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MORPHOSTRUCTURAL DEVELOPMENT OF THE NORTH-EASTERN PART OF THE RYCHLEBSKÉ HORY MTS.

PhD thesis defended at the department of Physical Geography and Geoecology,
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ABSTRACT

Basing on field work, geomorphological mapping and geophysical measurements focused on survey of manifestations of neotectonics in the relief, the zones of enhanced erosion, linear arrangement of water sources, long rectilinear segments of slopes and valleys, conductive lines were identified. They are related to fault lines bordering marginal fault scarps of the Sokolský Ridge – NE part of the Rychlebské Mts. Moreover, based on morphology and geological setting, individual blocks of horst-like arranged ridge, stepwise descending to the NE, were identified. Differential uplift of the ridge and its neotectonic development were reconstructed.

Moreover, neotectonic development was compared with available intradisciplinary data surveying geodynamics within the Sudetic Marginal Fault zone (SMF) (precise levelling, GPS) and with instrumental 3D monitoring of micro-displacements by means of crack gauge TM71 installed on tectonic structures in the caves Na Pomezí and Na Špičáku in the studied area. All the above mentioned data suggest that the SMF zone is under compression, which is coherent with asymmetric, differential uplift of the Sokolský Ridge, situated north of the SMF.

KEYWORDS: morphostructural evolution, neotectonics, tectonic activity, monitoring, Bohemian Massif, East Sudeten, Rychlebské hory (Mts)

INTRODUCTION

The presented PhD thesis (Štěpančíková, 2007) deals with morphostructural development of the NE part of the Rychlebské Mts. The region in question is situated in the Javorník spur of the Czech Republic, where one of the most prominent neotectonic zone in central Europe separates the Sudeten Mountains from the Sudetic Foreland (Fig. 1). The mapped area comprises geomorphological unit Sokolský Ridge geologically belonging to the Fore-Sudetic Block.

The goal of the thesis was to determine the morphostructural development of the studied area with concentration on neotectonic uplift and to assess present-day tectonic activity. Partial goals were as follows:

1. to analyse landforms with special attention on their genesis and present-day processes,
2. to interpret results of landforms analysis with respect to published works (geomorphological, geological, geophysical) dealing with analogical areas within adjacent regions,
3. to compare the results on present-day processes with data obtained by instrumental methods.

The presented thesis was a main subject of the author´s grant project of Grant Agency of Charles University GA UK 201/2003/B-GEO/PřF "Manifestation of neotectonics in the landform of selected fault zones in the Bohemian Massif" (2003), which continued as the project GA UK 328/2004/B-GEO/PřF "Manifestation of neotectonics in the landform of the NE part of the Rychlebské hory Mts."(2004 – 2006).

STRUCTURE OF THESIS

The presented thesis comprises 10 chapters. *Introduction* (1), which includes setting of goals, the studied area and methods, is followed by three chapters (2. – 4.) consisting of four papers by the author published in reviewed journals (A – D).

Chapter 2 (*2. Development of geomorphological researches*) includes the paper A – *Štěpančíková (2006)*. The paper B (*Stemberk and Štěpančíková, 2003)* is involved in chapter 3 (*3. Geological setting, tectonic evolution of the area and geodynamic research).* The author's proportion of the paper is 50%. The main part of the thesis is chapter 4 and 5. Chapter 4 *(4. Morphostructural analysis)*, dealing with the influence of structural setting on morphology in the studied area, consists of two papers: C (*Štěpančíková, 2005)* and D (*Štěpančíková et al., 2008, in press*), where the author has the proportion of the paper 85%. Chapter 5 (5. Analysis of selected landforms) describes the results of geomorphological

