S T U D I A G E O M O R P H O L O G I C A C A R P A T H O - B A L C A N I C A

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GEOMORPHOLOGICAL CONDITIONS OF THE MINE AREA TROJANOVICE IN THE MORAVIAN-SILESIAN CARPATHIANS, CZECH REPUBLIC

Abstract. The authors analyzed the flysch relief of the Trojanovice mine area in the Moravian-Silesian Carpathians. The studied relief is a result of the erosion megaphase in Pliocene caused by neotectonic movements, spreading and climatic changes. Compilation of digital geomorphological map enabled quantitative evaluation of the relief and geomorphological processes. Author distinguished 3 levels of pediments and alluvial fans coalescing into bahada. The flysch relief is very sensitive to any human impact due to high degree of slope instability.

Key words: the Moravian-Silesian Carpathians, geomorphological mapping, Pliocene erosion megaphase, rock pediments, bahada and geohazards

INTRODUCTION

The Moravian-Silesian Carpathians (S t r á n í k et al. 1993) are the westernmost member of the Western Carpathians in the southeastern part of the Czech Republic (Figs. 1 and 2). The hard coal mine area of Trojanovice in the Moravian-Silesian Carpathians was proclaimed on June 30, 1989; with an area of 63.17 sq. km, it is one of the largest mining areas in the Czech Republic. The mine area stretches from the edge of the Moravian-Silesian Beskids in the south and south-west through the depression of Frenštátská brázda in the centre to the Ondřejník highland in the north-east (Figs. 2 and 3; Tab. 1). The coal-bearing Carboniferous deposits extend from the town of Frenštát pod Radhoštěm to the foot of the Moravian-Silesian Beskids in the south. Two hard coal deposits are situated in the Trojanovice mine area: Frenštát-West and Frenštát-East. The total reserve of black coal reaches 1.5 billion tons. Two winding shafts over 1000 m deep were sunk in Trojanovice in the 1980s. These winding shafts are now conserved but there are still discussions about the underground mining of hard coal or natural gas in the mine area of Trojanovice.

Fig. 1. The Moravian-Silesian Carpathians on the territory of the Czech Republic with the location of the studied area (mine area Trojanovice)

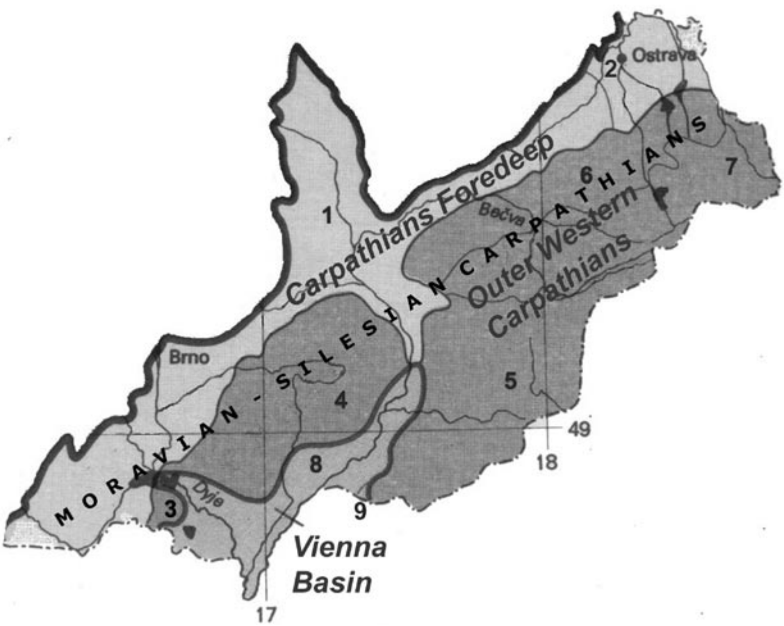

Fig. 2. The Moravian-Silesian Carpathians and the Pannonian Basin (Vienna Basin) in the southeastern part of the Czech Republic. Explanations: the Moravian-Silesian Carpathians 1 — the Western Carpathians Foredeep, 2 — the Northern Carpathians Foredeep, 3 — the South Moravian Carpathians, 4 — the Central Moravian Carpathians, 5 — the Moravian-Slovakian Carpathians, 6 — the Beskidian Foothils, 7 — the Western Beskids. The Pannonian Basin, Vienna Basin, 8 — the Lower Moravian Graben

Table 1

Hierarchy of geomorphological units composing the mine area Trojanovice (Figs. 1 and 3)

<table>
<tr><td colspan="12">Moravian-Silesian Carpathians</td></tr>
<tr><td>GS</td><td colspan="11">IX Outer Western Carpathians</td></tr>
<tr><td>GSS</td><td colspan="8">IXD Západobeskydské podhůří (piedmont)</td><td colspan="3">IX F Western Beskids (mountains)</td></tr>
<tr><td>GU</td><td colspan="8">IXD-1 Podbeskydská pahorkatina (hillyland)</td><td colspan="3">IXF-3 Moravian Silesian Beskids (mountains)</td></tr>
<tr><td>GSU</td><td>IXD-1E Štramberská vrchovina (highland)</td><td colspan="7">IXD-1E Frenštátská brázda (furrow)</td><td colspan="3">IXE-3A Radhošťská hornatina (mountains)</td></tr>
<tr><td>GW</td><td>IXD-1D-3 Ondřejník (ridge)</td><td>IXE-1E-1 Lysohorské podhůří (piedmont)</td><td colspan="6">IXD-1E-2 Radhoštské podhůří (piedmont)</td><td colspan="3">IXE-3A-1 Hodslavický Javorník (mountains)</td></tr>
<tr><td>GSW</td><td></td><td>IXE-1E-1-b Čeladenská kotlina (basin)</td><td>IXD - 1E - 2 -a Licháková kotlina (basin)</td><td>IXD-1E-2-b Helštýn monadnock</td><td>IXD-1E-2-c Trojanovická brázda (furrow)</td><td>IXD-1E-2-d Kunčická pahorkatina (hilly land)</td><td>IXD-1E-2-e Žarský hřbet (ridge)</td><td>IXD-1E-2-f Humbarecký práh (ridge)</td><td>IXE-3A-1-a Velkojavornická hornatina (mountains)</td><td>IXE-3A-1-b Horečská vrchovina (highland)</td><td>IXE-3A-2 Radhošťský hřbet (ridge)</td></tr>
</table>

