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RECENT ROCK MASS MOVEMENTS INVESTIGATED IN THE TERRITORIES OF BULGARIA AND CZECHOSLOVAKIA

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Abstract: Long-term measurements of movements in discontinuities of rock massifs enable the stability conditions on slopes and the slowly proceeding processes of deep failuring to be characterized. In addition to gravitational slope processes, also the deformational effects of seismic origin and manifestations of the recent tectonic activities could be intercepted. Measurements resulted in data, which can be used for the interpretation and classification of such individual processes and effects and for the evaluation of the actual behaviour of the massif.

Key words: rock movements; field measurements; neotectonic activity

1. INTRODUCTION

A joint research project between the Czechoslovak and Bulgarian Academies of Sciences concerning the origin and manifestations of slope deformations provided comparative data of the two territories as to the investigated problems. In many aspects the territories are different. The Bohemian Massif is an old, relatively solid and stable block, while the Bulgarian territory shows tectonically and seismically active fractures of much younger orogeny. There is, however, a lot in common. If the Simitli graben denivelation in respect to Pirin Mts. (Bulgaria) is evaluated to 3400 m, the Krušné Hory Mts. (Czechoslovakia) are estimated at 1500 m of uplift, both of them in the neotectonic period, which is well comparable. In addition to that, studies of similar deformations under dissimilar conditions in both the seismic and aseismic areas help to understand the powerful factor of seismicity, especially when the same instrumentation has been applied.

Some jointly performed observations cover a period of more than 15 years. During such a long period, it has been possible to observe very slow processes such as the creep of slopes, and at the same time, the interference of seismic events. Tectonic deformations were successively included in the research projects because it became evident that gravitational and tectonic deformations develop very often in close mutual relationship.

Four regions, among many sites that have been monitored, were chosen to be described more closely, the first two being examples of block-type slope deformation apparently dominated by gravitational forces, the second two taken from neotectonically active regions.

Examples from Czechoslovakia originate from the western part of the territory, the Bohemian Massif, where the neotectonic activity is usually low, with the exception of its boundary, to which the activity has been transferred from the interior. Thus, the Tupadly region is an example of block field with little chance for seismic interference. Geological structure, where solid blocks overlay more soft and plastic sedimentary layers, is quite usual in Czechoslovakia not only in the western part but even so in the Carpathians. Such deformations are huge and dangerous to civil structures (Pašek and Košťák, 1977), although being usually very slow. Volcanics in NW Bohemia (Středohoří) and central Slovakia (Vtáčnik) are the examples. Analogically, in the Bulgarian territory, massive block movements developed along the Black Sea coast (Taukliman). Contrary to the Tupadly block field, the Taukliman coastal section is affected by earthquakes, and some researchers suggested its actual form to be due to earthquakes exclusively.

Another example from Czechoslovakia is concerning with the boundary of the Bohemian Massif, where some seismically active foci can be found. The most important tectonic fault cuts the NW rim where a coal basin of the primary importance for the Czechoslovak industry is located. Here the open pit mines get into very close contact with the Krušné hory Mts., where steep slopes reach the elevation of 600 m above the basin level. The stability problems include natural aspects as well as those resulting from the human activity. This is the fault zone which can be directly compared to the Krupnik area in SW Bulgaria, where similar complex slope deformations occurred recently.

The Bulgarian territory results from intensive neotectonic and recent movemen Total amplitude of vertical movements in SW Bulgaria reached 3400 m during the neotectonic period. Recent uplifts according to geodetic measurement approach 5 mm per year.

Slopes of numerous regions are affected by large gravitational deformations which can be classified as presently active. Such regions can be found along the Black Sea coast, as well as along the high banks of the Danube river, then in the Rhodope Massif, and in the grabens of Tertiary basins in SW Bulgaria. Geological, geomorphological and seismic data provide evidence of activity of numerous faults.

The Krupnik area in SW Bulgaria is of primary importance in this connection. All factors interfering with the slope stability can be met here. This is an epicentral area, tectonically active, where steep slopes and deep valleys in both hard and softer sedimentary rocks can be found.

Obviously, planning and construction in such regions need urgently data about displacement and stability of slopes to avoid economical losses. Reasons for the research are therefore not only theoretical but also highly practical.

2. MONITORING

Both the tectonic and slow gravitational movements need sensitive monitoring equipment to detect displacements as low as 10^{-6} mm per year, which is by one or two orders higher sensitivity than that provided by geodetic methods. Attention was therefore paid mainly to relative displacements within cracks, which may be seen as natural indicators of movements and progressive failure (Košťák, 1987). A new crack gauge was developed to this purpose. This gauge has become the main tool of the monitoring, although more sophisticated monitoring systems were needed in complicated situations. The crack gauge is based on the moiré interferometry principle and works as a simple mechanical-optical indicator, which is, however, equipped to provide three-dimensional data of displacement components. A new model is also equipped to indicate rotation as well (Košťák, 1982; Košťák, 1991).

A high stability of this equipment and its robust workmanship contribute greatly to its operation reliability and good results. A more complex situation required sometimes special observational polygons to be formed. A polygon near Krupnik (SW Bulgaria) includes crack measurements, geodetic network, and a seismological station. A polygon at the Krušné hory Mts. (NW Bohemia) includes geodetic measurements, all kinds of extensometric measurements both on the surface and underground in a gallery, borehole inclinometry, crack gauges and geophysical Earth tide inclinometers. Many organizations contribute with their data. The monitoring system supplies a lot of information which needs a sophisticated interpretation. We have, of course, to state that a well-designed monitoring system does not need all kind of available instruments but rather a good engineering geology prognosis and sensitive location of instruments of appropriate response.

