MORPHOSTRUCTUAL EVOLUTION OF THE RELIEF OF THE RYCHLEBSKÉ HORY (MTS)

(SE SUDETEN MTS, CZECH REPUBLIC)

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Petra Štěpančíková: Morphostructual evolution of the relief of the Rychlebské hory (Mts) (SE Sudeten Mts, Czech Republic). Geomorphologia Slovaca et Bohemica, 7, 2007, 1, 6 Figs., 84 Refs.

Morhostructural evolution was reconstructed based on morphotectonic research carried out in the Rychlebské hory (Mts) and the adjacent area, situated in the NE spur of the Bohemian Massif. This region is located within the Sudetic Marginal Fault zone (SMF), which is one of the morphologically most prominent neotectonic structures in central Europe. During neotectonic period starting in Miocene, paleosurfaces were faulted and uplifted within the Sudetic block and resulted in the formation of the Sudeten (Mts). On the other hand, Fore-Sudetic block representing Sudetic Foreland subsided and several grabens filled with hundreds meters of related (correlative) deposits were developed close to the SMF. Tectonic activity was accompanied also by volcanism. In Pleistocene, the continental ice-sheet reached the studied area as such in Elsterian glaciation twice. After deglaciation, since Saalian 1, three levels of fluvial terraces/alluvial fans were deposited. Many blocks within the Fore-Sudetic block were then uplifted, probably as a result of glacioisostatic rebound, which caused a deformation of the fluvial/alluvial deposits levels. The uplift rate diminishes towards the Late Pleistocene, from cca 20 m to cca 5 m. Paleoseismological trenching within the SMF zone revealed thrusting during Pleistocene/Holocene. Ongoing uplift of the studied portion of the SMF zone is confirmed by spatial arrangements of enhanced erosion as well as monitoring of displacements on tectonic structures.

Key words: morphostructural evolution, neotectonics, recent activity, Bohemian Massif, Sudeten mountains, Rychlebské hory (Mts), Žulovská pahorkatina (Hilly land)

1 INTRODUCTION

This paper resulted from morphotectonic research carried out in order to determine the neotectonic development of the Rychlebské hory (Mts) situated in the NE spur of the Bohemian Massif (ŠTĚPANČÍKOVÁ 2007). The research was based on analysis of available interdisciplinary knowledge and data, own field work and 3D monitoring of micro-displacements on tectonic structures. The studied area comprises the north-eastern sector of the Rychlebské hory (Mts), so called Sokolský hřbet (Ridge), belonging to the Sudeten Mountains and the adjacent part of the Žulovská pahorkatina (Hilly land) in the Sudetic Foreland. The researched area is situated within the Sudetic Marginal Fault zone. This zone is one of the morphologically most prominent neotectonic structures in central Europe, separating the Sudeten Mountains from the Sudetic Foreland at the length more than 150 km by well-pronounced morphotectonic scarp (**Fig 1**).

The study area is composed of the Variscan Žulová granite pluton, which is the apical part of a vast granitic body marked by an extended gravity low (CHÁB and ŽÁČEK, 1994), and its Devonian metamorphic cover including a belt of predominantly gneisses, amphibolites, quartzites, and marbles. The entire studied part of the Žulovská pahorkatina (Hilly land) and the north-western marginal slope of the Sokolský hřbet (Ridge) is composed of granitoids of the Žulová pluton, whereas the eastern part of the Sokolský hřbet (Ridge), as well as the entire Rychlebské hory (Mts), is built up of the metamorphic cover (**Fig 2**). Neogene sediments linking to relative subsidence of the Fore-Sudetic block within Sudetic Foreland occur in the adjacent part of the Vidnavská nížina (Lowland) and are more than 270 m thick there (GABRIEL et al. 1982). They cover a kaolinised (to a depth of 50 m) granitic basement (ONDRA 1968; KOŚCIÓWKO 1982), which was dislocated and placed to different altitudinal le-

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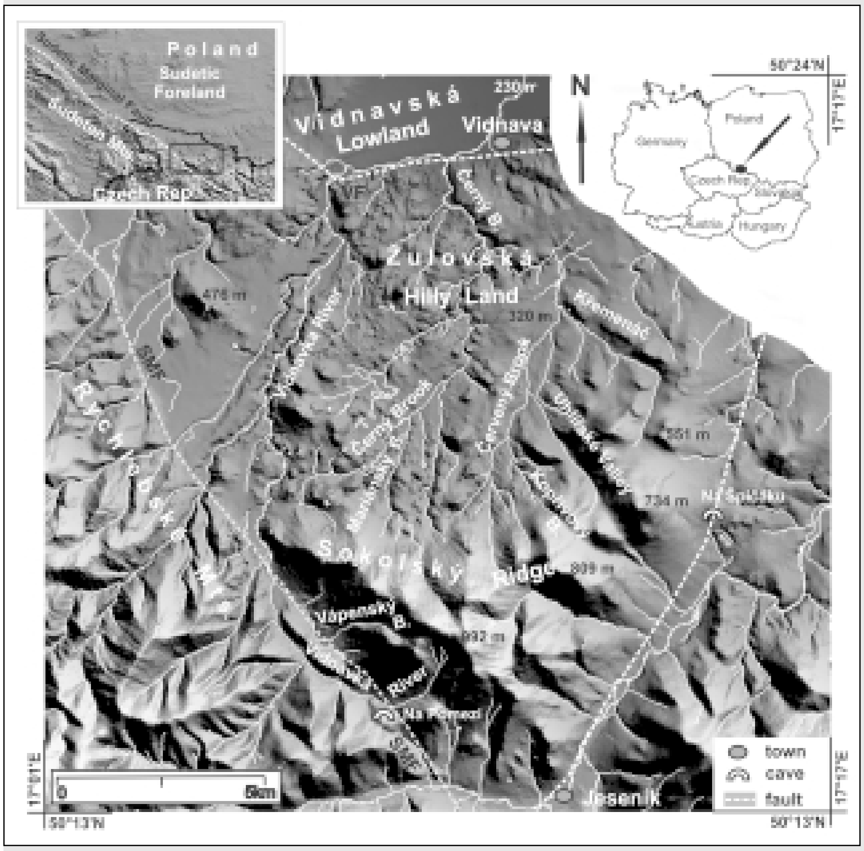

