964) describes this phenomenon as the boundary between broad alluvial plain of the Váh river and the antecedent breakthrough-valley of the Váh river (although some believe the valley to be of epigenetic origin, Maglay, pers. comm.). Droppa (1964) states that the boundary is oriented in the NE–SW direction. Boundary's location and orientation is well-correlated with the mapped NE–SW fault trace (compare Figs. 2 and 4). This fact, along with the occurrence of the travertine mound, presents direct evidence of Quaternary-activity of the NE–SW faults.

Another prominent landform is the Jánska dolina valley. The valley is characteristic of the asymmetry in the transverse profile, distinctive asymmetry of fluvial terraces as well as asymmetry in occurrence of other morphostructures. Slopes on the right side of the valley are generally steeper than on the left side (Figs. 4 and 5), landslide and triangular facets are present on the right side of the valley. Hilltops and elevations on the right side are situated in higher altitude (around 10 m), than corresponding hilltops and elevations on the left side. The left side is characterized by planation surfaces that are tilted eastward. These facts support the notion of the Quaternary-active faults located in the Jánska dolina. Furthermore, the facts suggest that hanging wall of these faults tilted to the east.

The Suchá dolina valley presents landform with several remarkable terrain features in its vicinity. Most obvious aspect of fault activity is an offset observable in the valley west to the Suchá dolina valley (Fig. 4). The NE–SW strike of valley and the offset oriented in the NNE–SSW direction occurs near the valley's mouth. Direction and location of the offset fits perfectly with location and orientation of the mapped fault (compare Fig. 2 and 4).

An influent stream occurring in the Suchá dolina valley is indicative of the presence of karst phenomena. The NNE–SSW

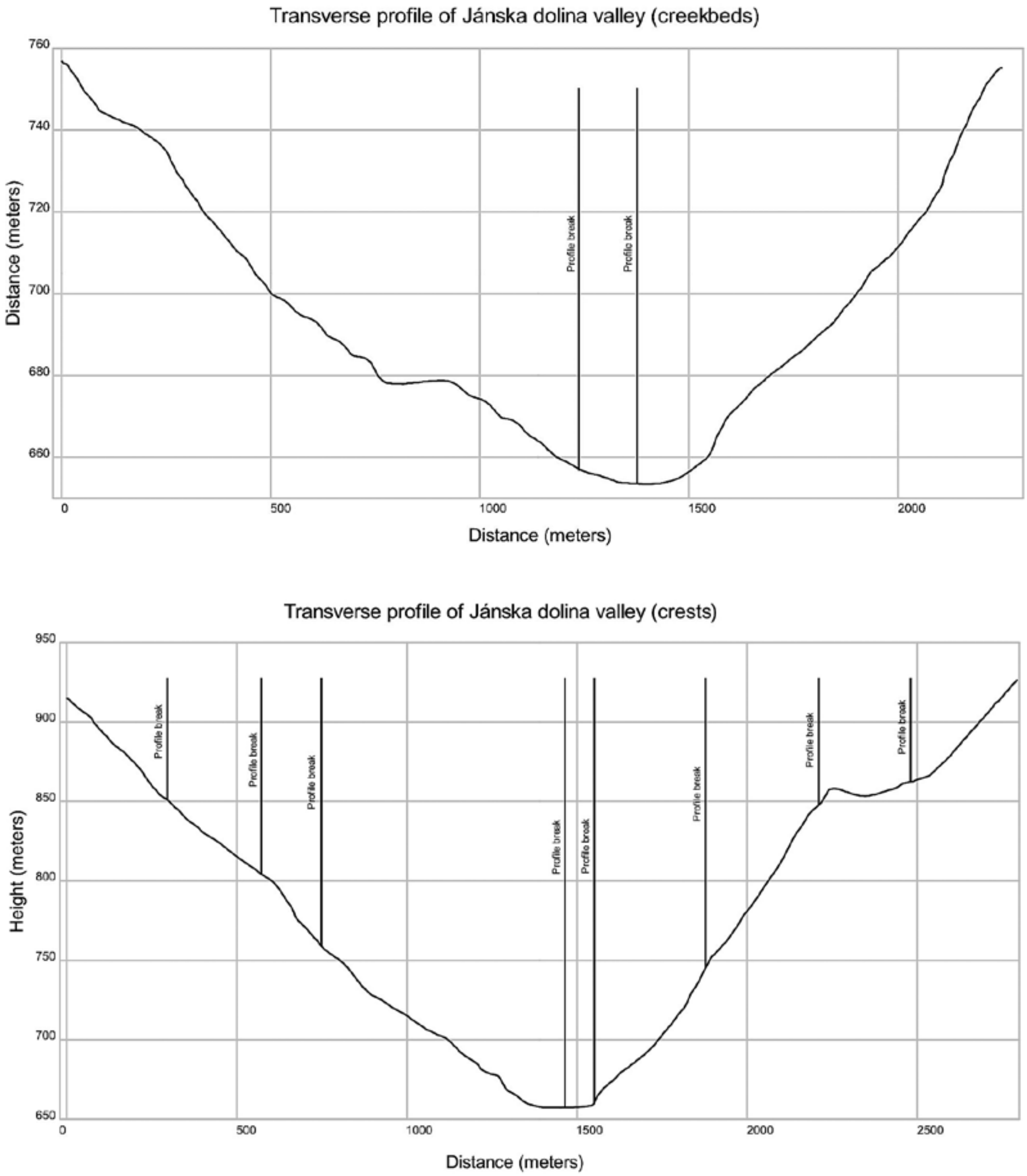


Fig. 5. Transverse profiles of the Jánska dolina valley. First profile is drawn through creek beds of tributaries of the Štiavnička river, second is drawn along crests perpendicular to the Jánska dolina valley.
Obr. 5. Priečne profily Jánskej doliny. Prvý profil je vedený dnami prítokov Štiavničky, druhý je vedený podĺž hrebeňov kolmých na Jánsku dolinu.

