Acta Geodyn. Geomater., Vol. 5 (151), 267–274, 2008

DESTRUCTION OF MARGINAL PARTS OF SANDSTONE PLATEAUS IN THE PROTECTED LANDSCAPE AREA BOHEMIAN PARADISE

Ingrid FORCZEK

Institute of Rock Structure and Mechanics, Academy of Sciences of the Czech Republic, v.v.i., V Holešovičkách 41, 182 09 Prague, Czech Republic.
Corresponding author's e-mail: inuseinuse@gmail.com

(*Received* May 2008*, accepted* July 2008)

ABSTRACT
The article deals with geodynamical phenomena of marginal parts of sandstone plateaus. The area of interest consists of several partial areas in the Bohemian Paradise natural reserve. These areas rise above terrain as relics of a once uniform sandstone plateau. The current relief developed mainly in the Pleistocene, when the Jizera River carved present day wide valley and the underlying soft clay rocks were uncovered. Thus favorable conditions were created for slow destruction of sandstone plateaus. Here, the slope movements occur up to the present days in the form of landsliding and slow block movements and their epiphenomena. Due to this continuing activity of the slope movements, human settlements and cultural monuments are endangered. Research in this area helps us to clarify the relation between slope movements and other factors, such as the presence of a significant tectonic failure in the vicinity or the influence of the water regime.

KEYWORDS: landslides, block movements, hazard, cleft cave

INTRODUCTION

Landslides and other geodynamical phenomena are very widespread in the area of the Bohemian Cretaceous Basin in north and northeast Bohemia. Their origin is conditioned by morphological, lithological and hydrological settings. Research in the area of Bohemian Paradise was initiated by Prof. Q. Záruba in connection with the catastrophic landslide occurring in 1926 when part of the municipality Dneboh was destroyed (Záruba et al., 1966). In 1963, the governmental research was aimed at complete mapping of the area between the rivers Jizera and Labe from the point of view of geodynamical phenomena. Up to these days, a number of authors engaged in this area from the point of view of diverse problems. Recently, the mechanisms and influences on failure of slope stability are intensively observed at some selected localities of the Bohemian Paradise. I deal with two localities in this article.

1. NATURAL CONDITIONS

The area of interest is a part in the Protected Landscape Area Bohemian Paradise. Some parts are specified as national reservations and natural parks. The whole area is geomorphologically very interesting and variegated. The territory can be characterized by the relief of the thick-bedded sandstones with unrivalled varieties of meso-forms of weathering and erosion of sandstones.

The research area is mainly formed by sediments of the Bohemian Cretaceous Basin. Stratigraphically, the Cretaceous is represented by sediments from Cenomanian to Coniacian. The area is formed by Coniacian thick-bedded sandstones with characteristic cuboidal jointing by a system of subvertical joints and subhorizontal bedding planes. These sediments are the thickest complex of Bohemian Cretaceous and in the space of castellated rocks reach up to 240 m (Ziegler, 1977). The sandstone layers incline to the southeast under angle of 1°. The second most common rock types are Turonian pelites. They comprise of calcareous clays and marls, which do not crop out to the surface, particularly in the original composition. Turonian pelites are covered by sand rock debris and they are affected by old slope deformations, too. Sandy limestones, conglomerates and clays can be found in the area as well.

The occurrence of Tertiary volcanics is also documented there. They are represented by undersurface body, by erosion prepared volcanic vents, dykes, fissure or interfoliated veins. Rarely, the bosses and pipe fillings are indicated (Ziegler, 1977).

The Bohemian Cretaceous Basin was broken up to some minor individual blocks during the saxonian tectonic movements. The area is divided by three systems of Saxonian tectonic structures. The systems consist of: Krušné Hory Mountains system (southwest - northeast), Sudetic system (northwest – southeast) and Jizera system (north – south). The most expressive fault line in the area is the Lugian fault. Along this fault the sandstone layers were dragged out and even toppled over in some places.

THE PROBLEMS OF SLOPE MOVEMENTS

The localities of interest are situated in the central part of the Jizera River valley. The relief of this valley developed mainly in the Pleistocene when the Jizera River incised present day wide valley and the underlying soft argilliferous rocks were uncovered. It means that the geological structure of the area is characterized by two different rock complexes with different mechanical properties. The overlaying complex has a higher solidity than the underlaying complex. The rocks of the overlaying complex are hard, frangible, rigid, and of great shear strength. They are more resistant against weathering, able to keep up the steep of slopes and are very well permeable for water. The rocks of underlaying complex are soft, plastic, compressible and of low shear strength. They are not so resistant against the weathering, able to keep up only a small angle of slopes and they are mostly water impermeable. Relatively soft marls do not provide enough support for overlain frangible sandstones. Marginal blocks of sandstones, broken by fissures, are crumbled away and they are sinking into marls. The marls are deformed and expelled. Very important is the existence of enough intensive erosion, which denudes the complex of underlaying rocks. By this way, the castellated rocks are formed with all other shapes and forms such as the pseudokarst sinkholes (Záruba et al., 1966). The thick debris, which is cumulated in the foreland of the sandstone blocks, is affected by landsliding (Fencl, 1966). Some places lack the accumulated debris and the high sheer cliffs are affected by rock fallings.