Explanation: GS — geomorphological system, GSS — geomorphological subsystem, GU — geomorphological unit, GSU — geomorphological subunit, GW — geomorphological ward, GSW — geomorphological subward

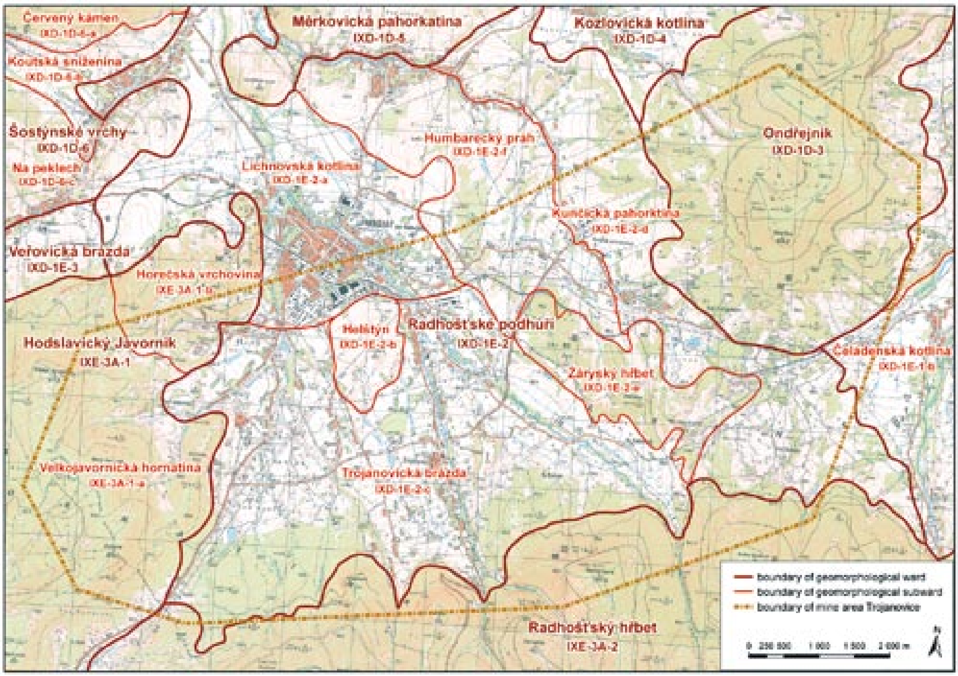

Fig. 3. Location of the mine area Trojanovice in the Moravian-Silesian Carpathians, geomorphological units

METHODS

The authors used the method of detailed geomorphological mapping, evaluation of borings and remote sensing data. Information obtained by field mapping and by remote sensing was visualized in colour digital geomorphological map of the area at 1 : 10 000 scale (Figs. 4A and 5). The ESRI ArcGIS 9.2 software was used during the work. The related geomorphological database consists of 3 layers (polygon, point symbol and line symbol layer) in the ESRI format (SHP). Other methods used in the study were structural-geomorphological analysis, engineering-geomorphological analysis and modelling in the GIS environment.

STUDY AREA

MORPHOSTRUCTURAL SETTING

The study area is situated at the edge of the Carpathian orogenic front where collision of the northern part of the African plate with Eurasian lithospheric plate occurred from the Upper Cretaceous to the Tertiary. The study area lies on Moravian-Silesian terrane that was formed by two overlapping structural levels.

The lower level of the terrane consists of a Proterozoic crystalline complex (Brunovistulicum — D u d e k 1980, M e n č í k et al.1983, D o p i t a et al. 1997). The upper level is formed by a folded and faulted Devonian-Carboniferous complex of Variscan age (M ü l l e r ed. 2001). In the Czech part of the Upper Silesian basin, coal-bearing strata (Namurian and Westphalian A, B) generally dip southwards, beneath the complexes of the Western Outer Carpathian sediments. In the Tertiary, during the Alpine orogeny, the margins of the Pannonian block were thrusted over the levelled and deeply weathered surface of the Moravian-Silesian terrane. The thrust occurred in two phases, i.e. during the Old Styrian and the Young Styrian. The Old Styrian and the Young Styrian flysch nappes were overthrusted along nearly horizontal thrust planes over the foreland, formed by the Moravian-Silesian terrane (C h l u p á č et al. 2002). The flysch nappes in the mine area belong to the Silesian and Subsilesian units of the outer group the Western Outer Carpathian nappes of Jurassic to Oligocene ages (C h l u p á č et al. 2002). The Godula Nappe of the Silesian Unit was thrusted over the Subsilesian Unit and the sediments of Miocene age that were discordantly deposited on the subjacent productive Carboniferous layers of the Moravian-Silesian terrane. Rocks of the flysch nappes are strongly tectonically deformed (M a r t i n e c et al. 2008, p. 144). The study of deep borings has shown that the thickness of flysch nappes beneath the front escarpment of the Moravian-Silesian Beskids reaches 850–1200 m in the Trojanovice mine area. There is still the residual shear stress at the base of the Subsilesian Nappe despite the fact that the main overthrusting movements of this particular nappe ended already in the Badenian (K r e j č í et al. 2004, p. 99).

Two winding shafts (No. 4 and No. 5), with diameters of 8.5 m were sunk into the depths exceeding 1000 meters in the years 1984–1988 in the Frenštát-West hard coal mine in the village of Trojanovice (M a r t i n e c et al. 2008).