The following examples may illustrate important results collected with relatively limited funds.

3. TUPADLY BLOCK LABYRINTH

The valley of the river Liběchovka near the Tupadly village attracted attention of engineering geologists. Here huge Turonian sandstone blocks hanging high on slopes are supported by weak sediments of siltstones and limonic sandstones. The block labyrinths cover large areas in the local Polomené hory Hills forming block fields prone to slope creep movements. The valley at the Tupadly village comes to its deepest configuration since the river leaves out the Polomené hory Hills here. The potential slope energy is high giving a good chance to check the activity of movements and the origin of labyrinths due to it.

Three crack gauges were installed here, the first as early as 1965. The chosen cracks were 6 to 10 m deep and 0.7 to 3 m wide. The gauges were set inside, at the bottom, well shaded and protected.

A typical result is given in Fig. 1. All the three components of displacements measured here are arranged in sinusoidal curves which follow, with some delay, the climatic temperature changes of individual years. Amplitudes reach 1.0 to 1.5 mm per year.

The observations cover now more than two decades. Most important, no trend could be observed here; the crack gauge well covered against daily temperature fluctuations will return after a year to the original position within 10^{-6} mm. Surprisingly, no creep could be registered, even the most steep slopes did not allow for slope movements and the area is manifested as stable. Thus the absence of slope movements supports the hypothesis of erosion and denudation genesis of the relief, which agrees also with results from the geomorphologic analysis of the present landforms.

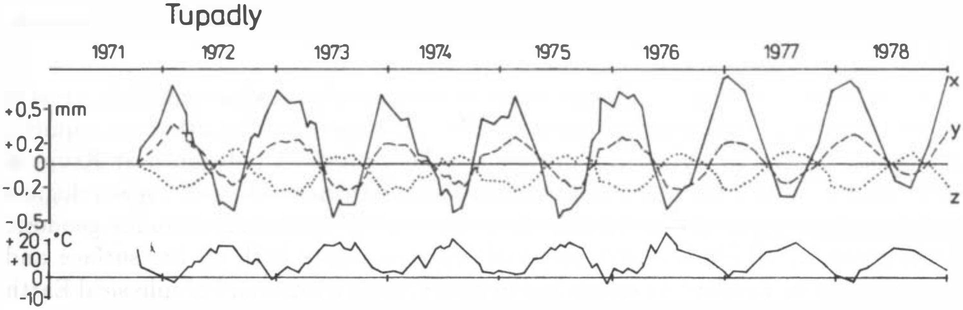

Fig. 1. Diagram of recorded displacements at Tupadly (N Bohemia) shows only climatic dilatations, no trends: evidence for stability in the block labyrinth.

The Tupadly case (Kalvoda and Košťák, 1984) may well serve as a model for stability verification. It may often take several years to come to such a result, because of temperature dilatations affecting the observations carried out near the surface. Negative results providing data on stability are obviously not less important than positive results. The area is still under observation because stable objects may give chance to observe detailed behaviour in respect to individual factors.

4. TAUKLIMAN BLOCK DEFORMATIONS

Huge steps of Sarmatian limestones rimming the Bulgarian Black Sea coast north of Cape Kaliakra witness for giant slides. There is no simple explanation for the origin of the slide complex, because powerful factors like the important sea level variations in the Pleistocene, sea abrasion, the two layer system with weak lower creep-prone beds, and also seismicity may compete to be responsible for it. A particular economic pressure is exerted to establish summer resorts in this coastal area of unusual romantic beauty, which called for finding an answer as to the origin and stability of rock blocks.

The research started with geodetic measurements which, however, did not prove to be able to check slow movements, if present at all. Three crack gauges were installed, therefore, one after the other, into the cracks cutting the margin of the plateau above the affected coastal area called Taukliman (Fig. 2).

Fig. 2. A huge coastal deformation at Taukliman (Bulgarian Black Sea coast). Long and curved sinking steps of limestones at the margin of the Dobrudzha Plateau, where crack gauge measurements proved systematic displacements. Photo B. Košťák.

The instability became evident after about two years of observations (Košťák and Avramova-Tačeva, 1981). The marginal cracks of the plateau were opening at a steady rate of about 0.2 mm . yr^{-1}. This confirmed the hypothesis of creep in Oligocene clays under the limestone blocks. Creep is manifested in the displacement diagram (Fig. 3) by the trend of the x-component, while the other two components (y and z) show a typical variation due to the climatic cycle, so well established at Tupadly.