The origin of geodynamical phenomena is not conditioned by two–bed structure of slopes only but also by other factors. One of these factors is structure of the rocks. The underlaying marls were strongly affected by periglacial conditions during Pleistocene. The original texture was damaged by discharging and by froze penetration. These processes resulted in failure of the consistency and in creating of slope deformations. The failure of marls was proved up to the depth of 30 m during drilling in the area of the Příhrazy plateau. The marls were totally mixed and they looked like shattered clays. Further factor is the mineral constitution of the rocks. The mechanic properties are affected also by the influence of leaking water, because they have plenty of montmorillonite (Záruba et al., 1966). Another factor is a tectonic failure. Separation and shifting of border sandstone blocks is feasible because of the above mentioned cleavage along tectonic structures. Fissures and faults created in this way are gradually enlarged by contribution of climatic conditions and water. The fissures represent the ideal permeable environment for water and preferentially used as well. At the same time, mechanical abrasion, washing out of elements and deepening of fissures come up very quickly.

TYPES OF SLOPE MOVEMENTS

Two basic types of slope failures are presented in the border parts of sandstone plateaus. One of them happens when the landslides affecting sand debris and rock rots (wastes) of Turonian marls. The slow block movements and their epiphenomena is the other one. The slow creep movements (due to gravitational disintegration) occur mainly above the edge of thick-bedded sandstones in form of inclined blocks, rock towers, pseudokarst sinkholes, linear depressions and fissures. The pseudokarst phenomena are bounded to two main systems of fissures. The dependence on fissures is proved by their ground plan. The longitudinal axes of pseudokarst sinkholes are of the direction of fissures. The most frequently dish-shaped sinkholes are present. Oval or linear sinkholes occur very often as well. Dish-shaped sinkholes visible in the ground are the first signs of dilatating fissures. At some places several sinkholes join to one linear sinkhole. In some cases, linear sinkholes continue to the edge of rock wall and verge into crevasse fluently (Forczek-Kyrianová, 2003).

In some places rock walls are able to keep up steep inclination and height of more than 10 m. Surface weathering proceeds very quickly under present climatic conditions, so that the sand debris cumulates on the bottom of rock walls. Exposed blocks have no support which can cause the rock falls. These high walls also allow keep up higher inclinations of debris slopes than can be possible without any support. Because of this higher inclination, the debris is more sensitive and susceptible to landsliding.

Senonian sandstones are very well permeable. The precipitation goes quickly through and stops on the surface of impermeable Turonian marls. In this way, a significant horizon of groundwater is created, which effects origin of landslides. This groundwater also feeds the debris. Where the marls are damaged, the water is not able to keep up on their surface. Therefore, the water does not cumulate in the debris and the slopes can start to slide after efficient rainfalls only (Záruba et al., 1966).

RESEARCH OF GEODYNAMICAL PHENOMENA ON SELECTED LOCALITIES

PŘÍHRAZY PLATEAU

The Příhrazy plateau is a slightly tectonically deformed sandstone block with rock formations moderately inclined from the northwest to the southeast. The originally compact table is divided by deep valleys with character of canyons and gorges without constant water flows (Balatka, 1980). Numerous forms of selected weathering and of removal of rocks, often of pseudokarst character can be found. Furthermore various forms of block movements and landslides in foot debris can be found. The Příhrazy plateau has been preserved as a relict of originally compact table due to the volcanic neck of