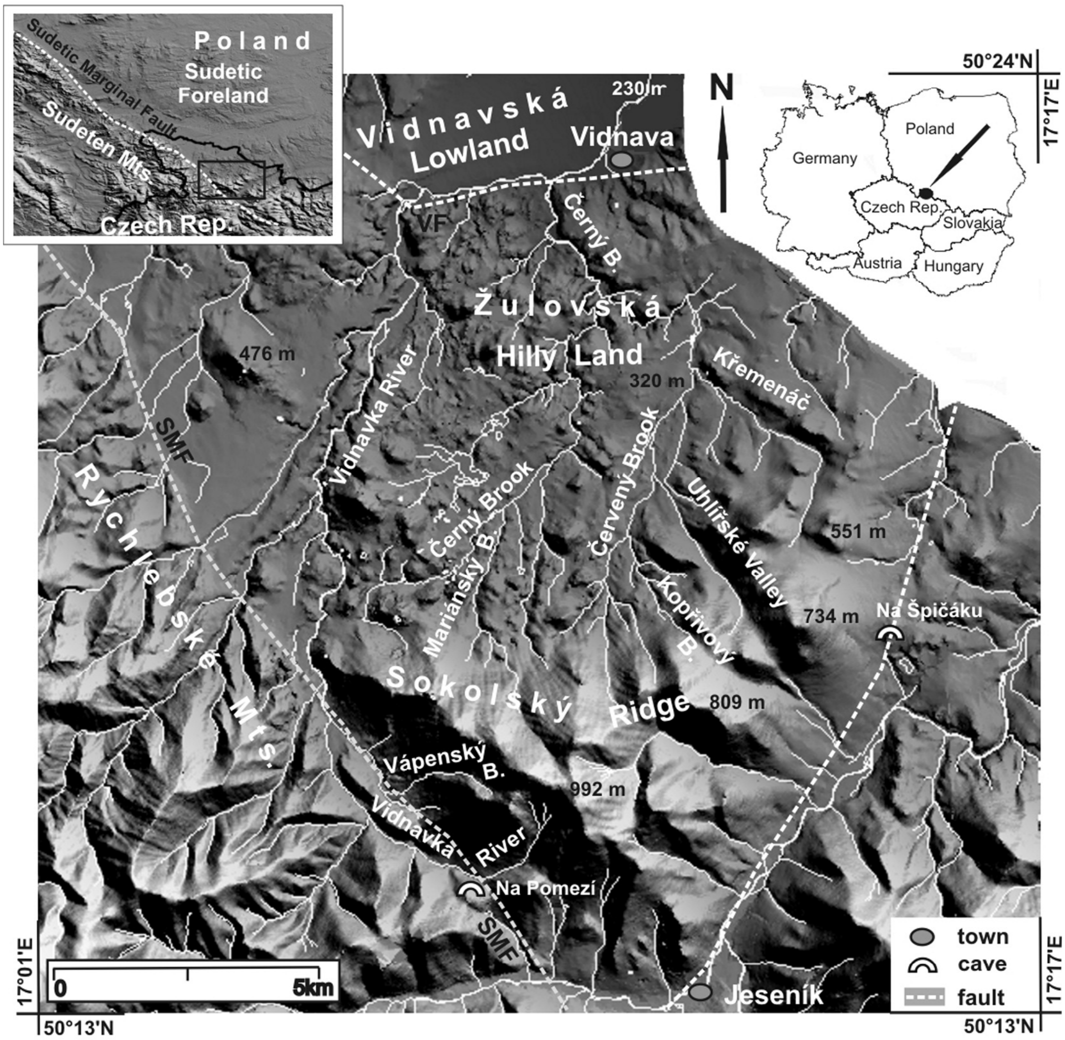

Fig. 1 The geographical location of the study area and its morphology (adopted from Štěpančíková et al., 2008).

field mapping, with focusing on genesis of the forms. Geomorphological map (1 : 25 000) could be found as the supplement no. 3. Synthesis of the previous analytical parts is included in the chapter 6 *(6. Morphostructural development of the relief)*. Chapter 7 *(Conclusions)* sums up the contribution of the thesis and new knowledge. *Supplements* in chapter 8 comprise detailed results of geophysical works carried out in order to verify fault lines (Suppl. 1) and methodology of using the indices of similarity for comparing spatial relationship between linear landforms and structures (joint and faults) (Suppl. 2). Alphabetical list of the references used in the chapters 1, 5, 6, 7 and 8 and the list of the figures, photographs and supplements is included in chapters 9 and 10.

METHODS

The preparatory phase included study of literature focused both regionally and thematically. Selection of works was orientated to papers and unpublished manuscripts relating geology, geomorphology, hydrology. This phase served also as a basis for a following working hypothesis.

Field research represented a crucial part of the work. Field mapping focused on identification of landforms, where special attention was paid to forms potentially related to tectonic activity. Character, reach and intensity of present-day erosion processes as well as depositional forms were researched. Field works were based on topographic maps ZM ČR 1: 10 000 when final version of geomorphological map is in 1: 25 000 to show spatial relationships better-arranged. Cross-profiles within important valleys were constructed directly in the field with laser range finder. During the field works also structural measurements (joints and faults readings) were carried out.