GENERAL GEOMORPHOLOGICAL CONDITIONS

The mine area of Trojanovice is situated in the rugged terrain on the contact of mountainous relief of the Moravian-Silesian Beskids, intramontane depression of Frenštátská brázda and the highland of Štramberská vrchovina in the Moravian-Silesian Carpathians (Tab. 1).The mine area includes the eastern section of Hodslavický Javorník (a part of the Moravian- Silesian Beskids). The relief of Hodslavický Javorník Mts. is distinctively stepped (Fig. 4A). The elevations of individual steps (blocks) sink from the highest Mt Velký Javorník (917.8 m a.s.l.) in the eastern direction towards the Pindula Pass and to the depression of Frenštátská brázda. Particular flat-top blocks are separated by steep scarps (Fig. 4A). Pseudokarst landforms (closed drainless depressions, pseudokarst dolines) are common at the foot of the scarps and provide evidence of deep-seated slide surfaces. Mountain fronts are dissected by deep valleys of left tributaries of the Lubina River. There are many landslides on steep valley sides (Ž i ž k o v á, P á n e k 2006).

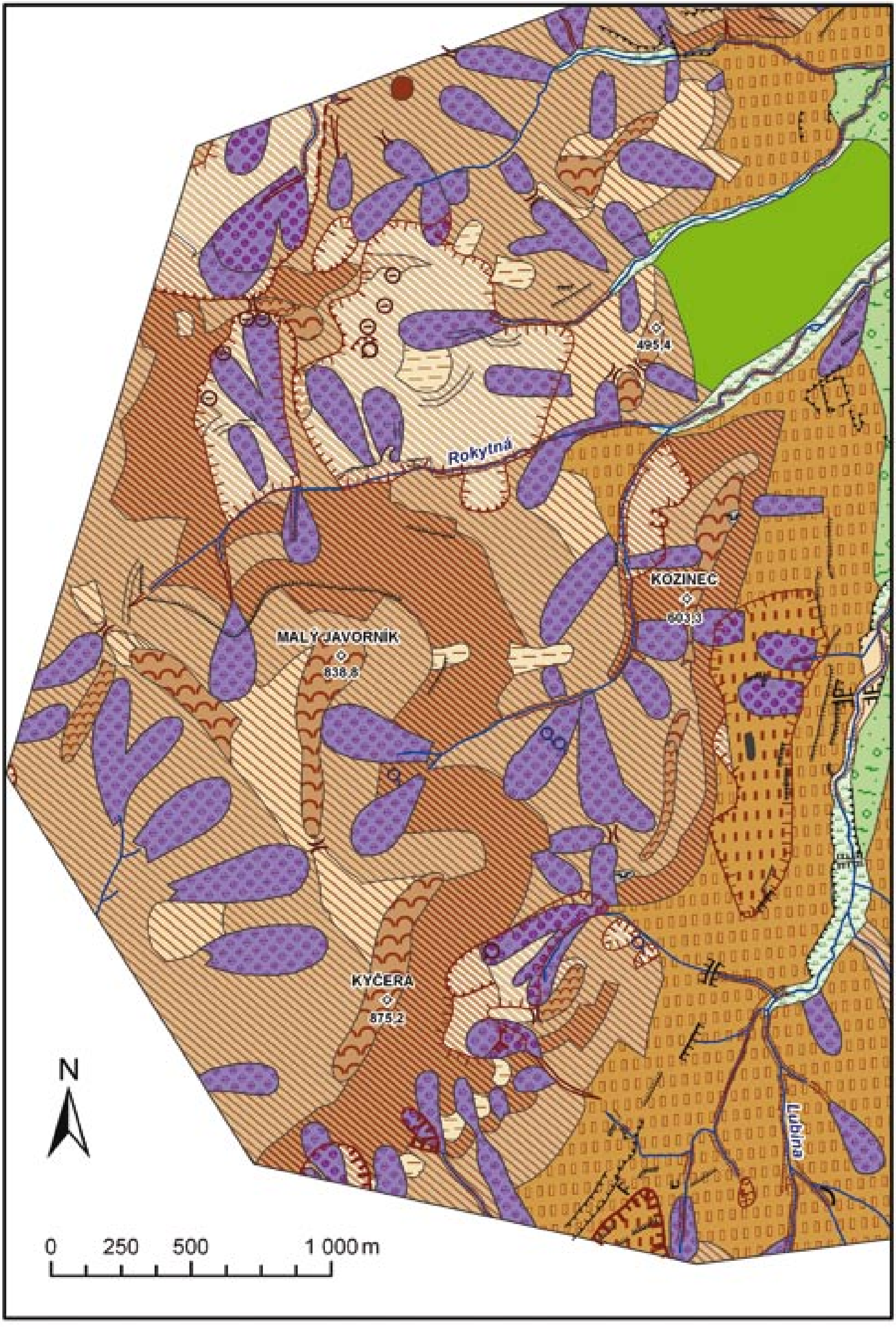

Fig. 4A. Digital geomorphological map of the Hodslavický Javorník in the western part of the mine area Trojanovice