In March 1977, the coast was hit by an earthquake with the epicentre near Vrancea, Roumania. Due to that, a permanent increase of the crack width appeared, attaining about 4 mm, and the creep continued at an increasing rate of

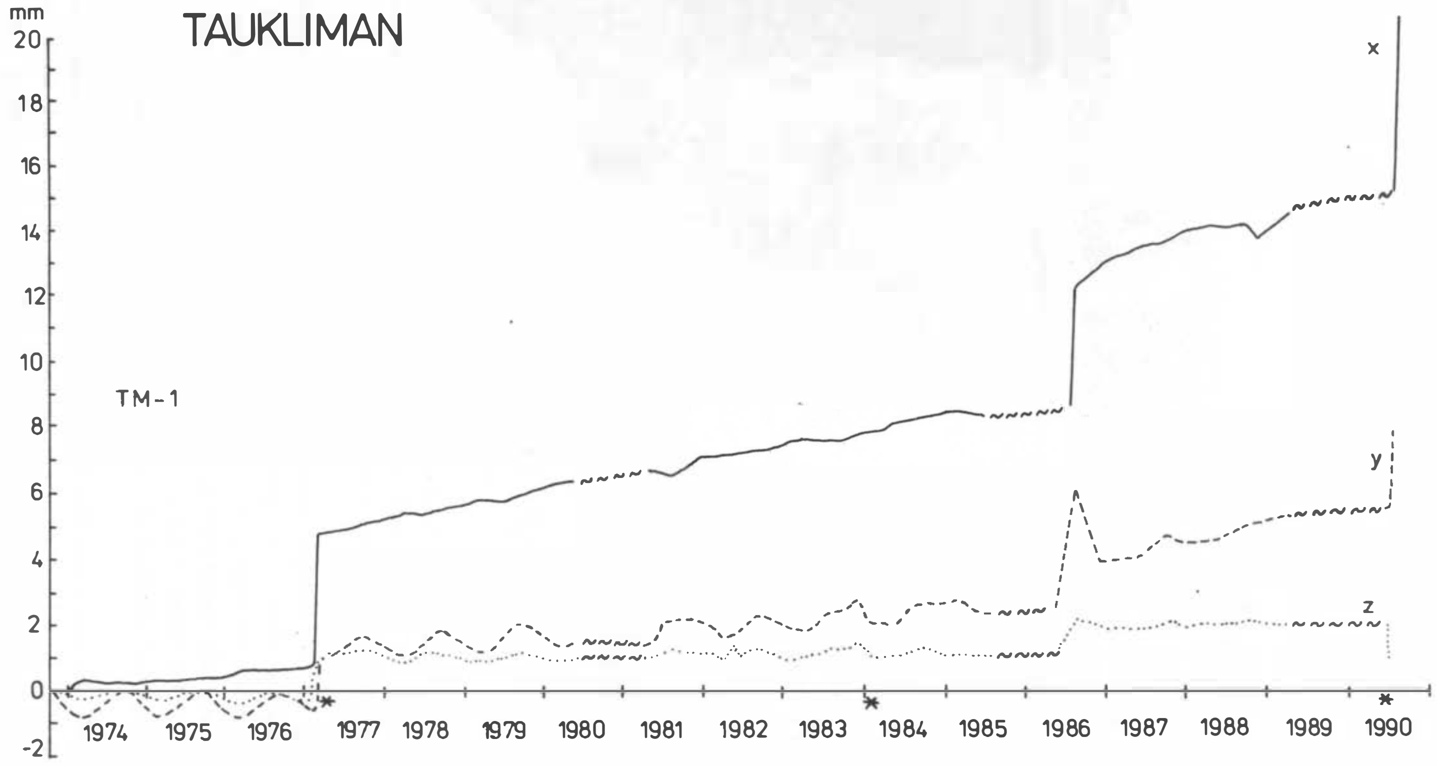

Fig. 3. Displacement diagram of the No. 1 crack gauge TM 1 at Taukliman. Results are dominated by creep as well as earthquake (*) effects.

about 0.5 mm. yr^{-1}. Vrancea earthquakes reappeared again in 1984, 1986, and 1990 with intensities of up to > 7 MSK. Smaller rockfalls were reported along the rockwalls and heads of narrow blocks (about 15 m high) vibrated with amplitudes > 10 mm, which induced them to find new positions.

The gauge No. 1 was placed high in a marginal crack fully affected by the seismic vibrations. The gauge was damaged but not destroyed, and allowed the event to be reconstructed. The gained experience was useful for the realization of several improvements in the device in order to cope with such vibrations. Other two gauges placed deep in the cracks registered also displacements but not the fatal vibration effects.

The measurement at Taukliman (Košťák and Avramova-Tačeva, 1977) provided evidence on propagation of the coastal deformations under combined influence of deep creep and seismicity. Mechanical studies with photoplastic models helped to clear up the mechanics and the history of this coastal phenomenon (Košťák and Avramova-Tačeva, 1981).

5. TECTONIC JUNCTION NEAR KRUPNIK

An attempt was made on a tectonic fault junction near Krupnik to monitor tectonic movements directly. The tectonic structure consists here of two main