striking topolineament can be observed even after the valley ends. The altitude differences between corresponding hilltops and elevations at both sides of the valley (hilltops and elevations at the right side being about 40 m higher) suggest that left side was relatively uplifted to the right side. The slope steepness differences of both sides of the valley (the right side being steeper than the left side) support this notion.

It seems that the course of the Lažtek creek was altered by the fault. At the point where the Lažtek creek suddenly turns to west, the Štiavnička river drainage system and the Brostová-Lažtek drainage system are separated by a narrow asymmetric crest. The right tributary of the Štiavnička river that springs near the crest, flows through shallow, broad valley, and barely shows any sign of erosion. The tributaries of the Lažtek creek cut narrow, deep valleys into the crest. Further downstream the Lažtek creek exhibits similar behavior. It seems that the Lažtek creek flowed to the east before, but then was its path obstructed by the relative uplift of the right side of the Suchá dolina valley. As a consequence, the creek changed its course to the west. That would also point out to relative uplift at the right side of fault. Height of the crest measured from the Lažtek creek's turning point (45 to 50 m) suggest similar throw as was measured from the differences in altitude of corresponding hill peaks.

The evidence suggests that fault trace is running through the Suchá dolina valley. This assumption is supported by data obtained by geological mapping. However, the evidence obtained from the analysis of terrain features suggests the opposite sense of movement than results of geological mapping. Former results indicate relative uplift of the right side of the valley, while latter indicate relative uplift of the left side. The Suchá dolina fault system was mapped as comprising several faults, with complicated and various modes of kinematics. Overall, they present result of activity of eastward-dipping normal fault. Also, the entire block between the Jánska dolina valley and the Suchá dolina valley is tilted eastward. This conflicting evidence is interpreted as a result of activity of a secondary reverse fault formed within the Suchá dolina fault system (Fig. 6).

Another noteworthy terrain feature is a stair-like arrangement of elevated surfaces at the crest of Okrúhla and Javorovica hills (1085 m asl.; 1063 m asl., and 1062 m asl.) and the crest of unnamed hill (804 m asl.; 812 m asl., and 829 m asl.). The

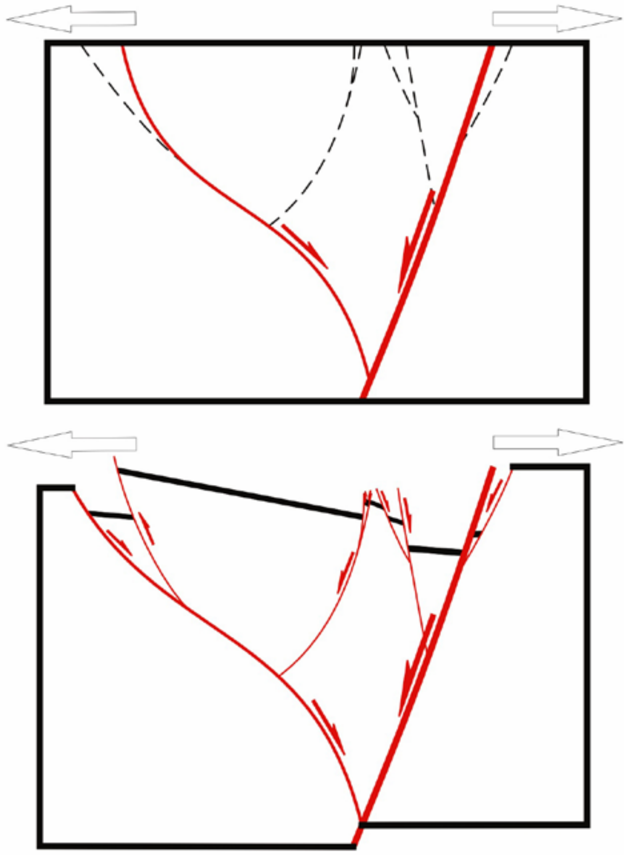


Fig. 6. Schematic example of origin of secondary reverse fault induced on normal fault.

Obr. 6. Schematický príklad vzniku sekundárneho prešmyku indukovaného na poklesovom zlome.

geological mapping revealed that faults traces run through sadlebacks between mentioned elevations. There are conflicting morphotectonic and geological results concerning kinematic interpretation of mentioned faults. The highest elevation on the stair-like arranged surfaces geologically represents most subsided block. This suggests that the surfaces were first tilted and then bisected by faults (Fig. 7). This way a crest with stair-like arrangement formed, while highest elevation would represent most subsided block.