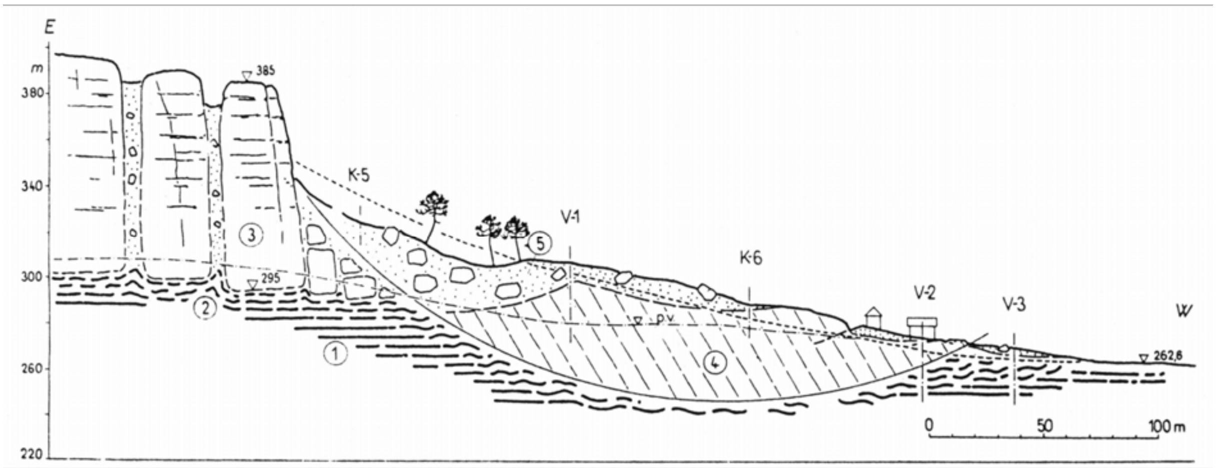

Fig. 1 Geological profile across landslide on the NW edge of the Příhrazy plateau. 1 – calcareous claystones; 2 – claystones with mixed texture; 3 – sandstones; 4 – landslide mass (claystones); 5 – debris; K5, K6 – borrow pits; V1 to V3 – boreholes (after Záruba et al., 1966)

the Mužský hill. The Mužský hill is an uncovered volcanic vent of olivinic-nefelitic composition.

Current forms of slope deformations were considered to be inactive for a long time, particularly fossil under present climatic conditions. Only morphologically relatively fresh block dumps gave evidence for occasional activity of rockfalling. Also landslides of debris and marls in the lower parts of slopes show occasional activity in dependence on the current climatic and morphological conditions. A new failure of a small rock tower was found above the large slope deformation near Olšina village in 1990. Also the new sinking of cover layer and suffosion phenomena along fissures were found in sandstones. The recorded occasional effluences of groundwater in the lower parts of slopes elute sand-clay material (Stemberk and Zvelebil, 1999).

To confirm the present activity of slope movements, a regular measuring of relative movements of blocks has been started by tactile dilatometric method at the northern slope of Mužský hill in 1990; over the edge of the extensive block deformation of the above mentioned thick-bedded sandstone tower. The activity of slope movements was successfully confirmed. Their movement rate achieves 1-2 mm/year as was evaluated in the case of the observed rock tower. The character of the movement (long-term linear course which accelerates after long rainfalls) shows that it continues to the underlaying marl layers, which are situated at the depth of cca 65 m.

In 1999, the control measuring was supplemented. The crack gauge TM 71 was installed in a crevasse near the locality of Drábské Světničky. The crevasse is a narrow, linear depression running parallel to the edge of the plateau. The depression is opened up to 20 – 30 cm. The results show that the movements are active also in this place. These movements are one order less than at the first locality (Stemberk and Zvelebil, 1999). The measurements go on continually at both localities.

Záruba et al. (1966) performed the systematic exploration of one landslide in 1966 on the northwest edge of the Příhrazy plateau. 3 core holes and 5 borrow pits were bored. Samples were taken from the holes to determine physico-mechanical properties and for petrographical analyses. Water samples were taken for chemical analysis as well. The authors conclude that it has been an old landslide territory, where further movements occur after long periods of inactivity. It has been deduced from the cross sections, that at the foothill rock walls, sandy debris sunk deep and lower on the slope marls rise near to surface. It was found both by the core holes and the borrow pits, that marls are deeply mixed in the landslide area and that they have a lacerated clay character to the depth of 30 m. Therefore this landslide is presented as a deeply based one with rotary slip surface (Fig. 1). The geologic observation was supported by calculation of stability.

Based on more recent observations of the landslide areas, it seems that the studied landslides are shallower with planar or rotate-planar slipping planes, which is confirmed especially by the shape of terrain and cross sections.

Therefore, two boreholes (Ol 1, Ol 2) were made on the northwest edge of the Příhrazy plateau in December 2006. Both boreholes are situated on the accumulation of the large landslide (Fig. 2) in order to get more accurate conception of the character of destruction of the marginal parts of the plateau. Both holes are equipped for monitoring of groundwater-level. The measurements have been running monthly since January 2007.