Fig. 1 Topography and morphology of the area under study. SMF – Sudetic Marginal Fault, VF – Vidnava Fault

vels. Quaternary sediments occur mostly only in the Žulovská pahorkatina (Hilly land). They include glacigenic, alluvial, fluvial and colluvial deposits (ŽÁČEK et al. 2004, PECINA et al. in print).

2 Morphostructural evolution of the relief

2.1 Paleogene

Due to Paleogene climate, favourable for kaolinic weathering, a thick regolith was formed in the studied area (KUŽVART 1965, KOŚCIÓWKO 1982, WALCZAK 1970). However, we can find also Mesozoic kaolinic regolith covered by Upper Cretaceous sediments not far from the area (e.g. KOŚCIÓWKO 1982), so some authors consider that also kaolinic regolith on the Žulová granite pluton was formed already during the Mesozoic (see e.g. BADURA in ŠTĚPANČÍKOVÁ 2007).

The evolution of the tropical tower karst near Supíkovice town is also dated to Paleogene (PANOŠ 1964). Depressions among karstic towers are filled by redish kaolinic weathered sandy and clay deposits (CZUDEK and DEMEK 1960). Pre-Miocene karst is presupposed to be formed also near Javorník town, being later covered by Miocene lacustrine deposits (SKÁCEL 2004).

During the process of peneplanation, the planation surfaces were developed in the studied area in the Paleogene. However, there is no uniform opinion on their evolution (see ŠTĚPANČÍKOVÁ 2006, 2007). DEMEK (in DEMEK et al. 1965) supposes deeply weathered surface with outstanding inselbergs occupied the granitic area of the Žulovská pahorkatina (Hilly land). IVAN (1983) estimates the original thickness of the weathered cover to be about 30 m. Consequently, the regolith was removed by etchplanation. Basal weathering surface was stripped during several phases as it is evidenced by relative heights of the inselbergs which exceeds the probable original thickness of the regolith (MIGOŃ 1997). Paleogene etchplain and its remnants, located today at different levels due to tectonic movements, are described in the Rychlebské hory (Mts) by IVAN (1966), DEMEK (in DEMEK et al. 1965). They are situated also under Miocene deposits in the Vidnavská nížina (Lowland).

However, according to MIGOŃ (1999, 2003), both the relief of the Sudeten (Mts) and the Sudetic Foreland were developed under conditions of so called dynamic etchplanation, where the rugged topography controlled by lithology existed already in Paleogene. Then the relief was dislocated and simultaneously deep selective weathering led to a still increasing differentiation. According to MIGOŃ (1999), the regional planation surface, as such, occured here for the last time in Mesozoic.

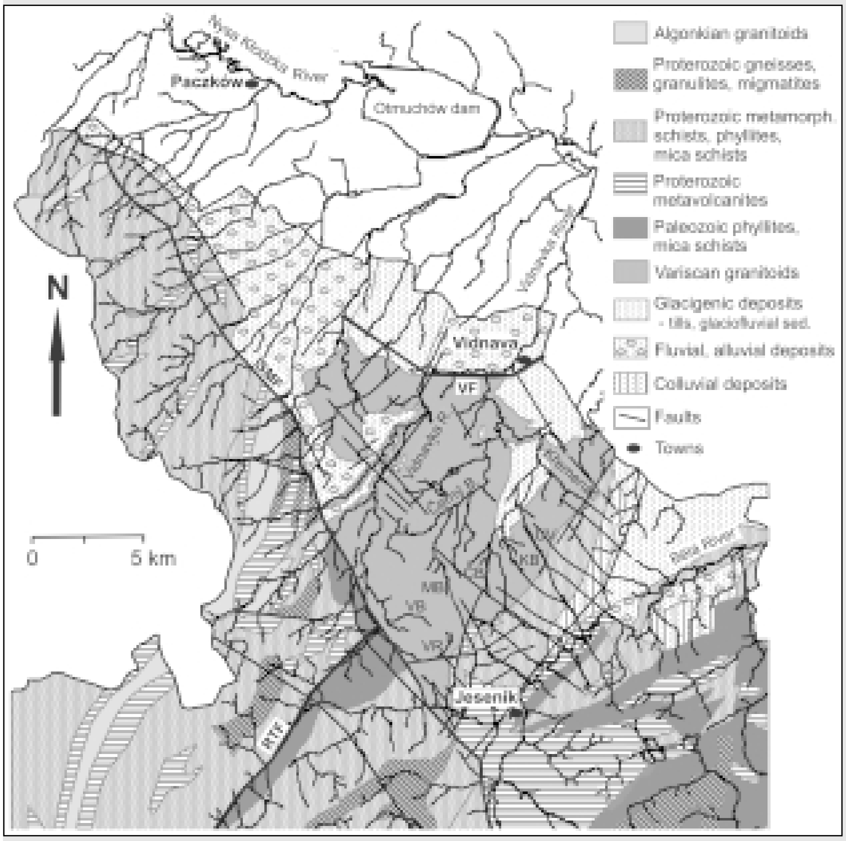

Fig. 2 Geological sketch of the studied area. SMF – Sudetic Marginal Fault, VF – Vidnava Fault, RTF – Ramzová Thrust Fault separating Lugicum and Silesicum, VR – Vidnavka River, VB – Vápenský Brook, ČB – Červený Brook, MB – Mariánský Brook, KB – Kopřivový Brook, UV – Uhlířské Valley Brook (compiled with the basic geological map by the CZECH GEOLOGICAL SURVEY 1998)