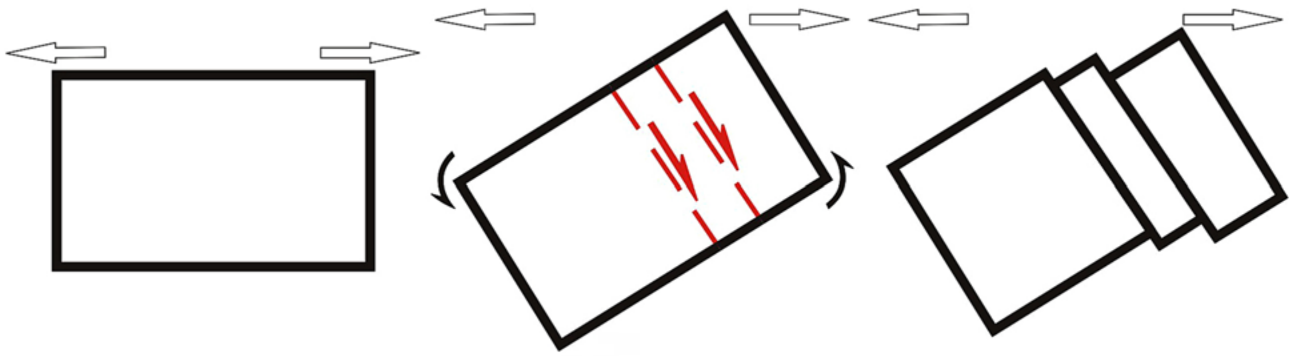


Fig. 7. Schematic example of origin of the stair-like arranged elevated surfaces, that are mentioned in the text.

Obr. 7. Schematický príklad vzniku schodovite usporiadaných vyvýšenín, ktoré sú zmienené v texte.

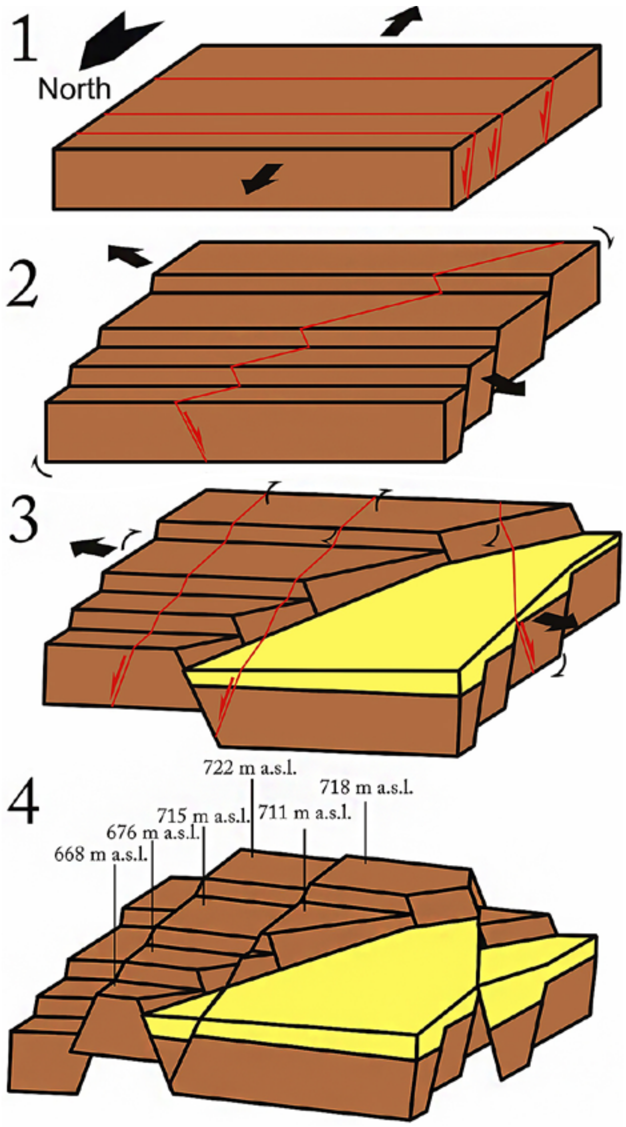


Fig. 8. Interpretation of origin of the terrain feature located to the N of the Hrádok hill (876 m a.s.l.).
Obr. 8. Interpretácia vzniku formy reliéfu nachádzajúcej sa na S od Hrádku (876 m n.m.).

Perhaps most intriguing terrain feature is located north of the Hrádok hill (876 m asl.) in a form of four hillocks and two planation surfaces (Figs. 4 and 8). Whole structure is bounded by a NE–SW topolineament. The altitude of tops of the hillocks lowers to the north and to the west (SE hillock – 722 m asl.; SW hillock – 718 m asl.; NE hillock – 715 m asl.; NW hillock – 711 m asl.). The northern and western slopes are slightly gentler than the eastern and southern slopes. Initially this area is interpreted as a former (?Pliocene) planation surface that was intersected by the WNW–ESE normal faults (Fig. 8 part 1) and formed a series of the stair-like arranged planation surfaces (Fig. 8 part 2). Subsequently, part of the terrain feature surface subsided along the NE–SW normal fault, while the rest of the surface tilted to the NW (Fig. 8 part 2 and 3). The final step in the origin of current terrain feature was the activity of the NNE–SSW faults accompanied with the tilting of blocks between the faults (Figs. 8 parts 3 and 4).