Both of the boreholes were closely documented. At first, sandy soils were found, which are supposedly

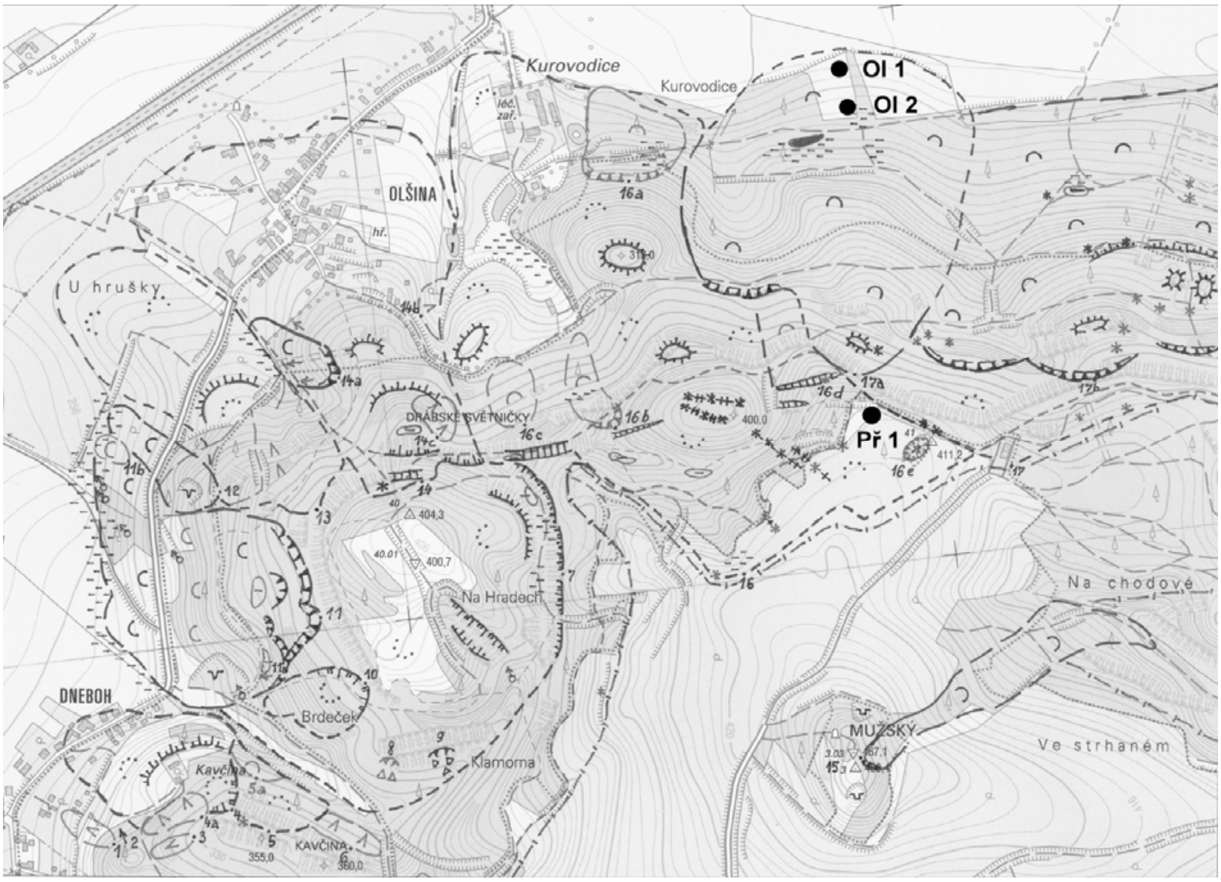

Fig. 2 Part of engineering-geological map with denotation of slope deformations and situation of boreholes Ol 1, Ol 2 and Př 1.

displaced debris and wastes of the sandstones. These soils were followed by calcareous clays with slightly conserved stratification. Sporadically, fragments of tough claystones were present and in a few isolated cases beds with soft and pasty consistence occurred. At the deepest part of profile, the tough, undamaged claystones were confirmed.

The samples for assessment of humidity were taken immediately after drilling. It has been found that beds with increased humidity in clay rocks in landslides can indicate the location of the slip plane or slip zone. The measurements of humidity were made by the norm ČSN CEN ISO/TS 17892. Figure 3 shows the graph of humidity from the borehole OL1.

After the documentation of the drill cores and determination of its humidity, it seems to be very probable that this is a shallow landslide with a planar or rotate-planar slip plane. Tough, undamaged claystones were found already at the depth of 11 m (borehole Ol 1) and 15 m (Ol 2), proving that slip plane does not occur under this depth. As further evidence, the laboratory tests showed the dampest layers at the depth of 9 m (Ol 1) and 10 - 11 m (Ol 2). These layers are probably the slip zones.