The NE part of the Rychlebské hory (Mts), the Sokolský hřbet (Ridge), was developed probably in an analogical way to the adjacent areas. This is suggested by isolated inselberg-like summits of the ridge. They could have been a part of the only etchplain together with the Žulovská pahorkatina (Hilly land), with granitic inselbergs, and the Bělská pahorkatina (Hilly land), with karstic inselbergs, before the ridge was uplifted during Neogene. Other uplifted inselbergs are described also in the SE part of the Rychlebské hory (Mts); they are also compared with the inselbergs of the Žulovská pahorkatina (Hilly land) by PANOŠ (1959).

3 Neotectonic evolution

3.1 Miocene

In the Oligocene, the transgression of the North Sea reached the Fore-Sudetic Block; however, it has not submerged the studied area (**Fig 3**). Nevertheless, the surrounding of the area was a part of a Parathetys bay and sediments were of marine to brackish origin (DYJOR 1981).

A new tectonic regime began in Lower Silesia at the turn of Oligocene/Miocene. The changes in the stress field parameters resulted in a rejuvenation of the Sudetic Marginal Fault and an uplift of the Sudetic block. These movements were also followed by incipient volcanism. So, the Paleogene planation surface was dissected and uplifted within the Sudeten (Mts), whereas on the subsided Fore-Sudetic block, a belt of depressions with the Roztoka, Mokrzeszów, and Paczków Grabens, as well as the Carpathian Foredeep including the Kędzierzyn Graben, was formed (OBERC and DYJOR 1969, SKÁCEL 1989, BADURA et al. 2004). These grabens are filled with related (correlative) deposits coming from the uplifted mountains and their thickness was estimated to exceed 600 m based on geoelectrical profiles. Nevertheless, only 300 – 400 m were proved by drilling (see BADURA et al. 2004, ONDRA 1968). According to IVAN (1966), these Oligocene/Miocene movements were still weak in the Rychlebské hory (Mts). The opinions on the character of the movements along the Sudetic Marginal Fault, which has a high dip, still vary. However, on many places, thrusts were evidenced (BADURA and PRZYBYLSKI 2000). Also IVAN (1966) came to a conclusion that the youngest movements in the Rychlebské hory (Mts) had thrusting character.

At the end of Middle Miocene, the bay of Parathetys in the eastern Sudetic Foreland receded towards SE. Miocene streams that had previously followed the Kędzierzyn graben to the E and also digressed to the SE, whereas in the western part of the Sudeten, the uplift resulted in a general inclination of the relief towards the north, which predisposed the stream orien-

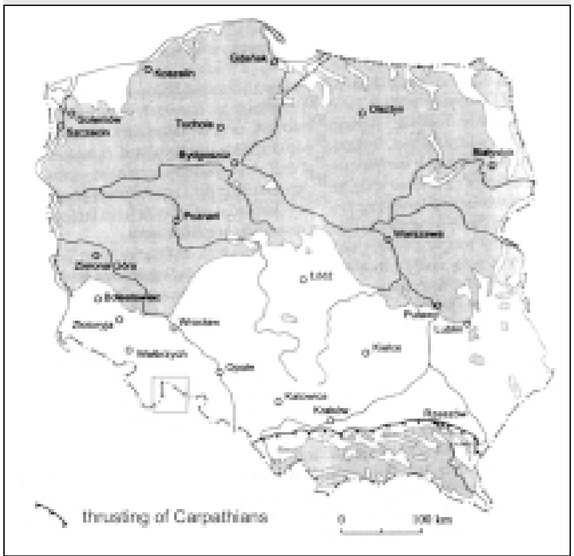

Fig. 3 Paleogene deposits in Poland (PIWOCKI in KOLEKTIV 2004)

tation (BADURA and PRZYBYLSKI 2004). The deposits of Early to Middle Miocene reach into the studied area within the Javorník - Vidnava basin, which is a part of sedimentation Paczków basin. The Vidnava basin is filled with a 300 m thick fluvial to delta deposits with coal seams that rest on kaolinic-rich regolith of crystalline bedrock. The deposits include strongly weathered to kaolinised material that comes from the adjacent Žulová pluton. The upper part of the deposit profile already includes material brought by rivers from the Rychlebské hory (Mts) (GABRIEL et al. 1982).

In the Javorník basin with lacustrine deposits, the uplift of the adjacent block occupied by the Žulová pluton, as well as of the Rychlebské hory (Mts) along the Sudetic Marginal Fault, is marked by coarse-grained alluvial fans near Uhelná town (FREJKOVÁ 1968). The coarse material from the mountains reaches up to 200 m thickness in the subsided basin between Javorník and Bílý potok town (ONDRA 1968). As these deposits rest on kaolinised crystalline bedrock, IVAN (1966) supposes that the relief of the area was low and flat before the uplift of the Sudeten mountains. A removal of the regolith occured in the Early Miocene when etchplanation continued also in uplifting planation surfaces.

The activity of Tertiary deep fault structures was accompanied by extrusions of basalts in Lower Silesia. It occured in many phases when extension and compression were alternating in the region. In the first phase in Late Oligocene during crustal extension, the Sudetic Marginal Fault was a normal fault. Later, the activity migrated to SE towards the Carpathians (BIRKENMAJER et al. 1977). The latest K-Ar dating from Lower Silesia showed the main phase in Oligocene and the second major activity in Early Miocene (BIRKENMAJER et al. 2004, BADURA et al. 2005).