Besides geomorphological mapping, geophysical work was carried out near Vápenná town in order to verify fault lines following the foot of the NW marginal slope of the Sokolský Ridge. The geoelectric method pol-dipol was used. Measuring was conducted and interpreted by Mgr. Jan Valenta (ISRM AS CR). Moreover, field works included readings of crack gauge TM71 installed in two touristic karst caves Na Pomezí and Na Špičáku on tectonic structures. The gauges monitor 3D micro-displacements on the structures – along axes x, y, z. Interpretation of the measurements was carried out by Ing. Blahoslav Košťák, CSc. (IRSM AS CR) and RNDr. Josef Stemberk, CSc. (IRSM AS CR). The results of monitoring were used for comparison with the results from geomorphological mapping and morphostructural analysis in order to assess present-day tectonic activity.

Indoor work both preceded and followed field research. Morphostructural analysis was based on topographic, thematic maps (geophysical, geological), and data from boreholes. Then the analysis was processed within Geographical Information System (GIS) basing particularly on 3D digital elevation model (DEM) using data ZABAGED 1 : 10 000 (ČÚZK).

Analysis of river longitudinal profiles was supplemented by stream length-gradient index SL (Hack, 1973), which was calculated for successive 100-m-long segments along the stream using the formula: $SL = (\Delta H/\Delta L)L$, where $\Delta H/\Delta L$ is the gradient of the studied segment, and L denotes the total upstream length. The sensitivity of the SL index to changes in the channel slope makes it possible to evaluate the relationships among tectonic activity, rock resistance and topography (Keller and Pinter, 2002). Moreover, SL indices were compared with stream gradients (m/km) computed for 100-m-long segments.

Moreover, altitudinal position of fluvial deposits and accumulation of alluvial fans within right-side watershed of the Vidnavka River in the Žulovská Hilly Land (outside the mapped area) was analysed. The deposits were identified based on geological maps 1: 25 000 (Žáček et al., 2004; Pecina et al., in print) and field mapping. Their altitude were read from topographic maps 1: 10 000 and put in the river longitudinal profiles.

Linear elements of the relief (morpholineaments) represented by a foot or trace of rectilinear slopes or landforms related to the drainage network (thalwegs, etc.) can be associated with tectonic dislocations or geological (lithostratigraphic) boundaries (see Ostaficzuk, 1981; Badura et al., 2003). Morpholineaments were identified based on 1 : 10 000 and 1 : 25 000 topographic maps, DEM, our own geomorphological and geological maps, and were processed within the GIS. The method of condensed contour lines were also used (Ostaficzuk, 1975). In this method, using 4 to 6 times reduced scale of the contour lines (without generalization) highlights important linear-arranged landforms (cf. Badura and Przybylski, 1999). In order to assess the causal relationships between morpholineaments and fault lines or joint systems, morpholineaments longer than 500 m were analysed. Their length in a direction were taken into account, in contrast to joint and fault systems where I counted their frequency in a direction. To quantify the degree of similarity between the pattern of joints and faults, and the orientation of morpholineaments, three indices of similarity (closeness) were used. They were suggested by Ing. Marek Omelka, Ph.D. (MFF UK) for this purpose. These indices measure the degree of similarity if histograms of relative frequencies of directions of faults or joints and morpholineaments.

RESULTS AND CONCLUSIONS

Based on analysis of available interdisciplinary data, own field work and 3D monitoring of micro-displacements on tectonic structures, new knowledge and conclusions emerged. The most important of them which are related to the morphostructural development of the studied area are summarized as follows:

1. The Sokolský Ridge as a NE part of the Rychlebské Mts. underwent the largest portion of uplift during Miocene, when the most intensive (fastest) uplift can be probably put into Pliocene, analogically to the adjacent Mts, which are of similar character. The summarily biggest uplift took place in the SW part of the Ridge so it descends stepwise toward NE along faults of sudetic direction (NW – SE). Many of following facts are consistent with this differential, asymmetric uplift of the Ridge.
2. Drainage network of the Vidnavka River is markedly asymmetric. Right-side catchment includes only few short small streams with undeveloped valleys, which drain the slope originated in neotectonic period along the Sudetic Marginal Fault. This right-side catchment is in sharp contrast to left side, where the streams drain SE part of the Rychlebské Mts. within deep NE-oriented valleys, which originated in Paleogene. The streams very probably made for the NE originally and after uplift of the Sokolský Ridge they were forced to flow to a new originated stream of the Vidnavka River of NW direction, where today it follows the Sudetic Marginal Fault zone.
3. All streams within the Sokolský Ridge have non-rejuvenated wide valley heads with much lower SL indices than in lower situated segments. Downstream, in the middle reaches, where the Sokolský Ridge is rather steep, the streams have almost undeveloped valleys lacking apparent drainage divides between them. They also manifest themselves through the linear shape of their longitudinal profiles with rather higher gradients. It suggests that these segments and the slopes are young. Approaching the foothills, the