The geological cross section is situated across both boreholes. The cross section continues over the

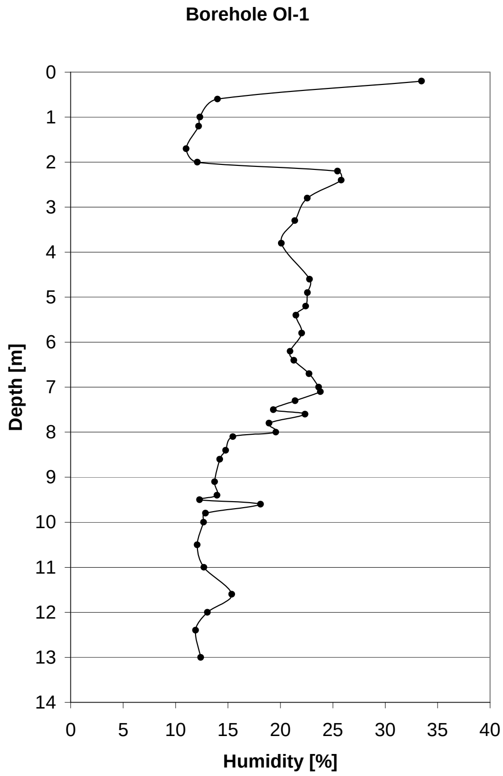

Fig. 3 Graph of humidity from the borehole Ol 1.

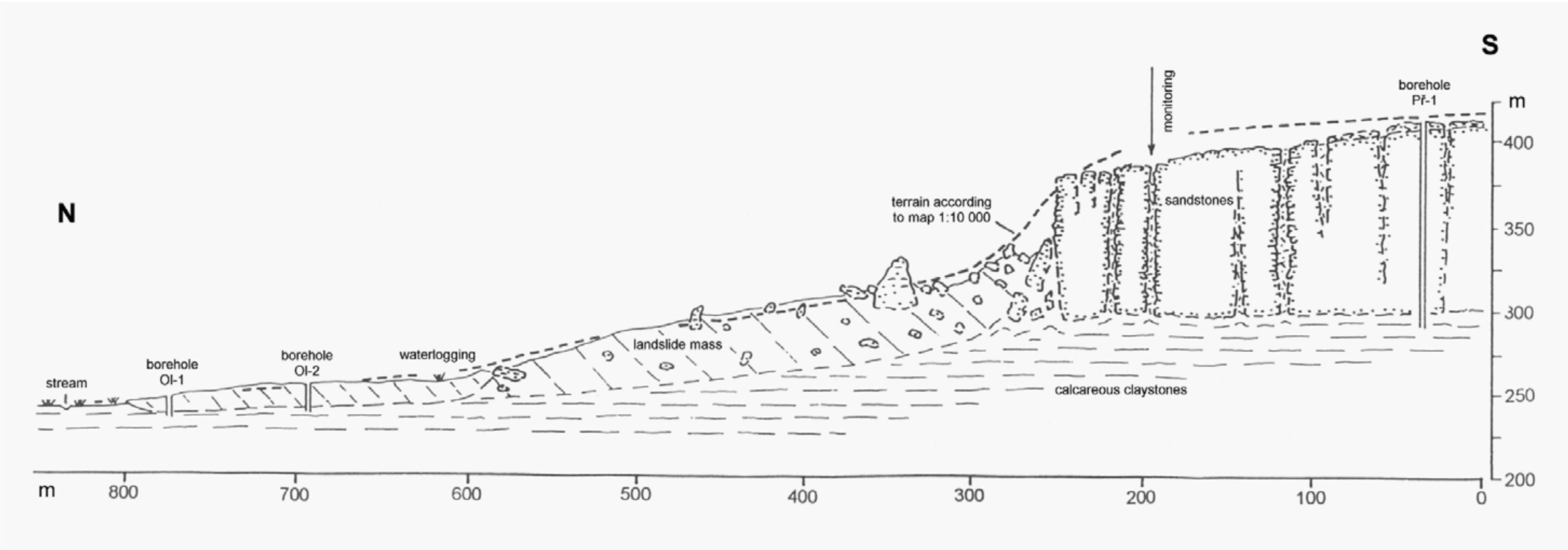

Fig. 4 Geological profile crosswise of boreholes Ol 1 and Ol 2.