In the Late Miocene, the Fore-Sudetic grabens kept subsiding. Poznań series from this period reaches 180 – 200 m here. The coarse-grained deposits in the Packów graben, as well as many other alluvial fans deposited on rims of grabens, reflect activity of bordering faults. After the retreat of shoreline of the Poznań basin, a new river drainage coming from the uplifted mountains directed to the basin was formed (DYJOR 1981).

3.2. *PLIOCENE*

According to DYJOR (1981), after the Poznań basin retreat to the north, a clay sedimentation was alternated by coarse-grained syntectonic deposits of the series Gozdnica. These gravels and sands have kaolin-rich matrix, in some places with coal clays set to Early Pliocene (SAWICKI 1997). Their thickness reaches up to 40 m and commonly varies around 5 – 15 m (BADURA 2003). The Late Pliocene deposits were already fluvial and were called „preglacial series“. In the studied area, they were deposited by Nysa Kłodzka river during four episodes (I–IV) (PRZYBYLSKI et al. 1998). The first three units (I – III) from Late Pliocene are characteristic for a large meandering river carrying sandy material. The strongly reworked quartz material with kaolinic-rich matrix comes from the Tertiary regolith of the Sudeten mountains. The upper unit (IV) from Early Pleistocene was deposited by a river with high stream power carrying coarse-grained material which resulted from a great regional uplift in Early Pleistocene or Cromerian complex. This material does not include kaolin, which suggests erosion of already unweathered bedrock. The amplitude of these vertical tectonic movements in the Fore-Sudetic block is estimated to be around 40 – 80 m and in the uplifting Sudeten mountains 60 – 70 m (PRZYBYLSKI et al. 1998). The changes of the sedimentation character in the Pliocene/Pleistocene were also influenced by climate changes (BADURA and PRZYBYLSKI 2004).

As it was stated by IVAN (1966), the NW part of the Rychlebské hory (Mts) underwent the most intensive uplift in Pliocene (Attic or Rodan phase). This is suggested by thick accumulations of alluvial fans in the mountain foreland as well as by very young hydrographic changes of the Klodzká Bělá river SW of the Rychlebské hory (Mts) described by DUMANOWSKI (1961). However, there is no certainty of the Pliocene uplift of the studied Sokolský hřbet (Ridge), since there are no deposits nearby. The ridge was uplifted as a horst of which topography is characterised by stepwise inclination to the NE along sudetic faults (NW – SE) as a result of differential uplift.

Besides the movements along the Sudetic Marginal Fault and other parallel or oblique faults, IVAN (1997) also supposes large warping, epeirogenetic or isostatic uplift as a result of the denudational unloading, which led to overall uplift of the Rychlebské hory (Mts). He takes into account both the summarized uplift and the subsidence (thickness of Miocene deposits in grabens) in order to estimate the total vertical movements, which are suggested to be about 1000 m (IVAN 1966). Towards the Žulovská pahorkatina (Hilly land),

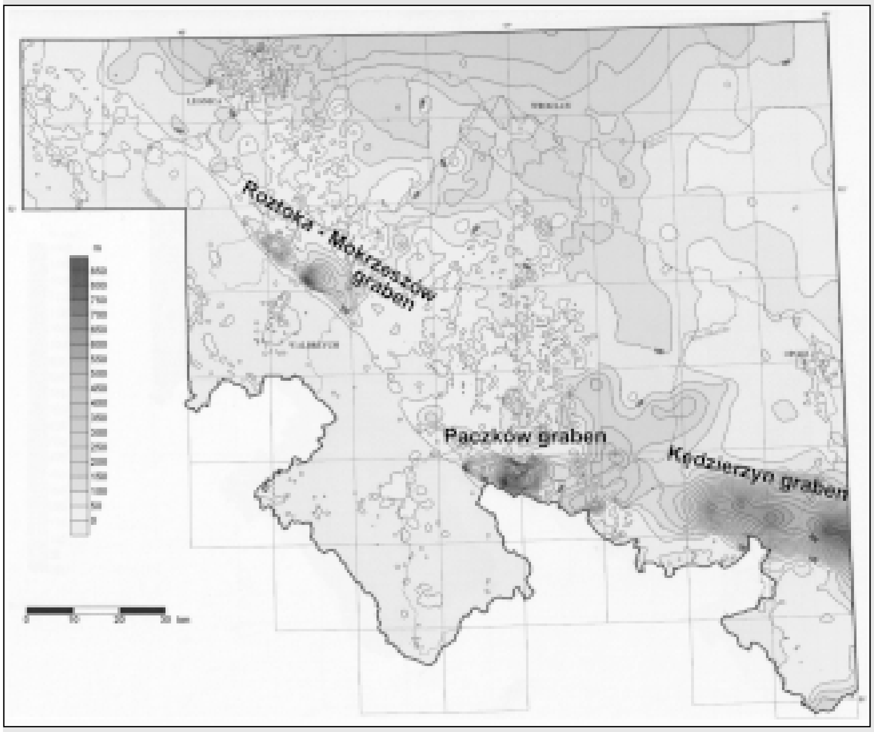

Fig. 4 Thickness of the Cainozoic deposits in the SW Poland reaches the maximum in the grabens within the Sudetic Marginal Fault zone (BADURA et al. 2004)

the Rychlebské hory (Mts) are uplifted over 500 m (IVAN 1972). The Sokolský hřbet (Ridge) was uplifted towards the adjacent area, e.g. remodelled etchplain with remnants of kaolin-rich saprolites within the Žulovská pahorkatina (Hilly land), also over around 500 m (ŠTĚPANČÍKOVÁ 2007). The movements along the Sudetic Marginal Fault were repeated as it is evidenced by two to five-tiers triangular and trapezoidal facets on the mountain front fault scarp in the Rychlebské hory (Mts) as well as in the Polish portion of the Sudetic Marginal Fault (IVAN 1966, BADURA et al. 2003, BADURA et al. in print). In the Late Pliocene/Early Pleistocene the tectonic movements generally increased within the mountain front of the Rychlebské hory (Mts) both in the NE and SW.