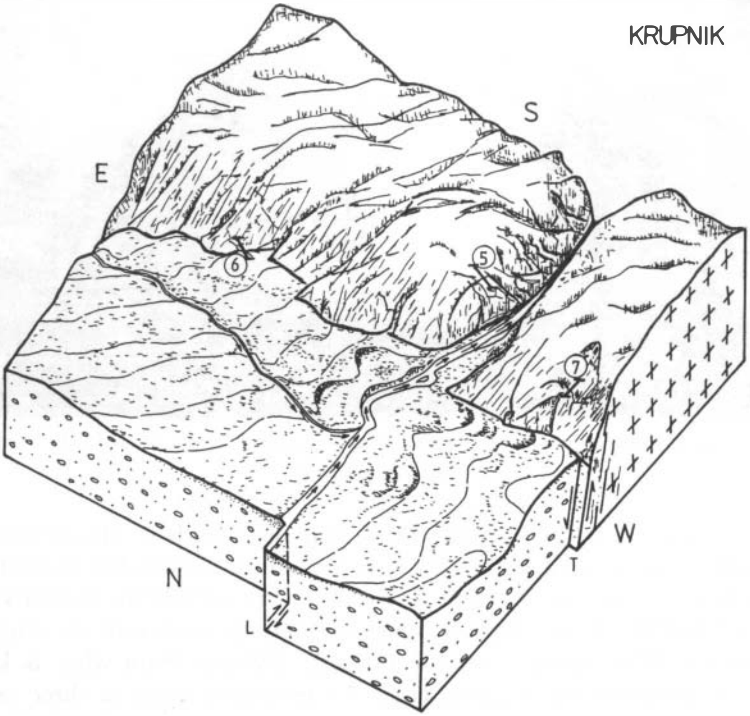

Fig. 4. A block diagram showing morphology and tectonic faults near the village of Krupnik in SW Bulgaria.

faults which are morphologically copied into the terrain, and give way to seismic effects of high importance. The crossing of the faults is known for one of the highest intensity earthquakes in Europe which occurred in 1904 near the village of Krupnik with catastrophic consequences. The transverse E–W oriented fault constitutes contact between amphibolites and granitoids in S and a basin filled up with Pliocene sediments in N. Morphologically, the hard rock lifted up appears in high and steep slopes shattered with many rockfalls. The second fault oriented N–S forms a bisectrice (Fig. 4) which morphologically follows the Struma river flow and cuts the slopes S in a deep and narrow valley (Fig. 5).

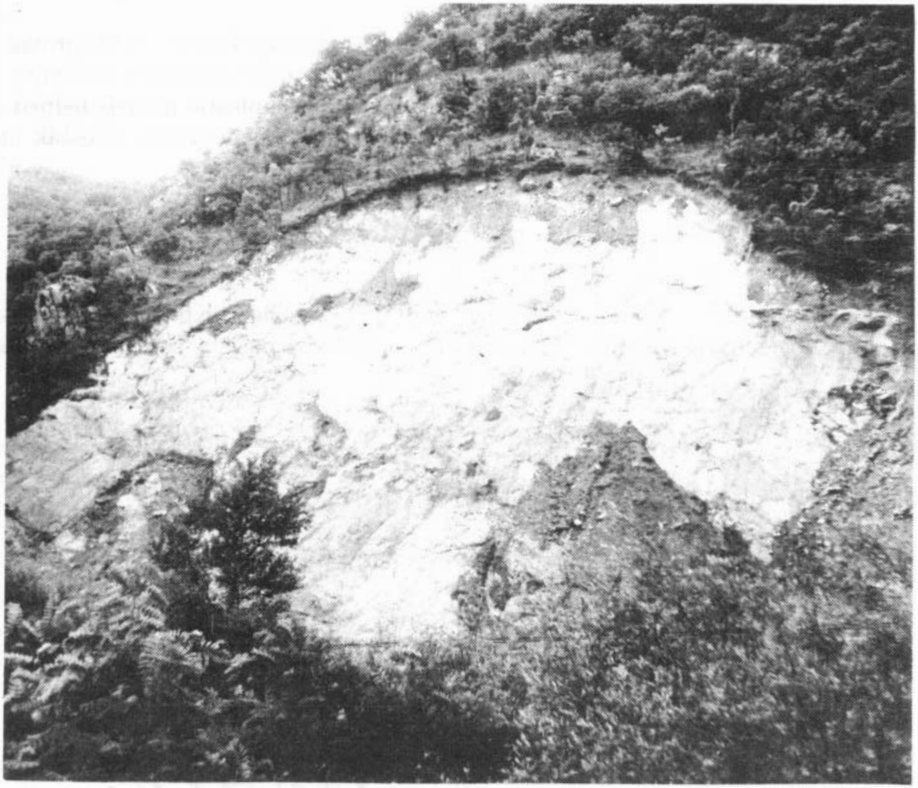

Fig. 5. The Struma fault is documented with a huge outcrop of a fault plane in the Struma valley. Photo B. Košťák.

Three crack gauges TM 5, TM 6, TM 7, were installed here, the second of which (TM 6) was set in an unusual arrangement to monitor directly the contact between hard amphibolites and incompetent Pleistocene sediments of the basin (Avramova-Tačeva and Košťák, 1986) (Fig. 6). The observations cover now the whole period from 1982 till 1990, giving data substantially different from what is known on slopes. The displacement diagram (Fig. 7), presented again in three orthogonal coordinates, shows considerably higher movements and irregular variations. The consistency of it appears only within the time span of several years.

The observation point No. 6 (Fig. 6) developed into one of the most difficult in operation. Seismic jitter is very high here, which appears in frequent pulses affecting the gauge. Earthquakes result in jumping slips recorded by several mm displacements in all directions. While at Taukliman a dangerous tremor may appear once in several years, tremors may hit Krupnik several times a month. The instrumentation must be adjusted to survive difficult moments. The authors did not succeed very much in automatically recorded continuous readings. They have rather collected data about resulting after-effects of tremors in intervals not longer than two months. The gauge had to be reset very frequently.