valleys deepen and widen in response to headward erosion dissecting the margins of the Sokolský Ridge from its foot. These different segments of slopes are most probably related to different stages of slope development. Also river longitudinal profiles reflect these different stages.

4. The exceptions from the above described undeveloped valleys are deep valleys of streams which follow fault lines (e.g. Uhlířské valley, Lubina Brook) and those of which the upper reaches of the NE direction also suggest their earlier origin when the general slope of the relief was to the NE. Following uplift of the area enhanced the deep erosion within these valleys (Lubina, Křemenáč).
5. It was possible to identify probable trace of one of the fault systems bordering the NW marginal slope of the Sokolský Ridge basing on linear arrangement of springs, of beginnings of stream segments with enhanced erosion within valley of neighbouring streams, of knickpoints in longitudinal profiles, and of rectilinear foot of neighbouring elevations. This fault zone is of NE – SW direction and can be identified within the segments from U Krmelce (447 m a.s.l.) to Staré Podhradí municipality. Another fault line following the foot of this marginal slope was geophysically verified east from the Vápenná town.
6. Marginal fault scarp on the NE, in contrast to the previous NW and SW slopes, has characteristic triangular facets and on the south-western end near Jeseník town also partial blocks suggesting differential movements along parallel faults.
7. Present-day erosion within valley of the Vidnavka River is the most intensive in the area Na Pomezí, where it follows Sudetic Marginal Fault and from where erosion spreads upstream from the foot of marginal slope of the Sokolský Ridge. Other places with enhanced incision can be found in the valley of the stream flowing around the Jestřábí Hill (507 m a.s.l.) from the right and of the Kopřivový Brook. The both mentioned streams follow a fault line and the beginnings of enhanced erosion are also controlled by faults (transverse ones). Similarly, also beginnings of the youngest erosional phase, which cuts down an older wider valley floor situated only a few meters (2-7 m) above the present-day valley bottom, are related to the foot of fault scarps or parallel faults. These spatial relationships suggest recent uplifting in the Sokolský Ridge and some degree of activity of the transverse faults crossing the ridge. The erosion rate diminishes towards the NE, which corresponds to descending of the topography towards the NE related to a decrease of uplift.
8. In the Sokolský Ridge as a horst, it was possible to distinguished around five partial blocks, bordered by sudetic faults (NW – SE), along which the Ridge descends stepwise towards the NE. The slopes related to these faults separate units, in which the most elevated parts include either denudational levels (planation surfaces) with inselbergs or wide flat saddles separating the inselbergs.
9. Analysis of fluvial terrace/alluvial fan levels within valleys of the Vidnavka River, Červený and Černý brooks in the adjacent Žulovská Hilly Land revealed that the Hilly Land was uplifted during the Middle and Late Pleistocene. All analysed accumulations were deposited after the retreat of the last continental ice-sheet (post-glacial). In some places they overlay glaciofluvial deposits or tills of the last glaciation, which took place here during Elsterian 2 (400 – 460 ka) according to the newest research. Their relative heights above the river channel are greater than terrace levels of the same age along the main Nysa Kłodzka River. The height differences attain 20 m at the highest level 1 (Saalian 1; 240–280 ka), at least 8 m at level 2 (Saalian 2; 130–180 ka), and up to 2–3 m at level 3 (Weichselian; 10–80 ka). These discrepancies imply post-Saalian 1 uplift of the Žulovská Hilly Land relative to the topographically lower Nysa Kłodzka valley.
10. This post-glacial uplift, its value and a trend to diminish towards the Late Pleistocene is consistent with results of Polish research carried out within adjacent area in the Fore-Sudetic block. The role of isostatic rebound in the uplift postdating the retreat of ice-sheet in the area remains disputable, particularly when taking into consideration the uplift of the adjacent non-glaciated Sokolský Ridge and that the ice-sheet reached the area with marginal parts of limited thickness. However, in the region peripheral to glaciated areas we can assume forebulge, when asthenosphere reacts to the removal of load of ice-sheet, and as a result, adjacent areas are uplifted (see e.g. Liszkowski, 1993). According to analysis of fluvial terraces by authors Tyráček et al. (2004) the increase of uplift tendency took place in the beginning of the Middle Pleistocene (around 0.9 Ma). According to Westaway (2002), it was caused by increasing flow in the lower continental crust which was produced by isostatic response to cyclic surface loading, caused by the growth and decay of continental ice sheets and the associated sea-level fluctuations. As a result of the uplift, enhanced erosion took place and wide flat valleys changed to deep canyon-like valleys followed by creation of fluvial terraces. The increased uplift rate in the Middle Pleistocene or in Late Middle Pleistocene is documented also in other regions within the Bohemian Massif (see e.g. Vilímek, 1992; Stemberk, 1994; Ložek et al., 2004).