The youngest phase of volcanic activity in Lower Silesia took place in Pliocene (5,46 – 3,83 Ma; BIRKENMAJER et al. 2002) when basalt extrusion occured in the southern foothills of the Rychlebské hory (Mts) near Lądek town. However, previously, these basalts as well as basalts close to Zálezí in the Rychlebské hory (Mts) were considered to be younger than 0.7 mil years, based on remanent magnetization (MAREK 1974, PŘICHYSTAL 1993).

A drainage of the consequent streams with young character was formed within the uplifted mountains (VOSYKA 1959, SKÁCEL and VOSYKA 1959). So, Late Pliocene/Quaternary erosion played a major role (IVAN 1966), although the direction of drainage of the region towards NE existed as early as in Paleogene (WALCZAK 1954, IVAN 1966, BADURA and PRZYBYLSKI 2004). In the studied area, the original NE direction of drainage is suggested by asymmetric drainage pattern of the Vidnavka river. Here, the left-side catchment drains the SE part of the Rychlebské hory (Mts) to the NE, which was probably interrupted by the uplift of the Sokolský hřbet (Ridge), which is drained only by short streams with undeveloped valleys of younger age (**Fig. 5**). Also, the character of other streams within the Sokolský hřbet (Ridge) supports this theory, since the only streams that have well developed valley have direction NE, i.e. they are older and were, to some extent, founded before the uplift of the ridge (see ŠTĚPANČÍKOVÁ 2007, ŠTĚPANČÍKOVÁ et al. in print).

3.3. Pleistocene

The Sudetic Foreland was covered by a continental ice-sheet up to a mountain front of the Sudeten (Mts) three times, twice in Elsterian and once in Saalian period. The last glaciation (Saalian 1 = Odranian) did not exceed the altitude 300 – 320 m in the eastern and western Sudeten unlike to the central Sudeten (550 – 580 m a.s.l.; BADURA and PRZYBYLSKI 1998). Although, previously authors considered the Saalian 1 glaciation in the studied area (PROSOVÁ 1981), based on latest research, the margin of ice-sheet reached the area only in Elsterian 1 (OIS 16) and Elsterian 2 (OIS 12), and it flew around the Sokolský hřbet (Ridge) (BADURA and PRZYBYLSKI 1998, CHÁB et al. 2004, ŽÁČEK et al. 2004). Saalian 1 glaciation ended north of the Nysa Kłodzka river valley in the Otmuchów-Nysa (Hilly land) as it was earlier supposed by ANDERS (1939). Also ZAPLETAL (1932) considered the latest glaciation in the studied area in Elsterian 2.

The highest situated till and glaciofluvial relicts of Elsterian 1 in the studied area are 530 – 545 m a.s.l.

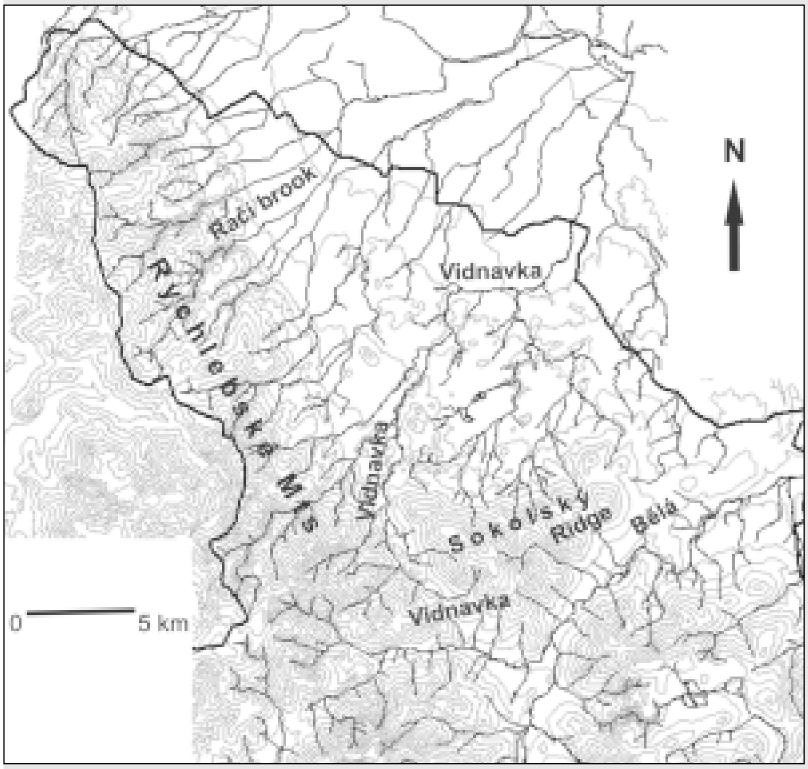

Fig. 5 Drainage pattern of the studied area directed to the NE. Markedly asymmetric river network of the Vidnavka river catchment in the SE part of the Rychlebské hory Mts in the SW versus in the Sokolský hřbet (Ridge) in the NE