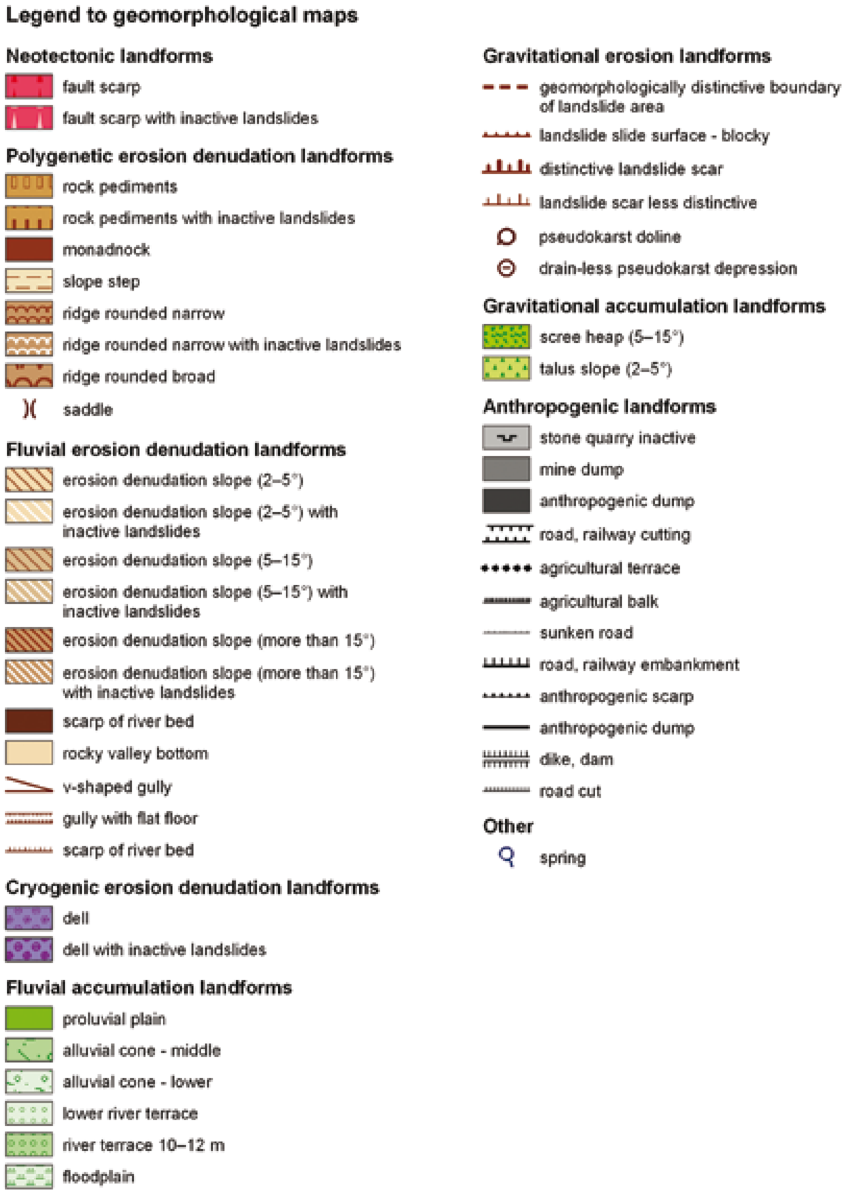

Fig. 4B. Legend to digital geomorphological maps

Fig. 5. The basin Trojanovická brázda and the front escarpment of the Moravian-Silesian Beskids with rock pediments at the foot

The southern part of the mine area extends onto the ridge of Radhošťský hřbet (a part of the Moravian-Silesian Beskids). The steep northern front escarpment of the mountains is dissected by deep valleys of the Lubina River and its tributaries (Radhoštnice, Bystrá). The striking steps on the front escarpment are subsided blocks of resistant Middle Godula sandstones. Pediments developed at the foot of the front escarpment (Fig. 5, D e m e k et al. 2011).

The core of the mine area lies in the depression of Frenštátská brázda. The Frenštátská brázda is an intramontane depression situated between the Moravian-Silesian Beskids in the south and the west, and the highland of Štramberská vrchovina in the north. The central part of the Frenštátská brázda to the south of the town of Frenštát pod Radhoštěm is called Trojanovická brázda (Furrow) (Figs. 3 and 5). The flat bottom of the depression of Trojanovická brázda features three rock pediment levels, partly covered by gravels of alluvial fans of the Lubina River and its tributaries (B u z e k 1969, 1972, 1973; I v a n 1987). The alluvial fans coalesced into a bahada (Fig. 6). The town of Frenštát pod Radhoštěm is situated on the bahada. The monadnock Helštýn (482 m a.s.l.) rises above the town and above the flat bottom of the Trojanovická brázda, controlled by Cretaceous volcanic rocks (Fig. 6).