Several conclusions can be drawn from the collected data. Trends are evident on irregular curves, which correspond partially to important jumps produced evidently by higher tremors, partially they result from gradual summing of unevidenced slips.

Some climatic effects may also be traced on the curves, e.g., periodical winter opening and summer pressing of the contact together with sediments sinking and rising (z-component). This is well expressed after 1985 and between 1986–1989 gets a character of a genuine variation (see x, z, Fig. 7). Other secondary effects, like watering and drying, no doubt, will be also present, and add to the irregularity of the curves. The seasonal amplitude in x is here, of course, considerably higher than that in the ordinary rock crack and becomes as high as 8 mm in 1986.

The trends can be followed during two periods. The first one is limited to 1983–1986, with contact pressing $x' = -4\ \mathrm{mm\,.\,yr}^{-1}$ and sediments rising $z' = -4\ \mathrm{mm\,.\,yr}^{-1}$, while horizontal shearing was $y' = 0$. The earthquakes, out of which most efficient are assumed to be those of 18.2.1986 (M_{L} 4.0 and 4.7; 3.7 (ATH) – Thessalonica) and 23.2.1986 (4.2 Richter – Yugoslavia), resulted in considerable shifts in all components. The second period, which started in March 1986, is continuing till now, summer 1990. It is during this period that seasonal amplitudes in x can be clearly observed. This period is manifested by trends of $x' = 0$, $y' = +3\ \mathrm{mm\,.\,yr}^{-1}$, $z' = -3\ \mathrm{mm\,.\,yr}^{-1}$.

The most serious displacement during the second period appeared in August 1987, and was in y similar to that of February 1986 having attained about 4 mm.

Generally, trends can be described as follows:

a) August 1982 – March 1986. Contact pressing up, with sediments of the basin lifting up. Horizontal shifts provide no decisive trend.

b) March 1986 – June 1990. The width of the contact provides no decisive trend, sediments of the basin continue to be lifted up and horizontally shifted. The shift is relative: either sediments to 200° SSW in respect to amphibolites, or otherwise amphibolites shearing 20° NNE along the contact.

The total uplift of the basin in relation to amphibolites attained 20 mm and the horizontal shear along the contact 20 mm, both per 8 years of observation. The contact pressed up by about 6 mm during the same period. This seems to indicate that this contact is under steady pressure from S or SW. The slope does not show any signs of gravitational deformations. These would undoubtedly induce displacements in opposite sense than those observed. It seems therefore evident that there is a tectonic stress behind the movement.

Fig. 6. The Krupnik fault as seen from west to east. The Simitli graben on the left. Here the greatest uplift took place. The observation point 6 on the contact between sediments and amphibolites. Photo B. Košťák.

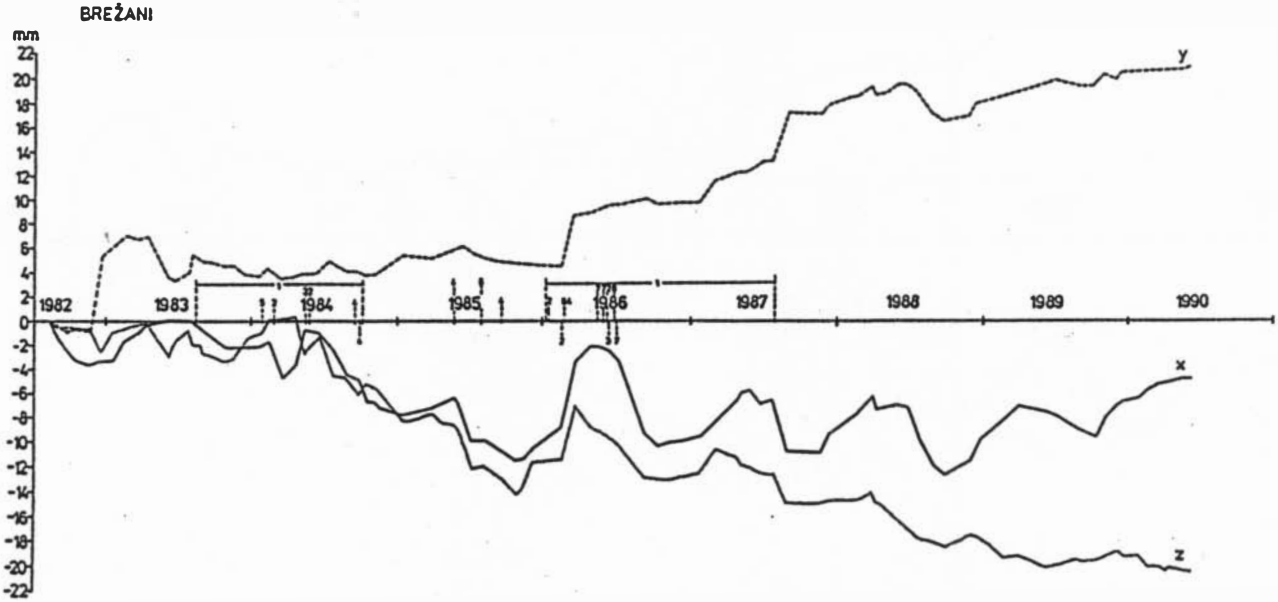

Fig. 7. Displacements found at the contact (TM 6) between amphibolites and Pleistocene sediments of the basin along the transverse fault near the tectonic knot of Krupnik.