in the saddle between hills Bílý Kámen (612 m) and Strážisko (610 m) in the adjacent Zlatohorská vrchovina (Highland). This is the highest position of glacigenic deposits in the Czech Republic (GÁBA 1972, NÝVLT in CHÁB et al. 2004). However, GÁBA (1972) pointed out that the differences in an altitude of maximum ice-sheet reaches could be a result of the Middle to the Late Pleistocene tectonic activity. In the Sokolský hřbet (Ridge), the Elsterian 1 ice-sheet got over the foot as it is evidenced by the till in the saddle at 465 m a.s.l. SW of the Jestřábí Hill (507 m). After the Elsterian 1 ice-sheet retreat, fluvial sediments are deposited within the Bělá river valley (CHÁB et al. 2004). The Elsterian 2 glaciation left a till and glaciofluvial deposits of up to 30 m thick in the Bělská pahorkatina (Hilly land) and at a lower thickness in the Žulovská pahorkatina (Hilly land) (CHÁB et al. 2004, ŽÁČEK et al. 2004). The eratic material between Písečná and Česká Ves town comes from the proximal proglacial sediments deposited close to Písečná. So, it points to the vicinity of the ice-sheet margin but not to the presence of the ice-sheet in the Bělá river valley near Jeseník town as it was supposed by FINCK and GŐTZINGER (1931), GÁBA (1972), PROSOVÁ (1981). The glacigenic deposits cover the strongly rugged Tertiary relief of the Bělská pahorkatina (Hilly land), which includes inselbergs and towers of tropical karst near Supíkovice town, so their thickness reaches up to 50 m (CZUDEK and DEMEK 1960, TIŠNOVSKÁ 1995). The cave Na Špičáku is situated on the foot of the Sokolský hřbet (Ridge) within the karstic inselberg Velký Špičák (482 m), which represents a nunatak (DEMEK 1976). The meltwater of the ice-sheet probably remodelled the cave corridors into a heart-like cross-section with a horizontal bottom (see ŠTĚPANČÍKOVÁ 2006). Also, many granitic inselbergs in the Žulovská pahorkatina (Hilly land) were nunataks. Under periglacial conditions, kryoplanation surfaces, frost-riven cliffs, castle coppies and block fields were formed (IVAN 1965, 1966, PANOŠ 1961). Also, the karstic caves Na Pomezí were influenced by the vicinity of the ice-sheet and affected by frost shattering (PANOŠ 1962).

After the Elsterian glaciation, the river valley deepened and fluvial terraces developed. Their evolution was related to a climate-controlled accumulation and erosion, to a changing erosional base linked with presence of the ice-sheet, and to glacioisostatic uplift. Within the studied area, three levels of fluvial terraces/alluvial fans were formed in the Žulovská and Bělská pahorkatina (Hilly land) during Saalian 1 and 2 and Weichselian (CHÁB et al. 2004, ŽÁČEK et al. 2004, PECINA et al. in print). In the Žulovská pahorkatina (Hilly land), the level 1 of Saalian 1 (Drenthe/240–280 ka; PECINA et al. in print) can be found 38 – 48 m above the Vidnavka river valley bottom, 35 – 40 m above the Červený brook, and 20 m above the Černý brook. The younger phases left level 2 of Saalian 2 (Warthe OIS 6/0.13–0.18 Ma) 12 m above the Vidnavka river, and 13 – 22 m above the Černý brook, and level 3 of Weichselian (OIS 4 - 2/0.01–0.08 Ma) 4 – 8 m above the Vidnavka river (ŠTĚPANČÍKOVÁ et al. in print).

As the relative elevation of these three levels above the stream channels have higher values when compared to the terraces of the same age along the main Nysa Kłodzka river, a tectonically induced downcutting is inferred. The height differences attain 20 m at the highest level 1, at least 8 m at level 2, and up to 2-3 m at level 3. These discrepancies imply post-Saalian 1 uplift of the Žulovská pahorkatina (Hilly land) relative to the topographically lower Nysa Kłodzka valley. These height differences suggest the greatest relative uplift of the Žulovská pahorkatina (Hilly land) postdating the Saalian 1 and diminishing towards the Late Pleistocene. This is in accordance with the results of neotectonic research carried out in the Polish part of the Fore-Sudetic block (DYJOR 1983, ZUCHIEWICZ 1995, PRZYBYLSKI 1998, BADURA and PRZYBYLSKI 2000). According to BADURA et al. (2003), this uplift is a result of both the glacioisostatic rebound and the tectonic extension inherited from the Late Neogene. The relationship between glacioisostatic uplift, which reactivated permanent unstable fault zones, and tectonic uplift is hard to estimate (KRZYSZKOWSKI et al. 1995). The post-Saalian uplift in the Fore-Sudetic block, relative to the Silesian Lowland, resulted in enhanced erosion and destruction of post-glacial landforms and according to PRZYBYLSKI (1998) to some extent, still continues.

This post-Saalian uplift also affected the Sudeten (Mts). Based on the hight differences at fluvial terrace levels of the Nysa Kłodzka and Bystrzyce river, the uplift within the mountain front fault scarp controlled by the Sudetic Marginal Fault reaches 20 – 35 m and decreases towards the Late Pleistocene to 2 – 5 m (BADURA et al. 2004). The total uplift along the Sudetic Marginal Fault during the Middle and the Late Pleistocene is estimated to be 20 – 30 m up to 60 – 80 m (MIGOŃ 1993, KRZYSZKOWSKI and PIJET 1993). However, within the antecedent segment of the Nysa Kłodzka river valley near Bardo town, the main phase of tectonic uplift took place as early as in Early Pleistocene, as it is evidenced by Pliocene deposits uplifted over 60 – 70 m towards the same unit situated in the Fore-Sudetic block. So, here the post-glacial (post-Saalian) uplift in the mountains marked by disturbed fluvial terraces reaches at maximum 25 m (KRYZSZKOWSKI et al. 2000).