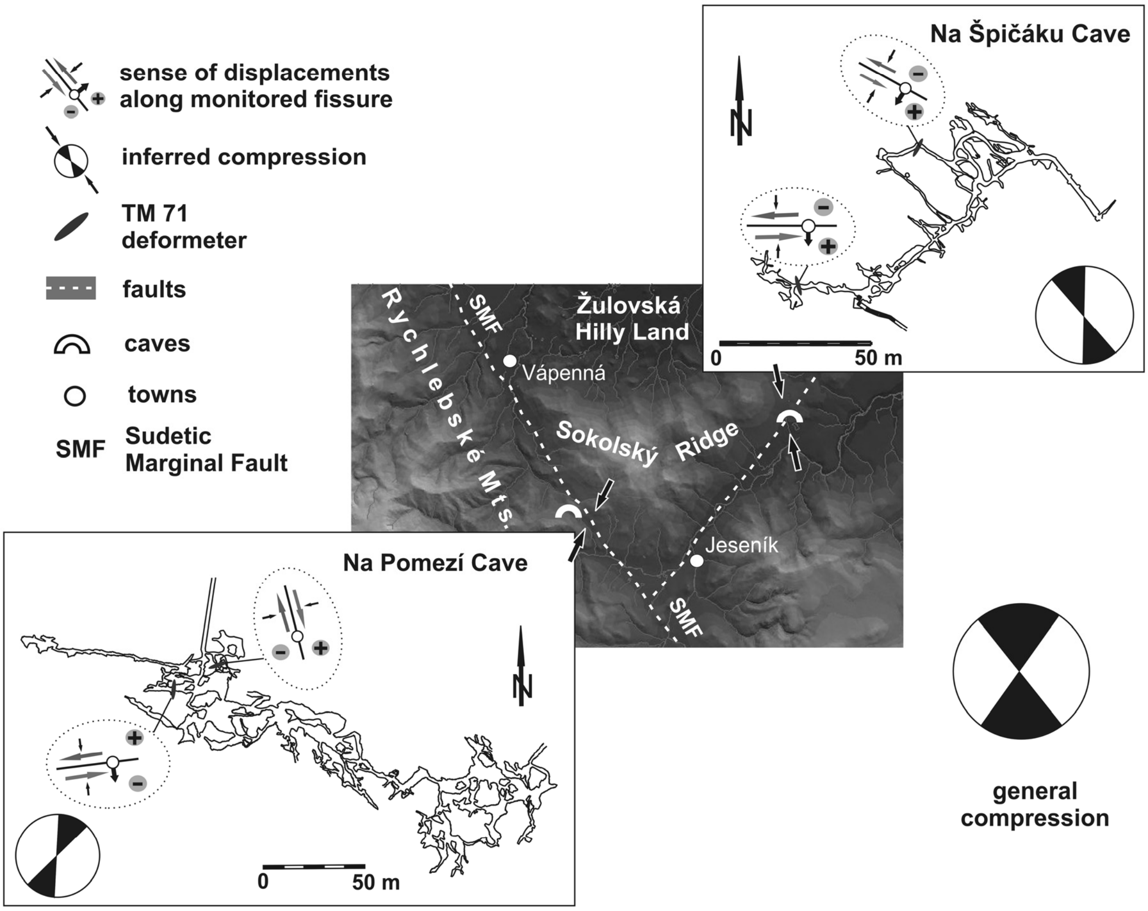

Fig. 2 Sketch of the monitored caves with locations of the TM71 deformeters, the sense of recorded displacements and the inferred compression orientations (Štěpančíková et al., 2008).