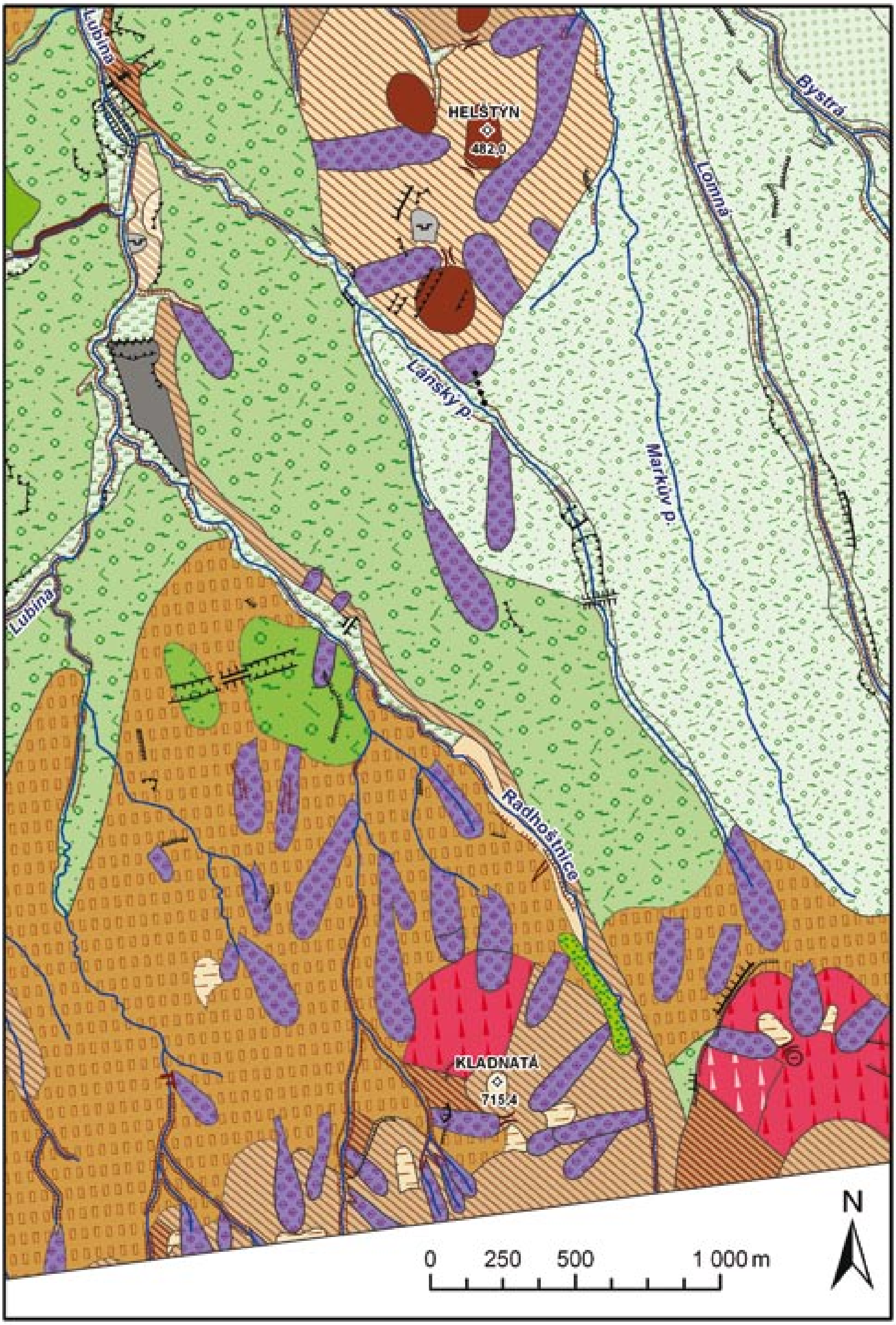

Fig. 6. Digital geomorphological map showing pediments at the foot of the Moravian Silesian Beskids and the bahada to the south of the town of Frenštát. Legend see Fig. 4B

The steep slopes of the structural subunit Žáryský hřbet limit the depression of Trojanovická brázda in the east (Fig. 3). The flat, top surface of the rigde represents structural flats developed on more resistant sandstone layers. Partly active landslides are common on the steep slopes of Žáryský hřbet . The less distinctive subunit Humpolecký práh forms the NE continuation of the ridge of Žáryský hřbet. The depression of Kunčická pahorkatina, drained by the Tichávka River, flanks the foot of the Ondřejník ridge and also the foot of the ridge of Radhošťský hřbet. The bottom of the Kunčická pahorkatina depression is formed by both rock pediments and alluvial fans coalescing into a bahada.

A distinctive part of the Štramberská vrchovina, Ondřejník, reaches 964.2 m a.s.l. at Mt Skalka (Fig. 3) and forms a central synclinal ridge composed of the resistant Middle Godula sandstones. The wide ridge is affected by several types of geodynamic processes (R y b á ř et al. 2006, P á n e k et al. 2011). Slope recession enhanced development of cuestas on the western side of the ridge. (B u z e k 1969, R y b á ř et al. 2006). Many extensive landslides developed on the highland slopes. The disrupted upper part is typified by the occurrence of pseudokarst landforms, including pseudokarst caves (H r o m a s et al. 2009).

RESULTS

NEOTECTONIC FAULT SCARPS

The northern front escarpment of the Moravian-Silesian Beskids is traditionally interpreted as a structural scarp on the head of the Godula Nappe. The author's analysis has shown that some parts of this escarpment are neotectonic fault scarps controlled by movements of blocks along faults parallel with the escarpment. These rejuvenated faults, detected in the Variscan basement, propagated through the flysch nappes to the surface. The fault systems are also marked on the geological map of E. M e n č í k and J. T y r á č e k (1985). The striking steps on the front escarpment are subsided blocks of resistant Middle Godula sandstones.

LITHOLOGICAL CONTROL

Rocks composing the mine area vary in resistance to weathering and erosion. Very resistant to erosion are coarse-grained quartzy sandstones of the Middle and Lower Godula Formation. Medium resistance is typical of silicified quartzy sandstones containing glauconite (Lhota Formation) and deposits of the Godula Formation (especially up to several metres thick layers of coarse- to medium-grained quartzy Ostravice sandstones (M ü l l e r ed. 2001). Claystones of the Lhota Formation and Veřovice Member exhibit low resistance to erosion. An important zone of tectonic melange developed at the contact surface of Young Styrian Subsilesian and Silesian Nappes (M a r t i n e c et al. 2008, p. 145). In this zone, the flysch deposits are sliced and extremely unstable, with blocks of rigid rocks.

DENUDATION CHRONOLOGY

Traditionally, the study of relief is focused on the analysis of the sequence and nature of geomorphological events recorded in the present configuration of the land surface (G u t i é r r e z 2005). This approach, called denudation chronology, is based mainly on the study of neotectonic landforms, planation surfaces, drainage patterns and slope deformations (W i t t o w 1984). Denudation chronology of the Moravian-Silesian Carpathians is closely connected with the information from Polish and Slovak Carpathians (B i z u b o v á 1998, M i n á r et al. 2004, P e t r v a l s k á 2009, Z u c h i e w i c z 2009).

THE EROSION MEGAPHASE IN PLIOCENE

The destruction of the Carpathian nappes started in the Pannonian, but the contemporary relief of the Moravian-Silesian Carpathians is mainly the result of the selective erosion megaphase in the Pliocene. Pliocene erosion initiated by neotectonic movements and climatic changes individualized geomorphological units of different order (mountain ranges, basins, hills, monadnocks). The origin of differences in altitudes and the formation of high and steep erosional valley slopes substantially contributed to the development of gravitational tectonics. Relief inversion developed in many places (e.g. synclinal massif of Ondřejník). The amount of material removed during the Pliocene erosion megaphase must have been tremendous.