The reactivation of the Sudetic Marginal Fault in the Late Pleistocene is supposed to also influence the evolution of the caves Na Pomezí, which are situated right within the fault zone (PANOŠ 1961).

3.4. *HOLOCENE*

During the Holocene within the Sokolský hřbet (Ridge), the valleys deepened and incised into the older valley bottom, which is situated 2 – 4 m above today's floodplains and in fault line controlled valley also up to 6 m. The beginnings of the stretches of increased headward erosion/rejuvenated erosional phase are concentrated at the foot of the marginal slopes of the Sokolský hřbet (Ridge), which supports the hypothesis that its uplift is still expressed in the relief (ŠTĚPANČÍKOVÁ 2007, ŠTĚPANČÍKOVÁ et al. in print).

Based on sudden anomalies of thickness of floodplain deposits, keeping knickpoints on fault lines (no retreat due to headward erosion), and on landslides probably linked to earthquakes, the Holocene tectonic activity is supposed in the Polish portion of the Sudeten (Mts) (KRZYSZKOWSKI et al. 1995). Also, preliminary results of paleoseismological trenching carried out in 2006 within the Sudetic Marginal Fault zone near Vlčice u Javorníka town across the zone on the foot of the Rychlebské hory (Mts) testify repeated movements during the Holocene. It is suggested by correlative deposits accompanying offsets on individual faults (ŠTĚPANČÍKOVÁ 2007).

The above mentioned ongoing uplift of the Sokolský hřbet (Ridge), as well as other parts of the Rychlebské hory (Mts), is also confirmed by 3D monitoring of micro-displacements measured directly on fault structures in the caves Na Pomezí and Na Špičáku by means of deformeter TM71. The recorded micro-displacements have an aseismic character with a rate in the range of hundredths to tenths of millimetre per year (0,01 – 0,1 mm/year) and at all observed sites, the vertical component of displacement prevails over the horizontal one. It implies oblique thrusting (dextral transpression in the studied portion of the Sudetic Marginal Fault zone) due to north-north-eastward-oriented compression, which results in thrusting of the Sokolský hřbet (Ridge) over the southern sector of the Rychlebské hory (Mts) probably along the Sudetic Marginal Fault, steeply dipping to the NE (STEMBERK and ŠTĚPANČÍKOVÁ 2005, ŠTĚPANČÍKOVÁ 2007, ŠTĚPANČÍKOVÁ et al. in print).

However, as the geodynamic processes are non-linear, it is not possible to extrapolate instrumentally measured movements to the past. Nevertheless, the thrusting of the Sokolský hřbet (Ridge) above the southern part of the Rychlebské hory (Mts) would correlate with asymmetric uplift of the Sokolský hřbet (Ridge), which is reflected also by erosion rate being the highest just in the SW part and diminishing towards the NE (ŠTĚPANČÍKOVÁ 2007, ŠTĚPANČÍKOVÁ et al. in print). Since the movements are relative, therefore, the general uplift of the Rychlebské hory (Mts) also south of the Sudetic Marginal Fault is not excluded as it was documented farther to the NW for the entire Sudeten (Mts) (e.g. DYJOR 1993, 1995; BADURA et al. 2003, 2004). Also, the ongoing subsidence in the Fore-Sudetic block was proved (DYJOR 1995, CACOŃ and DYJOR 2002).

The compressive stress field within the Sudetic Marginal Fault zone is evidenced also by GPS measurements. The maximum compression in the direction SW – NE (azimuth around 40°) even exceeds the measurement error four times (KONTNY 2003, 2004). Also, in the Fore-Sudetic block close to Pazcków graben area, CACOŃ et al. (2005) confirm the SW – NE compression based on GPS measurements, which resulted from the Alpine stress. The recent movements in this area are also confirmed by precise levelling and gravimetric measurements (CACOŃ and DYJOR 2002). Moreover,