Krzyszkowski et al. (1995) speak about the tectonic phase in Saalian 2, evidence of which can be found in many places in Poland or Germany. According to them, it suggests tectonic phase of pan-Europian extent.

11. Results of field mapping correspond to the results of 3D monitoring of micro-displacements on tectonic structures carried out by means of the crack gauge TM71 installed in the karst caves Na Pomezí and Na Špičáku. Measurements revealed slow micro-displacements (hundredths to tenths of millimetres per year). The displacements have an aseismic character and the vertical component always prevails over the horizontal one. The inferred compressive stress comes generally from the southern sector (SW – NE to SE – NW), which would imply dextral transpression in the studied portion of the SMF, where the northern part (the Sokolský Ridge) is thrusting over the southern one (SE sector of the Rychlebské Mts) (Fig. 2). The trend of these present-day movements corresponds well with the differential uplift of the Sokolský Ridge, which is the biggest in the SW part. Also erosion rates diminishing towards the NE is in accordance with this uplift. The compression within the SMF zone is consistent also with Polish geodetic surveys (precise levelling, GPS) carried out farther NW.
12. Analysis of joint systems revealed that the Žulová pluton is of different prevailing directions (NE – SW and NW – SE) in contrast to its older metamorhpic cover (N – S and NW – SE). Also in the frame of the metamorphic cover, individual belts of different lithology have different joint orientation. Nevertheless, for all types of rocks is typical the presence of the youngest direction - sudetic one (NW – SE). Prevailing directions of fault systems are also NE – SW and NW – SE, more precisely the strikes are 30–50° and 130–150°, whereas overall rose diagram of joint systems in the whole studied area shows slightly different strikes 10–30° and 110–130°, then shifted by 20°. The cause of this difference probably could be a different stress field acting

during the origin of primary joint systems (particularly in the Žulová pluton) from the stress field creating younger secondary faults.

13. Comparison of prevailing directions of morpholineaments (30–50° and 130–150°), which are represented in the studied area mainly by rectilinear traces of slopes and valleys, with joint and fault systems, revealed that the morpholineaments were related to younger, neotectonic faults, rather than to joint systems. These structure systems influence the arrangement of relief and drainage network in the studied area, not only as the passive morphostructure but also active one.
14. From the indices of similarity suggested for statistical assessment of causal relationship between direction of faults/joints and morpholineaments, the index I_2 reaches the highest values when comparing faults and morpholineaments using individual measurements, not sorted out into intervals.
15. Moreover, basing on results of geomorphological mapping, the borders of morphological unit the Sokolský Ridge can be slightly changed when attaching the small area in the NE part of the mapped area belonging to the Bělská Hilly Land. This area has probably uniform morphogenesis as the rest of the Sokolský Ridge.

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MORFOSTRUKTURNÍ VÝVOJ SEVEROVÝCHODNÍ ČÁSTI RYCHLEBSKÝCH HOR

Petra ŠTĚPANČÍKOVÁ

ABSTRAKT:
Na základě terénních prací, geomorfologického mapování a geofyzikálních měření, zaměřených na sledování projevů neotektoniky v reliéfu byly identifikovány zóny se zvýšenou současnou erozí, liniově uspořádané prameny, dlouhé přímočaré úseky svahů a údolí, a vodivé linie odpovídající zlomovým liniím, na které jsou vázány okrajové zlomové svahy Sokolského hřbetu, tvořícího sv. část Rychlebských hor. Dále byly na základě geomorfologických a geologických poměrů vymezeny jednotlivé bloky hrástovitě uspořádaného reliéfu hřbetu, stupňovitě se snižujícího k SV a podle odlišného charakteru různých úseků zlomových svahů určen etapovitý, diferenciální výzdvih Sokolského hřbetu a rekonstruován jeho neotektonický vývoj.
Neotektonický vývoj reliéfu byl dále srovnáván s dostupnými interdisciplinárními daty získanými ze sledování geodynamiky v zóně okrajového sudetského zlomu – OSZ (opakovaná nivelace, GPS) a dále s instrumentálními daty získanými při monitoringu pohybů pomocí terčových měřidel TM71 instalovaných ve zkoumané oblasti na tektonických strukturách v jeskyních Na Pomezí a Na Špičáku. Z výše jmenovaných podkladů vyplývá, že se zóna OSZ nachází v kompresním tlakovém poli, což odpovídá také asymetrickému diferenciálnímu výzdvihu Sokolského hřbetu, nacházejícího se na severní straně OSZ.