Apatite fission-track analysis was used to investigate the amount of erosion and geomorphological evolution of the Moravian-Silesian Carpathians. After O. K r e j č í et al. (2004, p. 98) the post-Badenian erosion of mountain summit parts of Moravian-Silesian Beskids reached 1 to 2 km. M. B í l et al. (2004, p. 64, 2005, p. 70) estimate the amount of post-Sarmatian erosion in the White Carpathians at approximately 1.4 km in the last 12 Ma years. M. D a n i š í k et al. (2008, p. 286) concluded that the post-Panonian erosion reached roughly 2 km in the Beskids Piedmont. The high post-Panonian erosion (approximately 2 km) in the Moravian-Silesian Carpathians contradicts the data from Polish Outer Carpathians where Pliocene-Quaternary tectonic mobility seems to have been relatively weak (Z u c h i e w i c z et al. 2002, Z u c h i e w i c z 2009). The lack of Pliocene correlative deposits in the Moravian-Silesian Carpathians from these erosion phases makes precise dating of planation episodes impossible (Z u c h i e w i c z 2009, p. 294).

PLANATION SURFACES – ROCK PEDIMENTS

The bottom of the Trojanovická brázda consists of rock pediments which are gently inclined from the frontscarp of the Moravian-Silesian Beskids to the centre of the depression (I v a n 1987). Pediments are essentially rock-cut surfaces that level flysch bedrock of varying resistance to erosion. The flysch rocks here, of Jurrasic to Oligocene age, represent Godula Sub-Nappe in the Silesian Unit of the outer group of nappes of the Moravian-Silesian Carpathians (B u z e k 1969). From the frontscarp of the Moravian-Silesian Beskids onwards there are layers of the Middle and Lower Godula Formation, Godula Formation, Lhota Formation, Veřovice Member and the Hradiště Formation (M ü l l e r ed. 2001). According to the present knowledge, pediments in the Trojanovická brázda occur at least at two and presumably at three levels. The higher level of pediments (the upper pediment) has been found on a narrow ridge running northeast from the village of Trojanovice above the Lomná River. At the foot of the frontscarp of the Moravian-Silesian Beskids, the elevation of the upper pediment ranges from 515 m a.s.l. in the north to 565 m a.s.l. (25 m above the Lomná River) in the south. On both sides, the erosion remnant of the upper pediment is limited by steep erosion slopes with protruding bedrock (sandstones of the Hradiště Formation and claystones of the Veřovice Member). Especially the western slope is rocky, expressive and steep. The upper rock pediment is partly covered by gravels of the alluvial fan. On the geological map (P e s l ed. 1981), the gravels are classified as proluvial gravels of preglacial age (Lower Pleistocene).

South of the locality Na Bystrém, a smaller remnant of the upper pediment is preserved at 549.1 m a.s.l. on the forested ridge on the rocks of the Lhota Formation. Another remnant of the dissected upper pediment is preserved on a rounded hill composed of claystones of the Veřovice Member (491.8 m a.s.l.), on the divide between the Malý Škaredý Brook and the Radhoštnice River to the east from the settlement of Buzkovice (part of the Trojanovice village (Fig. 6)).

The authors also found the upper pediment around Tížová (448.9 m a.s.l.), on the southeastern slope of Humbarecký práh (see Fig. 3) on the contact with Trojanovická brázda. In contrast to the above mentioned remnants of the higher pediment, the cover of this rock pediment is composed of proluvial gravels of Middle Pleistocene age. (R o t h ed. 1989).

The middle level of pediments (middle pediment) occupies a large area at the bottom of Trojanovická brázda, reaching 550 m a.s.l. in the south, at the foot of the frontscarp of the Moravian-Silesian Beskids and 420 m a.s.l. (15 m above the Lubina River) in the north around the town of Frenštát pod Radhoštěm. In the western part of Trojanovická brázda, at the locality of Na pasekách, the bedrock surface of the middle pediment is present on the divide between the Lubina River and The Malý Škaredý Brook, forming the foot of the steep foreland of the Moravian-Silesian Beskids up to the settlement of Buzkovice (part of Trojanovice). The bedrock of the middle pediment, composed of black-grey claystones of the Veřovice Member, also appears on surface on the divide between the Malý Škaredý Brook and the Radhoštnice River up to the settlement of Kopaná (part of the town of Frenštát pod Radhoštěm — Fig. 5). The bedrock base of the middle pediment is also exposed on the right side of the incised valley of the Radhoštnice River. The bedrock surface of the middle pediment appears as a narrow strip on the divide between the Radhoštnice River and the Lomná River at the foot of the foreland of the Moravian-Silesian Beskids (Fig. 5). On the other side, the outcrops of the middle pediment bedrock commonly occur on the surface of the divide between the Lomná River and the Bystrá River. The gently inclined bedrock surface of the middle pediment cuts mostly flysch rocks of the Lhota Formation, while the Hradiště Formation appears near the locality of Háje and extends north up to Na Bystrém. Close to the foot of the steep frontscarp of the Moravian-Silesian Beskids,the pediment surface is covered by slope deposits . In this area, the thickness of these deposits exposed in gullies reaches 12 m. The inclination of the pediment surface close to the foot of the steep frontscarp ranges from 5 to 15 degrees. The inclination of the rock pediment surface decreases northwards to 2 degrees.

Also the low pediment presumably developed in the Trojanovická brázda, bounded on the rock bottom of the Lubina River valley and its tributary valleys. The evidence of relation of the low pediment to rock bottom of valleys was found in boreholes from a construction site of the mine (Frenštát-West) in the village of Trojanovice, at the foot of the steep foreland of the Hodslavický Javorník Mts. The low pediment levels the deposits of the Lhota Formation. The bedrock of the rock pediment is covered by fluvial gravels, up to 4 m thick, and by younger slope deposits up to 16 m thick (P o l á š k o v á, P o l á š e k 1981). The number of bore holes available to the authors is not sufficient to allow delimiting the areal extent of this low pediment.

Rock pediments also developed in the southern part of the Kunčická pahorkatina depression at the foot of the steep front escarpment of the Moravian-Silesian Beskids, locally called Pod Stolovou. In the northern part of the Kunčická pahorkatina depression the authors mapped rock pediments at the foot of the western slope of the Ondřejník ridge in the village of Kunčice pod Ondřejníkem (Fig. 3).