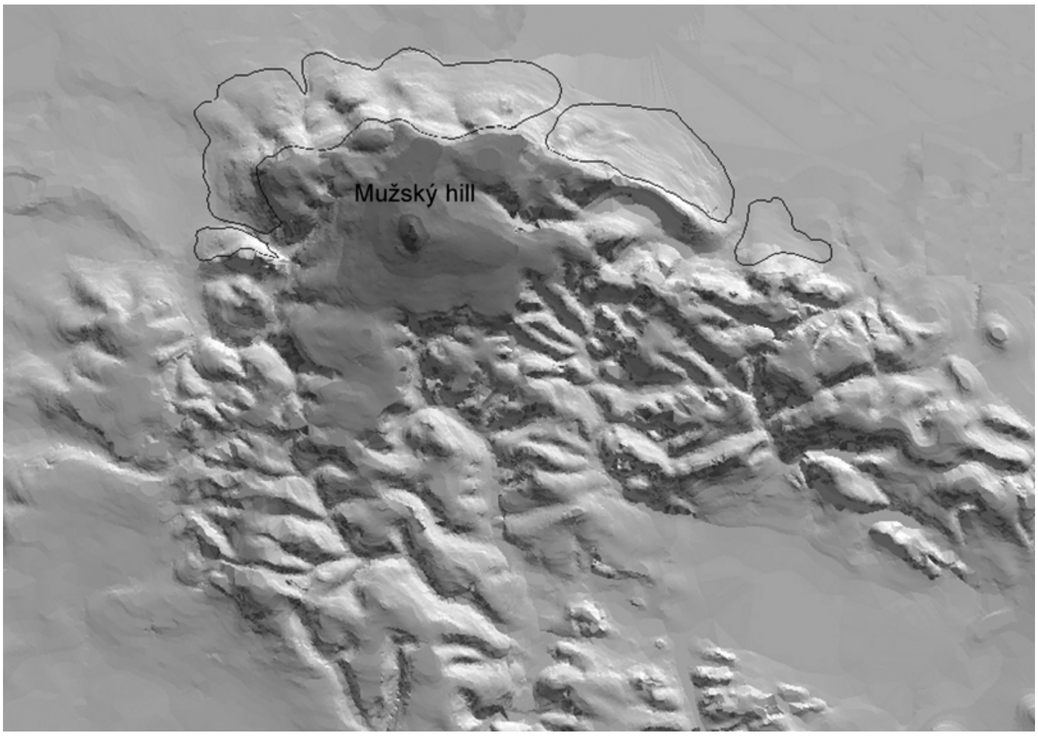

Fig. 5 General tectonical failure of the Příhrazy plateau.

edge of the plateau, to the borehole Př 1 (Fig. 2), which was made previously (Fig. 4). It is clearly visible, that the entire sandstone plateau is broken by fissures; the closer to the edge, the more broken (general tectonical failure of Příhrazy plateau can be seen on Fig. 5). A huge talus pile is accumulated under the steep rock wall on the edge of the plateau, containing blocks of sandstone, which are transported by slide movements down the hill. The number of sandstone blocks decreases down the hill and there are slided argilliferous masses with sandy admixture at the bottom of the landslide area. The slip plane is in the depth of 15 – 16 m here. The landslide area is thought to be inactive temporarily. There is a permanent waterlogging in the foreland of the landslide.

The samples for laboratory tests were taken from the drill cores. One of the tests was the mineralogical analysis of sediments. The aim of the analysis was the assessment of the type of clay minerals, because mechanical properties and other factors can determine a slope stability failure. The mineralogical composition was determined by X-ray analysis of the powdered sample and by analysis of oriented specimens prepared by sedimentation method. The assessment of carbonate was made by dissolution in diluted chloroacetic acid followed by calculation from insoluble residue. Finally textural analysis was performed by a wet method.

The studied rocks were determined as calcareous claystones with 20% of carbonate in the upper part of the formation and with 35% in the lower part. The content of clay minerals reaches up to 40 %, kaolinite and smectite are predominating, illite is just an admixture. In addition, quartz and K-feldspar are present.

The presence of these clay minerals (especially of the smectite) may be one of the predispositional factors during the origin of landslide. During rainfalls, this mineral ties up water to its interlayer space and swells. Then it becomes viscous and occassionaly slides down the slope along predispositioned surfaces. During the drought period clay minerals dry up and then the soils are shrinking.

The water influences clay rocks also in a different way. Due to high content of montmorillonite, the mechanical properties deteriorate rapidly by the percolating water containing potassium. Potassium is released from the upper layers containing glauconit by ionic exchange with calcium. The exchange causes the increase of concentration of hydrogen ions. The alkaline water causes dispersion of fine elements of clays and transfers them to the suspension. The suspension is subsequently eluted and carried away by the water. This process changes the mechanical properties of clay rocks, especially their plasticity and swelling (Záruba and Tyrolerová, 1960).

That is why the chemical analyses of water samples were made. The samples were taken from springs within the landslide area. The analyses determined potassium content about 3 mg/l. This is the same value which was previously measured on the

Dneboh landslide (Záruba at al., 1966). Considering that Záruba measured potassium content 11,5 mg/l in a near locality, we can suppose, that there is a real change of mechanical properties.

The whole territory of the Příhrazy plateau was mapped in detail in the scale of 1: 10 000. The engineering geological maps of slope stability with descriptions of all geodynamical phenomena were elaborated for individual sheets of maps. These descriptions present the data such as character, size, shape of slope deformations, inclination of slopes, water saturation, damage or risk of technical objects and survey or remediation works. The zonation maps were elaborated as a result of evaluation of slope instability. These maps are handed in to competent administrative bodies.