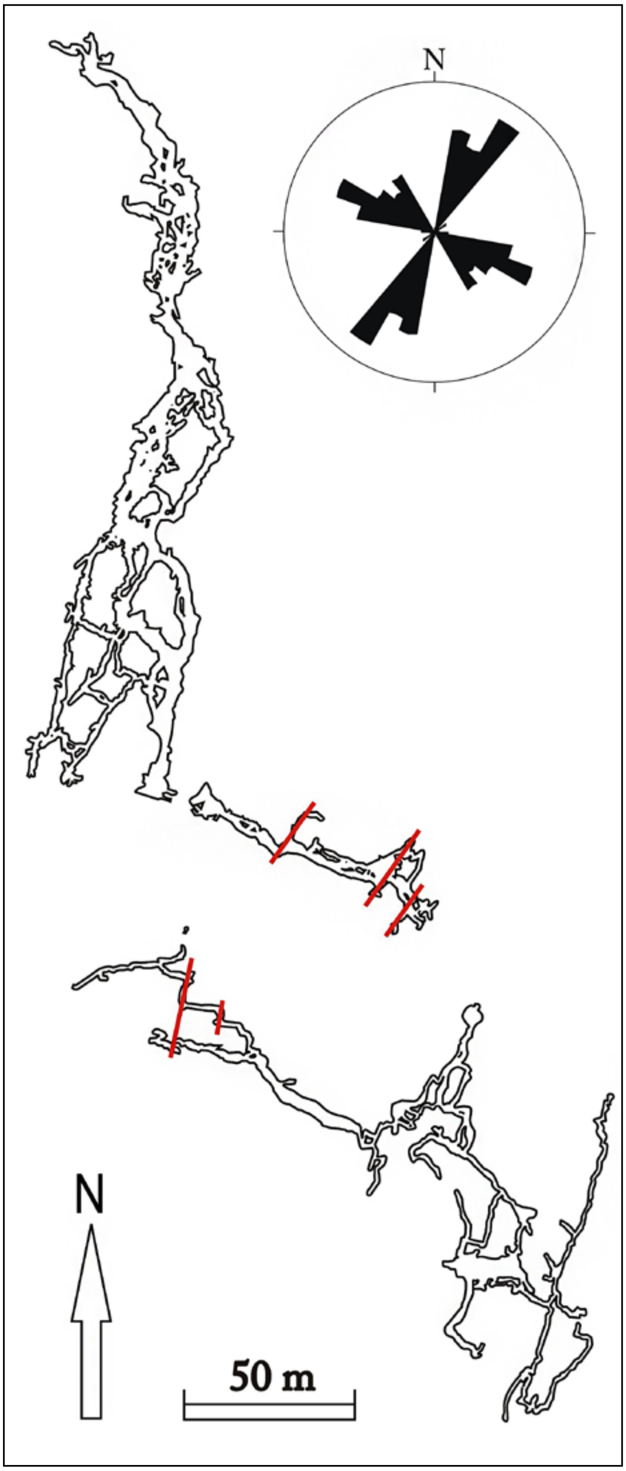


Fig. 9. Map of the cave corridors of the Stanišovské jaskyne Caves (redrawn from information board near the Stanišovské jaskyne Caves, that was created on basis of maps of Hochmut and Holúbek, digitalised by Danko and Biskupič), with marked offsets of the cave corridors and rose diagram showing orientation of the corridors in stereographic projection.
Obr. 9. Mapa jaskynných chodieb Stanišovských jaskýň (prekreslená z informačnej tabule pri Stanišovských jaskyniach, vytvorenej na základe máp Hochmuta a Holúbeka, zigitalizovaných Dankom and Biskupičom), s vyznačenými offsetmi jaskynných chodieb a ružicovým diagramom znázorňujúcim orientáciu jaskynných chodieb v stereografickej projekcii.

4.4. Analysis of orientation of cave passages

Although there are no well-studied cave spaces in the study area, Stanišovské jaskyne Caves with well-documented cave corridors are situated to the south of the study area. There are two general directions of the orientation of the cave passages (Fig. 9): the WNW–ESE orientation and the NNE–SSW orientation. The passages likely have tectonic predisposition. There are offsets visible in the WNW–ESE passages, indicating that the WNW–ESE passages are older than the NNE–SSW passages. Same thing can be reliably assumed for similarly oriented faults: the WNW–ESE faults are older than the NNE–SSW faults.

4.5. Structural analysis

During the fieldwork, several outcrops with faulted Quaternary deposits were located. Along these, several other outcrops with the faults of possibly Quaternary age were found (Fig. 2). Quaternary faults on localities L1, L3, L4 were oriented in the WNW–ESE to NE–SW direction. Locality L5 (Fig. 10) contains the WNW–ESE oriented faults, but Quaternary sediments seem to be located on the hanging block of unmeasured normal fault oriented roughly in the N–S direction. Joint set located in the same outcrop, where the WNW–ESE oriented joints are intersected by the N–S oriented joint, confirms this fault succession.

Quaternary age of faults on locality L2 was inferred. Limestone cropping out at the locality L2 underwent karstification and is covered by flowstone crust. The faults occurring at the outcrop intersect not only rock itself but also the flowstone crust which might be the indication of the Quaternary age of the aforementioned faults. These N-S faults are normal faults dipping both eastward and westward.

The vicinity of the Suchá dolina valley is of special note. The mesoscopic brittle structures located here are indicative of complicated tectonics. Faults depicted in fig. 11 represent secondary reverse faults induced on normal fault. Observed mesoscopic faults correlate well with proposed interpretation of the Quaternary fault movement at the Suchá dolina valley fault system (Fig. 6). Therefore, age of the mesoscopic faults is assumed to be Quaternary.