QUATERNARY ALLUVIAL FANS AND BAHADA

Rock pediments in the mine area are partly covered by Quaternary sediments. Together with the above mentioned slope deposits, there are mainly sands and gravels of periglacial alluvial fans which were deposited by streams and gravity flows coming from the Moravian-Silesian Beskids (Ž e b e r a 1955, R ů ž i č k o v á et al. 2001, p. 13). The authors used the term bahada (bajada) for alluvial plains formed on the lower parts of pediments, in periglacial climate of the Pleistocene, as a result of lateral growth of adjacent alluvial fans which ultimately coalesced to form a continuous inclined deposit along the mountain front escarpment of the Moravian-Silesian Beskids (Fig. 5). The sediments of alluvial fans mostly consist of gravels of various grading, with low degree of sorting and subangular to subround clasts. Alluvial fans are of Quaternary age, but their precise age is still a subject of discussion. The authors used the method of alluvial fan dating applied in geological mapping of the Czech Republic at the scale of 1 : 50,000

(P e s l ed. 1981, R o t h ed. 1989). Alluvial fans developed at several levels and partly cover rock pediments.

COMMENTS TO GENERAL GEOMORPHOLOGICAL MAPS

Detailed geomorphological maps are based on the philosophy of the IGU International legend of geomorphological maps (B a s h e n i n a et al. 1968, D e m e k ed. 1972). Geomorphological information obtained from field work, aerial photographs, satellite images and bore holes was stored in a geomorphological database consisting of three layers (polygon, point symbol and line symbol layer). Basic mapping unit represents a discrete landform, i.e. a discrete morphologic feature that is a functionally interrelated part of the land surface formed by a specific geomorphological process or set of processes. Shapes and locations of landforms are shown by contour lines and spot-heights. In addition to the contour lines, information on slope gradients is given. Landforms were divided into genetic groups in agreement with the above mentioned principles of the IGU Commission (Fig. 4B). Information stored in the database was visualised in the GIS environment as a digital geomorphological map at the scale of 1 : 10,000. (Fig. 4A and 6).

DISCUSSION ON DENUDATION CHRONOLOGY

The horizontal movements of flysch nappes ended in the Trojanovice mine area in the Badenian. Today, the mountains of the Moravian-Silesian Beskids (e.g. Mt Radhošť 1128.7 m a.s.l., Mt Kněhyně 1256.8 m a.s.l.) reach higher elevations than one should expect in the case of the simple overthrust of the Silesian and Subsilesian Nappes along nearly horizontal overthrust planes over the basement of the Moravian-Silesian terrane and its Neogene cover (K r e j č í et al. 2004). The whole territory must have been uplifted due to neotectonics and isostatic movement with gravitational faulting and spreading after the Badenian. Neotectonic movements and climatic changes caused tremendous erosion megaphase in the Pliocene. These geodynamic processes resulted in a disequilibrium in rocks and the large stress even increased by the dissection of the landscape by deep valleys of streams in the Pliocene and Quaternary. The stress caused common deep-seated deformations of rocks apparent in stepped structure of the relief. The Pliocene erosion articulated differences in the resistance of rocks in relation to weathering and erosion in the relief.

The authors suggest lithological control of flat top surfaces on ridges of the Ondřejník and Žáryský hřbet, which were earlier interpreted as planation surfaces (B u z e k 1969). Also the cuestas on the western slope of Ondřejník are lithologically controlled.

Typical and important landforms of the studied area are the rock pediments: rock-cut surfaces that level flysch rocks of various resistance to erosion (B u z e k 1969). Rock pediments form bottoms of depressions and surface of hilly land at foot of mountain escarpments. Rock pediments are controversial landforms and the world geomorphological literature presents two main theories of their origin:

i) Pediments are regarded as an active basal slope or slope of transport, left by recession of the mountain front,

ii) Pediments are formed by lateral planation by running water (W i t h e r - i c k et al. 2001, p.196). The processes of weak strata planation and formation of rock pediments, initially by rills and gullies and subsequently by distributary streams, were described by C. R. T w i d a l e (1978).

It has also been noted that pediments are usually associated with relief development in dry and subtropical climate (M e n s c h i n g 1968). Pediments also develop in humid tropics (W h i t t o w 1984, p. 391) and in periglacial climate (W a k o 1963, D e m e k 1972).The authors did not find evidence of recession of steep front escarpment of the Moravian-Silesian Beskids composed of resistant flysch sandstones of the Middle Godula Formation. Therefore, it is possible to agree with the opinion of A. I v a n (1987) that pediments in the studied area developed due to lateral planation by the Lubina River and its tributaries in medium and less resistant rocks of the Silesian Nappe.

The dating of pediment formation remains an open question. Cryogenic slope deposits and gravels and sands of Quaternary alluvial fans mantle only a part of rock pediment surfaces. Upper rock pediments must have developed in dryer climate of the uppermost Pliocene or Lower Pleistocene. A remnant of preglacial (Lower Pleistocene) gravels and sands (P e s l ed. 1981), mantling a part of higher pediments, can serve as evidence for this opinion. Middle pediments are partly covered by gravels and sands dated on the geological map as Middle and Upper Pleistocene. Coalescing alluvial fans form a periglacial bahada in the northern part of the studied area. It is possible that middle pediments developed as cryopediments during cold periods of Pleistocene.

PSEUDOKARST LANDFORMS

In the study area, deep seated rock deformations are a reason for development of many pseudokarst landforms such as deep open tensile fractures with pseudokarst caves. These processes and landforms are apparent on the front escarpment of the Moravian-Silesian Beskids, the Hodslavický Javorník Mts. (Fig. 4A) and on the slopes of Ondřejník. The evidence of the deep spreading of the Moravian-Silesian Beskids is the Kněhynská pseudokarst cave on slope of Mt Kněhyně (1256.8 m a.s.l.). The cave has been speleologically investigated (a manhole) to the depth of 57.6 m but it continues further inside the rock massif by open tensile fractures (H r o m a s (ed.) et al. 2009). Other pseudokarst caves and abysses controlled by open tensile fractures in the Godula sandstones were described a long time ago (W a g n e r et al. 1990). Dilatometric measurements on tensile fractures have shown that even under present conditions entire rock massifs are in movement. J. W a g n e r (2004) described opening of tensile fissures on the Lukšinec ridge near Mt Lysá after extreme precipitation in 1997.