TROSKY HILL

The locality of the Trosky hill is a dominant feature of the Troskovice upland. The Coniacian thick-bedded sandstones create distinct base around uncovered volcanic double vent of the Trosky hill. The Trosky hill is comprised from olivinic nefelinite with denudational rests of Coniacian calcareous clays. The flat relief (also conditioned by Tertiary tectonic activity) is covered by loess loams and is sected to rare net of canyons. The forms of block slope movements, pseudokarst phenomena and small castellated rocks occur at some places (Balatka and Sládek, 1984). The ruins of a medieval castle are preserved on the top of the Trosky hill.

The slopes around Trosky hill are affected by numerous old and recent slope movements. The occurrences of various slope movements are given by favourable geological, geomorphological and hydrogeological conditions. The locality of interest was mapped in the scale of 1:10 000. As a result, the engineering geological maps of slope stability and the zonation maps were elaborated. For an overview, a 3D model was projected where the outlines of slope deformation areas are highlighted. In comparison with the map from 1962 (Fencl and Zeman, 1963), it is evident, that the number of slope deformations increased. I mapped some new landslides on formerly unaffected localities and also some new deformations on areas previously affected by landsliding. The signs of new activity occur at many places, mainly fresh slope cracks and mare areas can be found.

Farther from the edge of the block in the more integral part of the sandstone body, fissure systems, suffosion and gravity form pseudokarst phenomena. In detail, these are undersurface cracks and fault gaps of various sizes; moreover the pseudokarst cave Sklepy was also formed this way. The Sklepy cave is a type of crevasse cave and it is created during the movements of sandstone blocks down the unstable steep slope.

The cave system consists of two parts. The first one follows the fissure system of WNW – ESE direction and is situated approximately up-right to the slope. The second one follows the fissure system of N – S direction, which is parallel to the slope. This second part is evolutionarily more dynamic and shows relatively quick processes of destruction of the corridors, which are conditioned by water and suffosion. The corridors in the lowest parts of the slope are filled by water during heavy rains or during snow melting when they are totally impassable.

The distinct slicken sides on the surface of some blocks, crush zones and wedged small rock blocks give evidence that the slow block movements continue in shifting up to these days. By this reason, four points for dilatometric measuring have been installed into the cave (Fig. 6). All points have been installed in the north-south gallery, which is parallel with the slope. Each point is measured in two positions – horizontally and crossways – to record all movements. After rainfalls or after snow melt, the lowest parts of the cave are submerged, especially in the south part of the main gallery. Therefore measuring point No. 4 is unavailable for the most part of the year.

Even though measurements have been running for 3 years only in the cave, small movements can be discerned. For example, both horizontal and cross-ways movements were measured at MP 3 (Fig. 7). To draw clear conclusions, more data will be necessary.

Although measurements are affected by the seasonal changes of temperature and humidity, these are minimal in the case of Sklepy cave, as it is a statical type of cave with constant temperature, in term of air circulation. The temperature fluctuates around 8 °C during the whole year.

CONCLUSION

The areas of interest are specific by their geological composition and morphological structure. Various types and sizes of slope deformations are present at these localities. The origin of geodynamical phenomena is mostly conditioned by two–bed structure of slopes, but also by mineral constitution, tectonic failure and water. Current forms of slope deformations were considered to be inactive for a long time, but measurements and mapping have confirmed, that all of these processes are still active. Some of them are so slow that they cannot be measured, others can be directly observed. It can be concluded that processes in combination with geological conditions have created a unique relief, which does not have analogue in other type of rocks.

ACKNOWLEDGEMENT

The work was realized with partial financial support of Czech Sciences Foundation, grant No. 205/03/0335 and of subprogram “ISPROFIN č. 215124-1”.