5. DISCUSSION

Obtained results are in good agreement with the results of Pešková & Hók (2008). Analysis of the corridor orientation in the Demänovské jaskyne Caves by Hlavnová et al. (2008) shows good fit with the orientation of the cave corridors of the Stanišovské jaskyne Caves. Hlavnová et al. (2008) consider the WNW–ESE corridors to be younger than the NNE–SSW corridors. However, offsets observable in the WNW–ESE corridors of the Stanišovské jaskyne Caves present indisputable evidence of the NNE–SSW corridors being younger, than the WNW–ESE corridors.

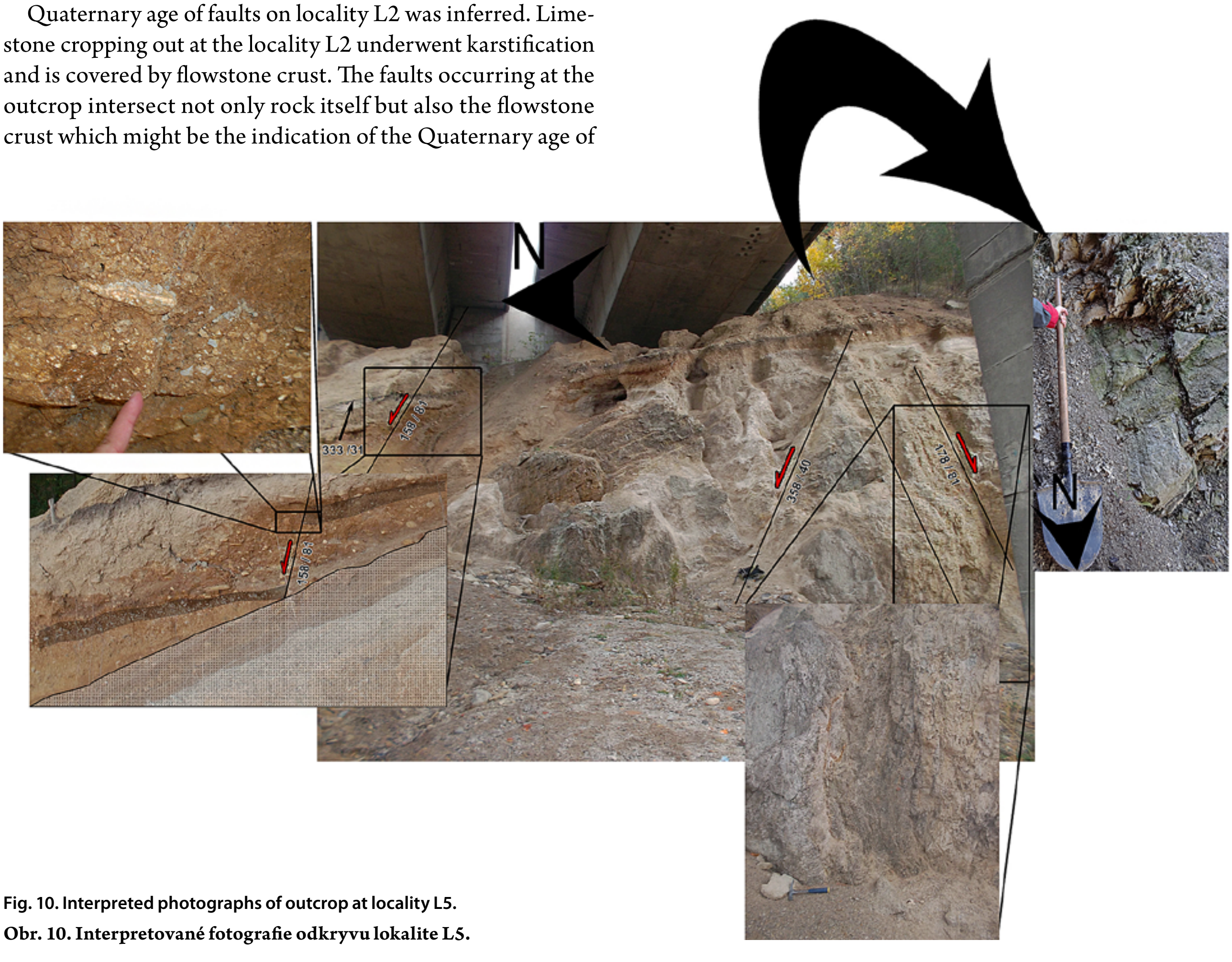


Fig. 10. Interpreted photographs of outcrop at locality L5.
Obr. 10. Interpretované fotografie odkryvu lokalite L5.

Fig. 11. Observed and interpreted structures of reverse fault induced on normal fault.
Obr. 11. Interpretované štruktúra prešmyku indukovaného na poklese.

Other studies from the western part of Slovakia (Hók et al., 2007; Vojtko et al., 2008; Králiková et al., 2010; Kováč et al. 2011) report change of Quaternary stress field from the NNE–SSW oriented extension to the NE–SW oriented extension. On the other hand the study of Vojtko et al. 2012, from the eastern part of Slovakia describes recent NW–SE extension. Studies from the northern part of the Western Carpathians (Pešková et al., 2009; Vojtko et al. 2010) describe recent stress field with extension component oriented in the W–E direction. The results of this study as well as the results of previous studies suggest that the current stress field of the Inner Western Carpathians represents the orogen-parallel extension.