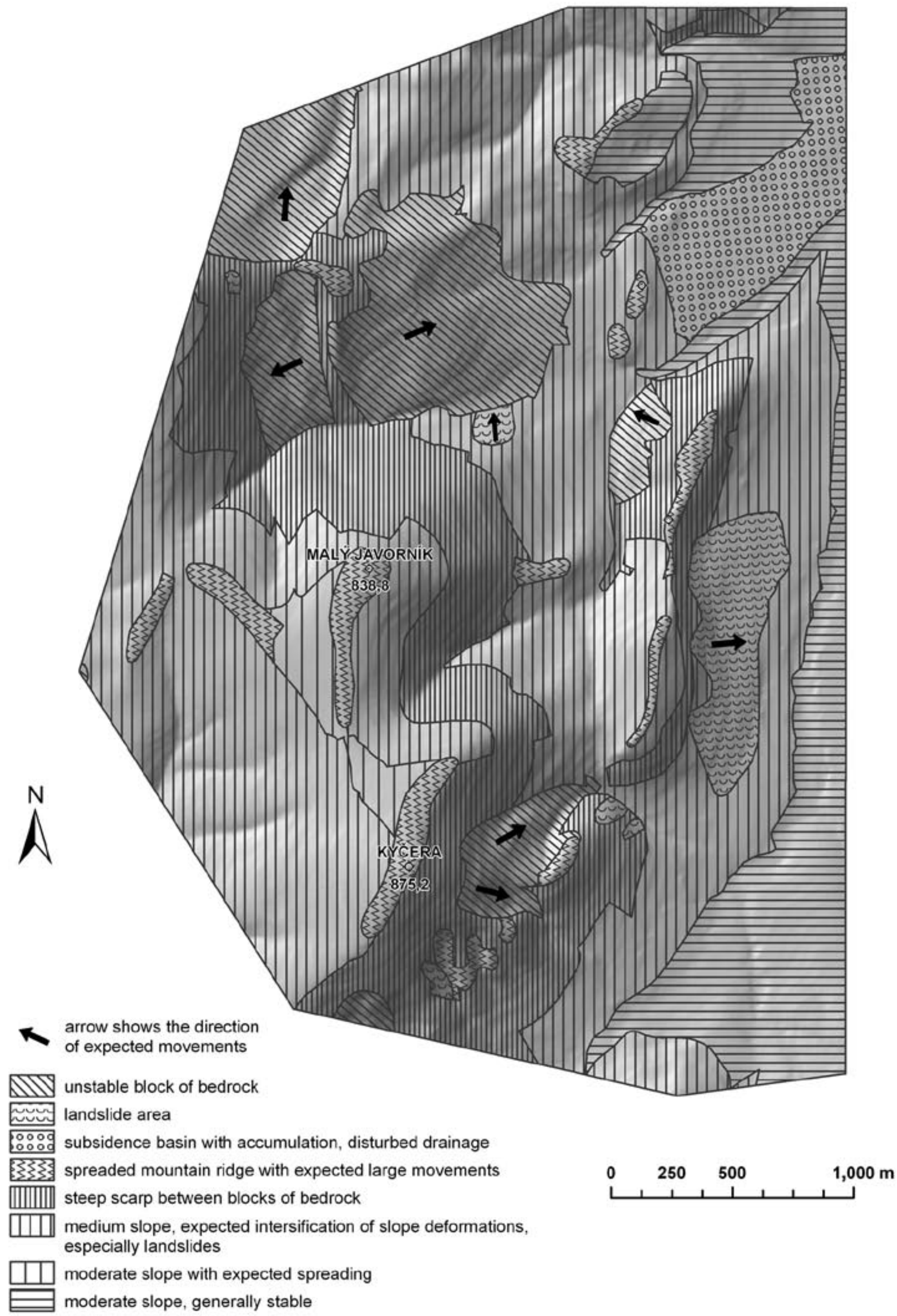

Fig. 7. Digital engineering-geomorphological 3D model of expected terrain deformations and geohazards in relation to planned deep mining of black coal in the western part of the Trojanovice mine area derived from the digital geomorphological map

Piping landforms (closed drainless depressions and pseudokarst dolines) are evidence of open fissures and movement of rock massifs (Fig. 4A).

GEOHAZARDS

There are many slope deformations of several types in the studied area (Fig. 4A). The area is very sensitive to any human actions. Based on geomorphological mapping, the largest impact on relief due to coal mining can be expected in the forested eastern part of Hodslavický Javorník (Fig. 7). The relief of this geomorphological unit is distinctly stepped. Flats forming the surface of subsided or rotated blocks are irregularly changing with steep slopes (J a n o š 2004). The authors present 3D engineering-geomorphological model of expected impacts of a coal mining project on the relief of the western part of the Trojanovice mine area (Fig. 7).

CONCLUSIONS

The Trojanovice mining area was uplifted due to neotectonics and isostatic movement with gravitational faulting and spreading after the Badenian. Neotectonic movements and climatic changes caused tremendous erosion megaphase in the Pliocene. Thus the most landforms in the studied area are of Pliocene age. The geomorphological development resulted in a rugged inversion flysch relief with strong impact of structure. There are no remnants of regional planation surfaces, only local Upper Pliocene and Quaternary rock pediments. Very common are slope deformations of various types. The relief is very sensitive to any human activities. The engineering-geomorphological analysis of the Trojanovice mine area has shown that underground mining activities can cause substantial or catastrophic changes in the relief of the Moravian-Silesian Carpathians. The consequences of underground hard coal mining in such a sensitive young mountain and highland terrain in the Czech Republic need a complex prediction.

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