There is also evidence for the damping capacity of the basin to vibrations coming from N and for an increased sensitivity to seismic energy release from S, i.e. Mediterranian Seismic Belt (Košťák and Avramova-Tacheva,1988). This may give chance to earthquake predictions (Shanov, 1993).

The measurement is a part of a larger observational polygon. The gauges should be considered as monitoring the behaviour of the main faults indirectly and results must be interpreted cautiously. Anyhow, they have brought valuable information, while the geodetic network has not yet come to definite results.

6. KRUŠNÉ HORY MTS. SLOPE NEAR JEZERKA

The section, where the Krušné hory Mts. form the Jezerka slope, represents 40% steep exposure of gneiss ribs (Fig.9) above the North Bohemian coal basin. The denivelation is up to 600 m. Since the open-pit mines cut the foot of the slope where debris of old rockfalls are accumulated, the slope becomes steeper and unsupported and also relatively higher due to mining. The cuts affect also

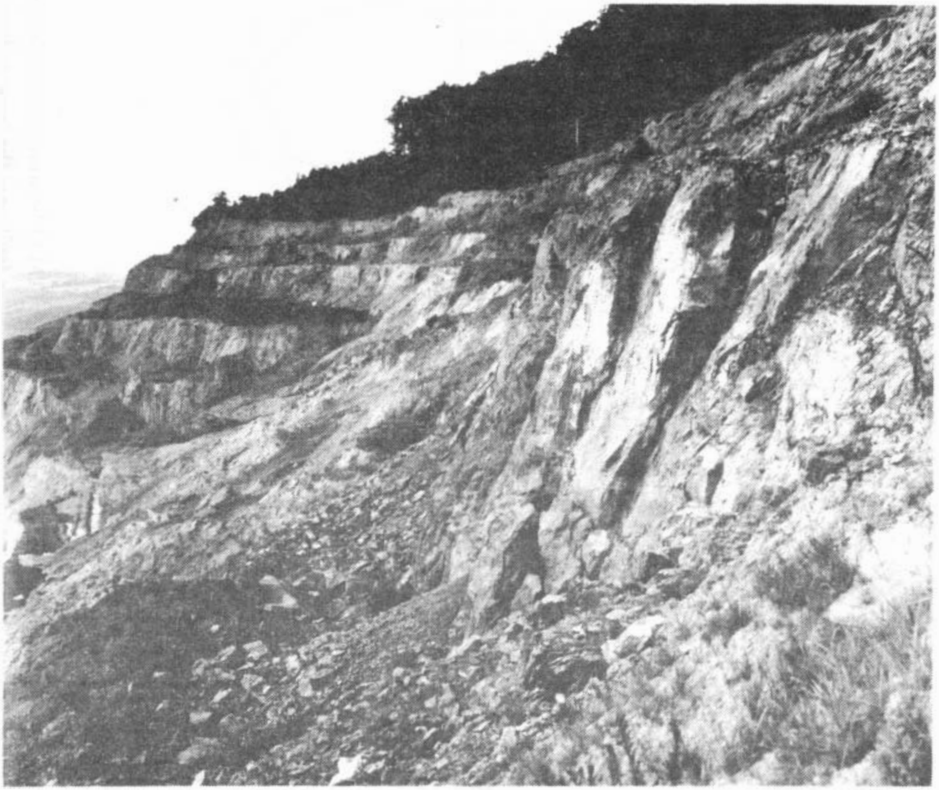

Fig. 8. Pit slopes cut to crystalline rock close to Jezeří castle in the Krušné Hory Mts. Photo P. Blaženín.

the crystalline rock and the slope becomes threatening (Fig. 8). Stress increase is to be expected and slope stability is under question. Finite element analysis has been made (Doležalová and Rozsypal, 1987) showing effects of mining advance. Extensive geotechnical and engineering geological survey has been carried out and slope deformation monitoring has been organized.

One of the first instruments installed was the crack gauge TM mounted into a cavity near the top of the Jezerka Hill. The cavity developed in an old tectonic fracture oriented parallel to the dangerous orientation in the slope structure. Later, other three crack gauges were installed upon a prominent slope rib, and extensometric, inclinometric, geodetic, geophysical, etc. surveying was carried out not only on the slope surface but also in a gallery (Fig. 9).

The results were analyzed regularly to check slope deformations and safety criteria of emergency plans. Alarming limits were proposed as warning states related to specific deformations in the monitoring system.

The main attention has been paid to sedimentary deposits and debris close to the pit. However, for the reason of great danger that it represents, the problem of stability in gneiss in the depth of the slope had to be observed as well.

The crack gauge in the cavity supplied deformation diagrams of Fig. 10. The start was quite regular with sinusoidal variations of the distance x between the cavity faces, showing well known winter opening and summer closing at the amplitude of about 0.8 mm. It can be seen that this regularity in x has not been interrupted until now, i.e. during the years 1982–1990, which gives also a proof of perfect performance of the gauge.

The regularity in vertical shear deformation z, which had a similar tendency of sinusoidal amplitudes due to seasonal temperature variations, was clearly interrupted twice: (1) from September 1984 to July 1985; (2) from December 1987 to July 1988. The horizontal shear y produced the same intervals of irregularity.

The first period did not produce permanent deformation. The second period read: z – increase of 0.55 mm; y – increase of 0.40 mm. Obviously, during the observation interval, which had started well before mining operation, hit the area seriously, there were two events that affected the slope, otherwise quiet.