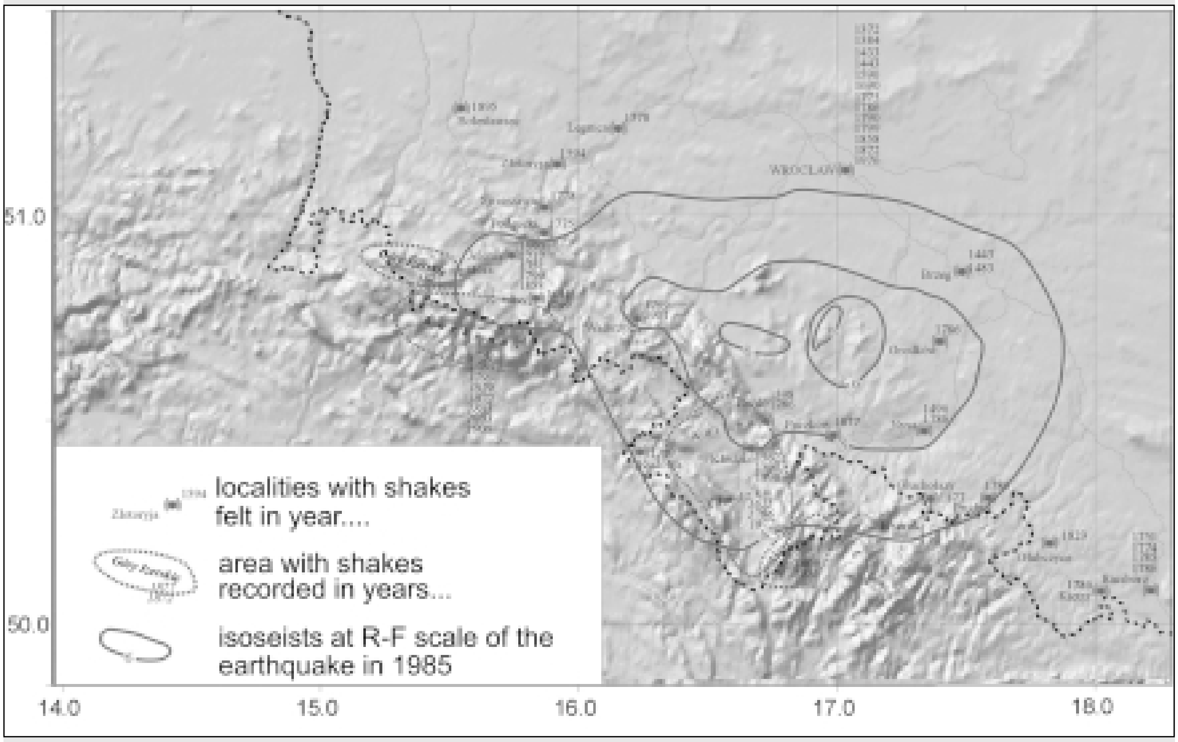

Fig. 6 Historical earthquakes in Lower Silesia (according to BADURA and PRZYBYLSKI 2000)

the inferred SW – NE stress in the studied portion of the Sudetic Marginal Fault is consistent with the results of the borehole breakout analysis performed within adjacent areas (present-day maximum horizontal stress within Fore-Sudetic Monocline SSW–NNE; see JAROSIŃSKI 2005, 2006). To compare the different results on the stress field in the adjacent area Jeseníky region farther to the east, see ŠTĚPANČÍKOVÁ et al. (in print). Also preliminary GPS measurements within the regional network EAST SUDETEN differ from the above mentioned inferred stress field (see SCHENK et al. 2003).

Ongoing tectonic activity in broader area is also evidenced by historical earthquakes (**Fig. 6**). In the adjacent area to the studied region, the earthquakes stroke especially Klodzko basin and the surroundings of Strzelin (OLCZAK 1962, PAGACZEWSKI 1972). Although the historical earthquakes were recorded within the Sudetic and Fore-Sudetic area in the broader zone of the Sudetic Marginal Fault in 15 – 19th century, the 20th century seems to be quiet (GUTERCH and LEWANDOWSKA-MARCINIAK 2002). The epicentre of the historical earthquake from 25 November 1877, which was felt according to PAGACZEWSKI (1992) near Stronie Śląskie, Głuchołazy, Paczków and Bystrzyca Kłodzka towns, authors GUTERCH and LEWANDOWSKA-MARCINIAK (2002) put close to Javorník town. However, no remarks can be found in parish chronicles of Jeseník nor Javorník town; so, probably the epicentre was later misplaced.

The present day seismic activity in the Sudeten (Mts) concentrates rather to the eastern part of the Jeseníky region (Opava, Šumperk region; HAVÍŘ 2002, KALÁB and KNEJZLÍK 2004). In 1986 from June to September, a swarm stroke the area NE of the Šumperk town. The maximum local magnitude reached M_L = 3,8 and intesity in epicentre I = 5,5˚ MSK-64 (PROCHÁZKOVÁ 1988). In the western surroundings of the studied part of the Sudeten (Mts) seismic activity is also recorded. It concentrates in the Hronov-Poříčí Fault zone, where shakes reach I = 4˚ – 7˚ (KÁRNÍK et al. 1981). Also CO_2 emanation and mineral or thermal springs linked to the sudetic faults and their crossing with faults of other directions confirm ongoing tectonic activity in the broader region (see e.g. BUDAY et al. 1995, BADURA and PRZYBYLSKI 2000).

4 Conclusion

The described morphostructural evolution of the studied area appeared to be very complex. The Sokolský hřbet (Ridge) as a NE part of the Rychlebské hory (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). Thus, the horst-like structure of the ridge is a result of this differential, asymmetric uplift.

New knowledge revealed by our morphotectonic research deals particularly with tectonic activity during Pleistocene and Holocene. Basing on anomalies in longitudinal terrace profiles within the adjacent Žulovská pahorkatina (Hilly land), the Middle and Late Pleistocene uplift is suggested. The uplift is very probably related to glacio-isostatic rebound, which caused a deformation of the fluvial/alluvial deposits levels. The uplift rate diminishes towards the Late Pleistocene, from about 20 m to 5 m.

Moreover, paleoseismological trenching within the SMF zone revealed thrusting during Pleistocene/Holocene and probably repeated in Late Holocene. The ongoing uplift of the studied portion of the SMF zone was confirmed by spatial arrangements of the valley segments of enhanced erosion/rejuvenated erosional phase within the studied Sokolský hřbet (Ridge), where the beginnings of the stretches are concentrated at the foot of the marginal fault scarps of the ridge. Erosion rates diminishes towards the NE, which is in accordance with the above mentioned differential, asymmetrical uplift.

In addition, the results of field mapping correspond to the results of 3D monitoring of micro-displacements on tectonic structures by deformeters TM71. Based on the recorded movements (10^{-1} – 10^{-2} mm/year), having aseismic character, with prevailing vertical component, the inferred compressive stress comes generally from the southern sector (SW – NE to SE – NW). It would imply dextral transpression in the studied portion of the SMF, where the northern part - the Sokolský hřbet (Ridge) - is thrusting over the southern one - SE sector of the Rychlebské hory (Mts). The compression within the SMF zone is consistent also with Polish geodetic surveys (precise levelling, GPS) carried out farther NW.

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