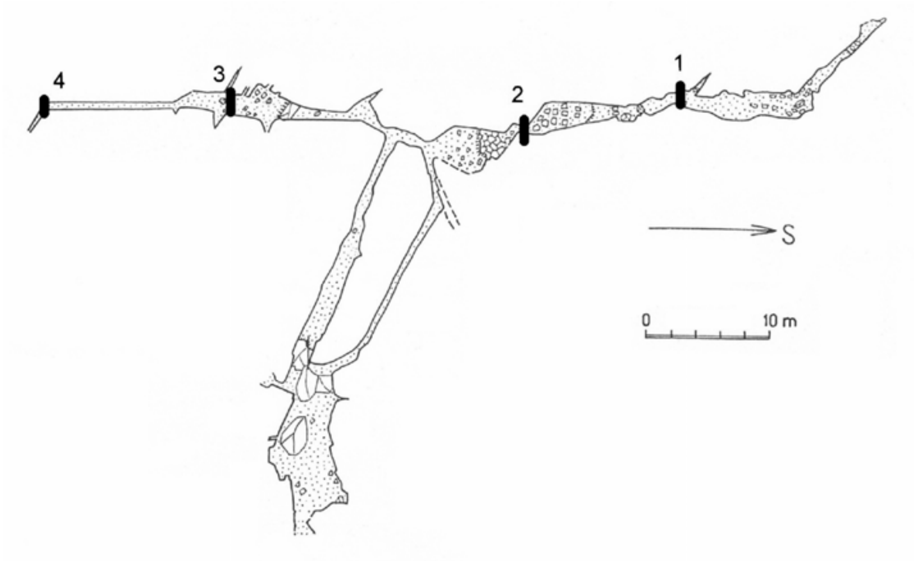

Fig. 6 The Sklepy cave system with denotation of measuring points.

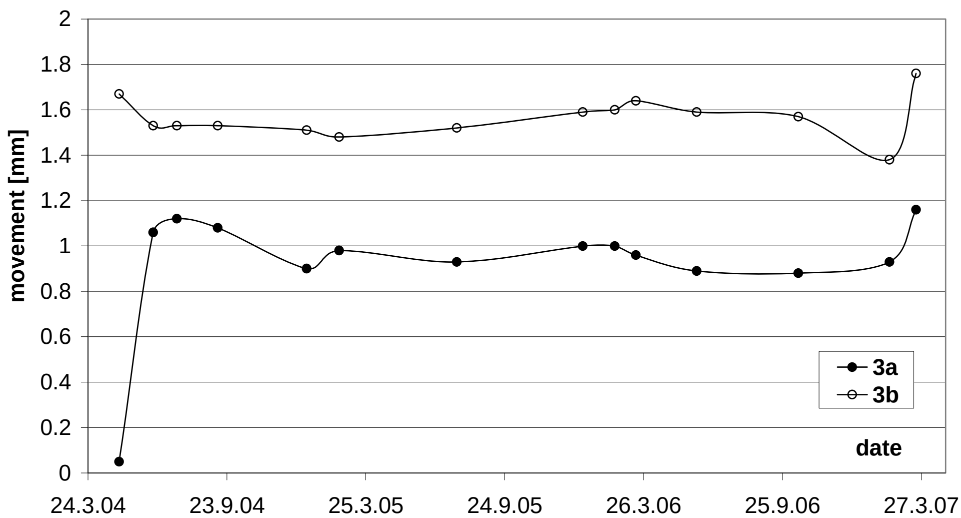

Fig. 7 Block movements in the Sklepy cave, MP 3.

REFERENCES

Balatka, B.: 1980, Superficial forms of Příhrazy Platform in the Natural Preserved Area of Český Ráj. - Památky a příroda (Monuments and Nature), 9, 554–559, (in Czech).

Balatka, B. and Sládek, J.: 1984, The typology of the relief on block sandstones in the Bohemian Cretaceous basin. - Rozpravy ČSAV (ČSAV Treatises), series MPV, 94, 6, Academia, Praha, (in Czech).

Fencl, J.: 1966, The types of the landslides in the Bohemian Cretaceous basin. - Sborník geologických věd (Proceedings of Geological Sciences), series HIG, 5, Akademia, Praha, (in Czech).

Fencl, J. and Zeman, O.: 1963, Northern part of Bohemian Cretaceous between the rivers Jizera and Labe. – Zpr. geol. Výzk. v roce 1962 (Geoscience Research Reports for 1962), 302–303, Praha, (in Czech).

Forczek-Kyrianová, I.: 2003, Analysis of geodymanical phenomena of the NE part of the Příhrazy plateau near the town of Mnichovo Hradiště. - MS Thesis Natural Sci. Faculty, Charles University, Praha, (in Czech).

Stemberk, J. and Zvelebil, J.: 1999, Changes of the slope movements activity along the north-western rim of the Příhrazy Plateau. - Geotechnika, 2, 15–20, Praha, (in Czech).

Záruba, Q., Fencl, J., Šimek, J. and Eisenstein, Z.: 1966, Analysis of the Dneboh Landslide. – Sbor. geol. Věd, Ř. HIG (Journal of Geological Sciences, series HIG), 5, 141–160, Praha, (in Czech).

Záruba, Q. and Tyrolerová, P.: 1960, Significance of glauconite in processes of landsliding. – Věstník ÚÚG, XXXV, Praha, (in Czech).

Ziegler, V.: 1977, The geological conditions in the Protected Landscape Area Bohemian Paradise. Bohemia centralis, 6, 7–41, Praha, (in Czech).