Here, a result can be seen which is not easy to interpret. The main information concerns intervals, time when unrest was indicated. More data from the monitoring system were necessary to decide about the process observed. In spite of extensive monitoring work, the data cannot be considered complete with regard to the volume of rock and vast area to be analyzed. Nor is it possible to give here all details and assumptions that had to be considered to come to a final interpretation. Let us only say that the first unrest period was confirmed in the gallery and a conclusion made that the massif in depth has experienced a relaxation period due to mining. However, the relaxation had stopped and new balance in the slope developed.

Interpretation of the second unrest period cannot be straightforward. An obvious assumption that deformation effects should be understood exclusively in close connection with mining operations could not be upheld in this case. A geodetic polygon with precise levelling indicated an uplift of slopes in respect to the reference point deep on the mountainous ridge. Effects of elastic lifting due to crust

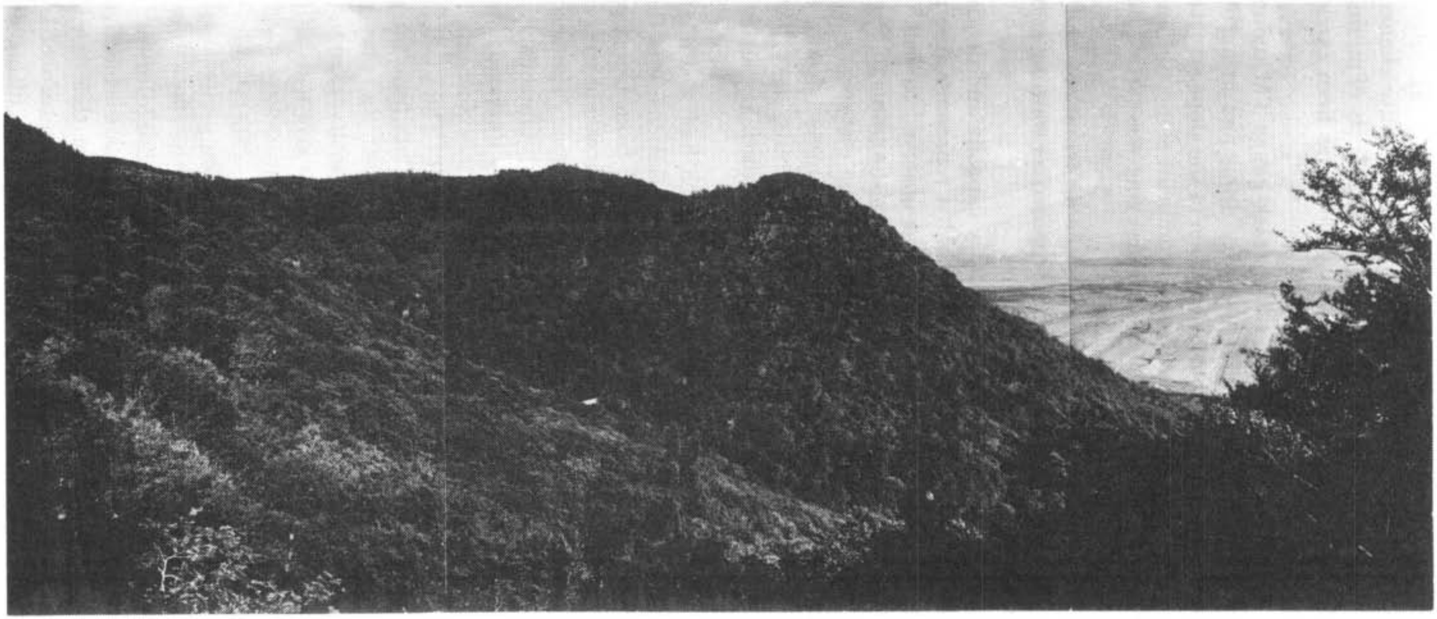

Fig. 9. The Krušné Hory Mts. Gneiss ribs above the Jezerka exploratory gallery. The slope is monitored for deformation.
Photo P. Blaženín.