The exception in the region of the Inner Western Carpathians presents the Kozie chrbty Mts., (Vojtko et al., 2011; Sůkalová et al., 2012). The NNW–SSE extension is dated (Vojtko et al., 2011) and is considered younger than the W–E extension. The reason of this anomaly has yet to be satisfactory explained.

The area of interest provides good opportunities to date activity of Quaternary faults with number of Quaternary sediment outcrops (Locality L5 being of special note, with 2 paleosol horizons of which one yielded wood remnants after short search) and Quaternary karsts phenomena. Besides the Stanišovké jaskyne caves, Demänovské jaskyne caves might prove useful in assessing age of stress field change as some parts of the passages in the Demänovské jaskyne Caves are already dated (Hercman et al., 2006). Most of the previous neotectonic studies considered the N–S extension to be of Pliocene age and the orogen-parallel extension being of Pliocene to Holocene age. The exception to this are works of Hlavnová et al. (2008), Pešková & Hók (2008) and Králiková et al. (2010) that assume Pliocene to Lower Pleistocene age of the N–S extension and Upper Pleistocene to Holocene age of the orogen-parallel extension. Decker et al. (2005) determined Middle to Upper Pleistocene age of change in the stress field in the western part of the Western Carpathians (Vienna Basin). As there is the evidence of the WNW–ESE faults bisecting Quaternary sediments, the results of this study support latter assumption, concerning age of the stress field change.

6. CONCLUSION

The Liptovský Ján area, situated on the northern slope of Nízke Tatry Mts., was subject to neotectonic research. Utilizing a wide spectrum of methods (geological mapping; reinterpreting archive data obtained from boreholes; structural analysis; study of historical maps; analyses of landforms, drainage pattern, topolineaments, transverse river valley profiles, and orientation of cave corridors) we were able to determine several faults that were active during the Pliocene or Quaternary. The oldest of them are the WNW–ESE faults. The NE–SW faults might be conjugated faults, being of same age or slightly younger. The NNE–SSW striking of faults represent the youngest faults.

This fault pattern suggests that stress field in the study area has changed during the Quaternary, from the NNW–SSE oriented tension to the tension oriented in the W–E direction. Dating of the fluvial terraces in the study area is based only on their relative height. Due to lack of precise dating, it can be only generally stated that the shift in the stress field occurred during the Quaternary. However, the area provides good opportunities for future research, precise dating of the Quaternary-active faults in particular. The comparison with other studies from the region of the Inner Western Carpathians shows that region of the Inner Western Carpathians underwent the change of the stress field during the Quaternary. In the most areas of the region the stress field changed from the N–S oriented tension to the orogen-parallel extension. The results of this work support the statement that change in the stress field orientation occurred during the Middle to Lower Pleistocene.

Acknowledgment: This work was supported by the Slovak Research and Development Agency under the contract Nos. APVV-0099-11, APVV-0625-11, APVV-0315-12 and by VEGA project number 1/0587/11. We would like to thank all people who contributed to this work with advice and consultation, namely RNDr. Juraj Maglay PhD., doc. Rastislav Vojtko PhD., doc. RNDr. Milan Sýkora CSc., prof. RNDr. Jozef Minár CSc., Ing. Peter Orvoš, PhDr. Ján Hlavienka, reviewers and all personnel of Stanišovské jaskyne Caves. Furthermore, we want to express gratitude toward Equis Ltd. for providing us with basic documentation.

References

Allmendinger R.W., Cardozo N. & Fisher D., 2012: Structural geology algorithms: Vectors and tensors in structural geology, Cambridge University Press.

Biely A., 1960: Chočský príkrov na severných svahoch Nízkych Tatier, Geologické Práce, Zpr., Bratislava, 20, 127–134.

Biely A., 1965: K paleogeografii spodného triasu chočského príkrovu, Geologické Práce, Zpr., Bratislava, 34, 71–74.

Biely A., 1976: Vysvetlivky k mezozoiku severných svahov Nízkych Tatier – východná časť. Manuscript – archive of GÚDŠ, Bratislava.

Biely A., Beňuška P., Bezák V., Bujnovský A., Halouzka R., Ivanička J. & Kohút M., Klinec A., Lukáčik E., Maglay J., Miko O., Pulec M., Putiš M., Vozár J., 1992: Geologická mapa Nízkych Tatier 1: 50 000. GÚDŠ, Bratislava.

Biely A., Bezák V. (Eds.), Bujnovský A., Vozárová A., Klinec A., Miko O., Halouzka R., Vozár J., Beňuška P., Hanzel V., Kubeš P., Liščák P., Lukáčik E., Maglay J., Molák B., Pulec M., Putiš M. & Slavkay M., 1997: Vysvetlivky ku geologickej mape Nízkych Tatier. GÚDŠ, Bratislava, 232 p.

Čajka O., Šošško A. & Jassinger F., 1969: Správa o inžiniersko-geologickom prieskume pre diaľnicu D-1, stavba Ružomberok. Dopravaprojekt, archive of Geofond, Bratislava, archive number: 22342, 46 p.

Decker K., Peresson H. & Hinsch R., 2005: Active tectonics and Quaternary basin formation along the Vienna Basin Transform fault, Quaternary Science Reviews 24, 307–322.

Droppa A., 1963: Paralelizácia riečnych terás a horizontálnych jaskýň. Geologické Práce, Zošit 64, ŠGÚDŠ, Bratislava.

Droppa A., 1964: Výskum terás Váhu v strednej časti Liptovskej Kotliny. *Geografický časopis*, 16, 4, Bratislava.

GRASS Development Team, 2012. Geographic Resources Analysis Support System (GRASS) Software, Version 6.4.2., http://grass.osgeo.org.

Google Earth version 6.1.0.5001. 2006: Liptovský Ján. 49° 02' 25,29'' N, 19° 40' 45,27'' E, eye alt. 6,85 km. Eurosense/Geodis Slovakia 2013. available at: http://www.google.com/earth/index.html [last visited 20. 9. 2013].

Gross P. (Ed.), Vaškovský I. & Halouzka R., 1979: Geologická mapa Liptovskej kotliny 1:50 000. GÚDŠ, Bratislava.

Gross P., Köhler E. (Eds.), Biely A., Franko O., Hanzel V., Hricko J., Kupčo G., Papšová J., Priechodská Z., Szalaiová V., Snopková P., Stránska M., Vaškovský I. & Zbořil Ľ., 1980: Geológia Liptovskej kotliny. GÚDŠ, Bratislava, 242 p.

Hancock P. L., Chalmers R. M. L., Altunel E. & Çakir Z., 1999: Travitonics: using travertine in active fault studies, *Journal of Structural Geology*, 21, 903–916.

Hanzel V. & Gazda S., 1973: Hydrogeologický výskum chočského príkrovu a série Veľkého boku Nízkych Tatier. Manuscript, archive of ŠGÚDŠ, Bratislava.

Hanzel V., 1973: Puklinovo-krasové vody Jánskej doliny v Nízkych Tatrách. *Geologický průzkum*, 15, 7/175, 208–211.

Hanzel, V. 1974: Podzemné vody chočského príkrovu a série Veľkého boku na severovýchodných svahoch Nízkych Tatier. Západné Karpaty, séria Hydrogeológia, inžinierska geológia, 1, 7–64.

Hanzel V., 1977: Puklinovo-krasové vody severovýchodných svahov Nízkych Tatier a vplyv skrasovatenia na ich režim, *Slovenský kras*, 15, 31–52.

Havrila M., 2011: Hronikum: paleogeografia (vrchný pelsón – tuval), štrukturalizácia príkrovu a stavba. Geologické práce, Správy, 117, 103 p.

Hercman H., Bella P., Gradziński M., Głazek J., Nowicki T. & Sujka G., 2006: Výsledky rádioizotopového datovania sintrov z Demänovského jaskynného systému v rokoch 1995-2005, *In:* Bella P. (Ed.): Výskum, využívanie a ochrana jaskýň, Zborník referátov z 5. vedeckej konferencie (Demänovská Dolina, 26. – 29. 9. 2005), Liptovský Mikuláš, 21–36.

Hlavnová A., Pešková I. & Hók J., 2008: The Quaternary stress orientation changes related to the origin of the Demänová cave system, *Mineralia Slovaca, Geovestník*, 40, 3–4, 220.

Hók J., Marko F., Vojtko R., Kováč M., 2007: Pukliny v granitoidoch pohoria Tríbeč, *Mineralia Slovaca*, 39, 4, 283–292.

Kettner R. & Šťastný V., 1931: Geologická mapa s. svahu Nízkych Tatier v okolí Liptovského Hrádku. *In:* Matějka & Andrusov (Eds.): Guide des excursions dans les Carpathes occidentales. Knihovna štátního geologického ústavu Československé republiky, Praha, svazek 13A, 397 p.

Klinec A., 1976: Geologická mapa Slovenského rudohoria a Nízkych Tatier (Slovenské rudohorie – stred, Nízke Tatry – východ) 1:50 000. GÚDŠ, Bratislava.

Kovanda J., 1971: Kvartérní vápence Československa. Sborník geologických Věd, Antropozoikum (Praha), Ústřední Ústav geologický (Nakladatelství ČSAV), Praha, 7, 240.

Kováč M., Hók J., Minár J., Vojtko R., Bielik M., Pipík R., Rakús M., Kráľ J., Šujan M. & Králiková S., 2011: Neogene and Quaternary development of the Turiec Basin and landscape in its catchment: a tentative mass balance model. *Geologica Carpathica*, 62, 4, 361–379.

Králiková S., Hók J. & Vojtko R., 2010: Reorientácia napäťového poľa odvodená z morfoštruktúr a zlomového porušenia pliocénnych sedimentov Hronskej pahorkatiny (Západné Karpaty). *Acta Geologica Slovaca*, 2, 1, 17–22.

Ložek V., 1961: Survey of the Czechoslovak Quaternary: Travertine. *Prace Geol. Inst.*, 34, Warszawa, 81–86.

Mazúr E. & Lukniš M., 1986: Geomorfologické členenie SSR a ČSSR, časť Slovensko 1:500 000. Slovenská kartografia, Bratislava.

Pešková I. & Hók J., 2008: Quaternary dynamics of the Liptovská kotlina Basin inferred from the travertine deposits and Váh River terrace asymmetry. *Mineralia Slovaca*, *Geovestník*, 40, 3–4, 220.

Pešková I., Vojtko R., Starek D. & Sliva L., 2009: Late Eocene to Quaternary deformation and stress field evolution of the Orava region (Western Carpathians). *Acta Geologica Polonica*, 59, 1, 73–91.

Peterka I., Hric V. & Frličková M., 1976: Diaľnica D-1 Liptovský Ján - Liptovský Hrádok trasa, doplňujúci IGP. IGHP, archive of Geofond, Bratislava, archive number 37463, 19 p.

Porubský A., 1968: Liptovskojánska žriedelná štruktúra a krasové vody. *Slovenský Kras (Martin)*, 1965-1966, 6.

Porubský A., Pavúr. K. & Malý J., 1959: Hydrogeologický výskum minerálnych prameňov v Liptovskom Jáne. Geologický prieskum, archive of Geofond, Bratislava, archive number: 4936, 75 p.

Šalaga I., Šalagová V., Kazmuková M., Šinková M. & Tyleček B., 1985: Mezozoikum Nízkych Tatier – SV časť, záverečná správa z vyhľadávacieho HGP s ocenením zásob podzemných vôd ku dňu 31.10.1983. IGHP, archive of Geofond, Bratislava, archive number 66389.

Sůkalová Ľ., Vojtko R. & Pešková I., 2012: Cenozoic deformation and stress field evolution of the Kozie chrbty Mountains and the western part of Hornád Depresion (Central Western Carpathians). *Acta Geologica Slovaca*, 4(1), 2011, 53–64.

Vass D. (Ed.), 1988: Regionálne geologické členenie Západných Karpát a severných výbežkov Panónskej panvy na území ČSSR 1:500 000. GÚDŠ, Bratislava.

Vaškovský J. & Ložek V., 1972: To the Quarternary stratigraphy in western part of the Liptovská kotlina basin. Geologické Práce, Správy, 59, GÚDŠ, Bratislava.

Vojtko R., Hók J., Kováč M., Sliva Ľ., Joniak P. & Šujan M., 2008: Pliocene to Quaternary stress field change in the western part of the Central Western Carpathians (Slovakia). *Geological Quarterly*, 52, 19–30.

Vojtko R., Tokárová E., Sliva L. & Pešková I., 2010: Reconstruction of Cenozoic paleostress fields and revised tectonic history in the northern part of the Central Western Carpathians (the Spišská Magura and Východné Tatry Mountains). *Geologica Carpathica*, 61, 3, 211–225.

Vojtko R., Marko F., Preusser F., Madarás J. & Kováčová M., 2011: Late Quaternary fault activity in the Western Carpathians: evidence from the Vikartovce fault (Slovakia). *Geologica Carpathica*, 62, 6, 563–574.

Vojtko R., Petro Ľ., Benová A., Bóna J. & Hók J., 2012: Neotectonic evolution of the northern Laborec drainage basin (northeastern part of Slovakia). *Geomorphology*, 138, 1. 276–294.

Internet

Štátny geologický ústav Dionýza Štúra (ŠGÚDŠ): Digitálny model reliéfu. Available at internet: http://mapserver.geology.sk/dmr/mapviewer.jsf?width=1396&height=665 , last visited

Ústřední archiv zeměměřictví a katastru (ÚAZK): Dobová podkladová mapa. Třetí vojenský mapování. Available at internet:

http://archivnimapy.cuzk.cz/mapy/map.phtml?dg=topo_Klad0,topo3v75_01&me=-1176871,-1736953.731346,13508,735654.268646&language=cz&config=3v&resetsession=ALL , last visited: 20. 9. 2013.

Resumé: Okolie Liptovského Jána, situované na severných svahoch Nízkych Tatier a kontakte pohoria s Liptovskou kotlinou bolo predmetom neotektonického výskumu. Oblasť je známa výskytom travertínov a sedimentov viacerých riečnych terás Váhu a Štiavničky. Územie je lokalizované v mieste ukončenia antecedentného údolia Váhu, kde sa niva Váhu náhle rozširuje, pričom v reliéfe sú pozorovateľné viaceré prvky, ktorých vznik je možné pripísať pôsobeniu krehkej tektoniky. Neotektonický výskum využil širokú paletu metód, od geologického mapovania, reinterpretácie archívnych vrtných dát, štruktúrno tektonického výskumu, cez štúdium historických máp, analýzu reliéfu, riečnej siete, topolineamentov, priečnych profilov údolím až po orientáciu jaskynných priestorov. V záujmovej oblasti je možné vyčleniť tri pliocénne až kvartérne aktívne zlomové systémy: zsz.–vjv. zlomy a sv.–jz. zlomy, ktoré sú staršie a najmladšie ssv.-jjz. orientované zlomy. Takúto konfiguráciu zlomov, ako aj ich vekovú sukcesiu, potvrdzuje analýza reliéfu, riečnej siete, aj štúdium orientácie jaskynných priestorov. Štruktúrna analýza potvrdila orientáciu, kinematický charakter a vek vymapovaných zlomov nálezom odkryvov s krehko porušenými kvartérnymi sedimentami. Výsledky práce naznačujú, že počas kvartérneho obdobia sa v predmetnej oblasti pôvodne ssv.–jjz. orientovaná extenzia zmenila na extenziu generálne orientovanú smerom V–Z. Po porovnaní s výsledkami iných prác, je možné vyvodiť záver, že recentné napäťové pole vnútorných Západných Karpát má charakter extenzie paralelnej s orogénom. Vek zmeny napäťového poľa je na základe výsledkov tejto práce možné odhadovať na spodný až stredný pleistocén.