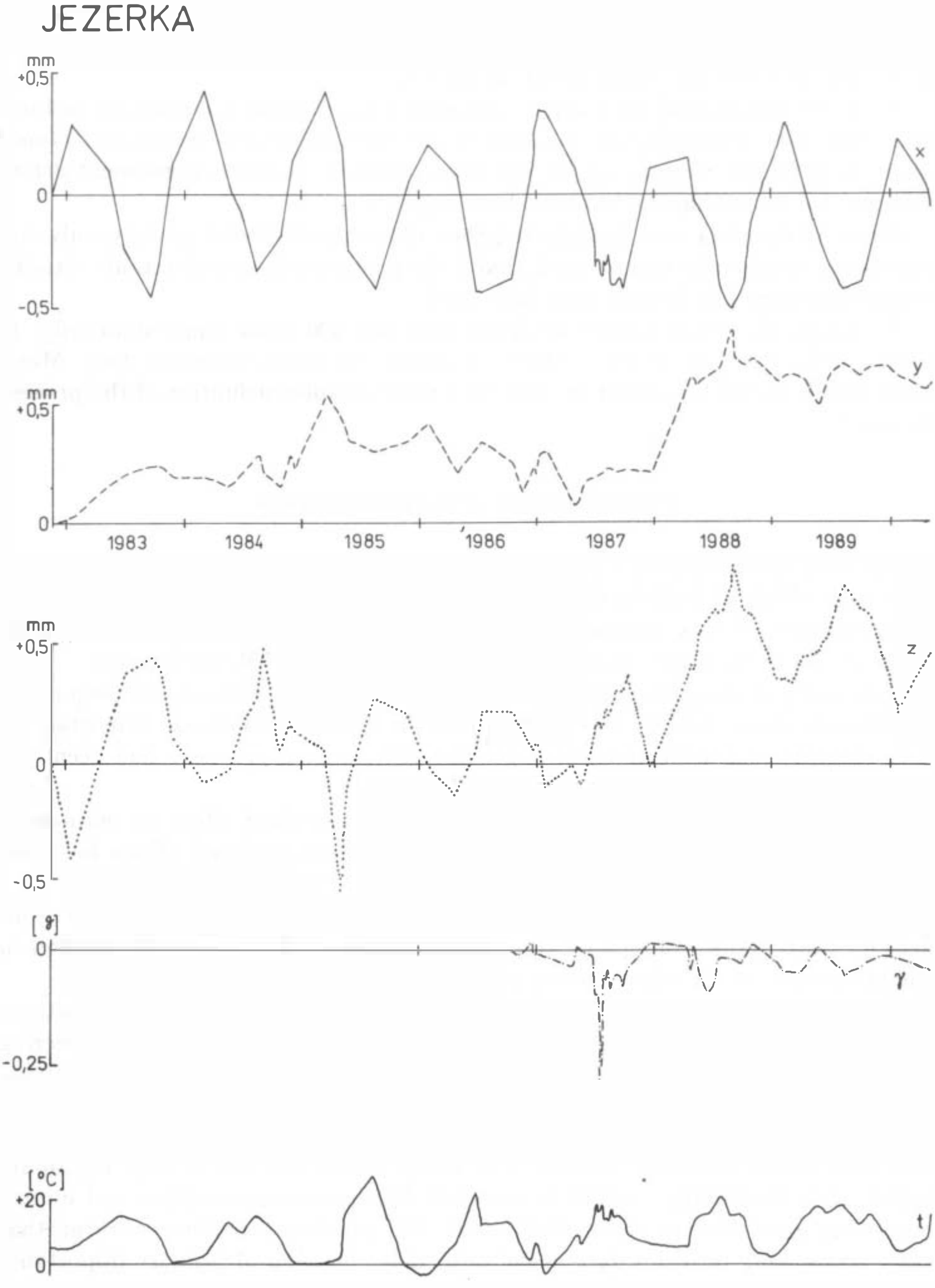

Fig. 10. Displacements recorded in the cavity near the Jezerka Hill top. $+x$ – increase in the width of the cavity; $+y$ – horizontal shearing, the face on the slope side moves to N; $+z$ – vertical shearing, the face downslope; $+\gamma_v$ – face to face rotation, widening at bottom.

unloading, i.e. removal of large masses from the surface, could have been recorded, as some interpreters argue. Other data contradict the relaxation effects anticipated as a result of removing weight (load) at the foot.

A precise geophysical inclinometer has indicated continuous downslope inclination. Also data supporting the evidence of increased horizontal stresses of tectonic origin were found. Seismic unrest has been reported, however, permanent deformations due to earthquake have not been registered.

When all the data were brought together and confronted with geology, only one conclusion seems to be uncontested, that is the presence of natural tectonic activity originating along the Krušné hory Mts. fault.

No doubt, the result cannot be drawn from the TM crack gauge data only. It will be difficult to say which method can supply the most important data. Much more details would be needed to come to a more complex definition of the process detected.

7. CONCLUSIONS AND PERSPECTIVES

The four given examples represent a spectrum of projects, in which valuable data were obtained both in Czechoslovakia and Bulgaria, by the use of monitoring techniques of rock movements. The results were based mainly on long-term observations of the three-dimensional components by the TM crack gauge.

a) Activity of many slope deformations has ben checked. Data about creep rates, orientation of movements, role of individual factors were obtained. Important as it is, stability and ineffectiveness of genuine gravitational processes had been also derived in particular cases.

b) Data were obtained showing seismic effects and their effect on permanent displacements within cracks, sensitivity to creep. Absence of such effects has been documented in some particular cases, where slope deformations are active.

c) Present movements of the tectonic origin near tectonic faults have been confirmed. Such results must be interpreted in terms of the geological situation in neighbourhood of the observational point.

Gravitational slope movements combined with seismicity and active tectonic forces may form complex situation calling for complex monitoring and engineering geological survey. The analysis of movements may prove to be essential in solving many stability problems. Useful monitoring projects have been realized in mining, in foundation engineering, in urban planning. Historical structures under reconstruction should be often monitored, as many defects are due to deep instability rather than weathering. Safety in transport lines, construction sites, and mining operations need much more attention today. The practical experience confirms that early monitoring provides data essential to make decision of primary importance as to the safety and economy measures.

New prospects appear since the monitoring data may be processed with modern methods and theories. A move has been made towards using these data for earthquake prediction (Shanov, 1992). On the other hand, the accuracy of other measurement methods can be increased in well organized polygons (Košťák and Cacoń, 1988; Cacoń and Košťák, 1987). The evaluation of temperature effects to rock movements may be especially important to this purpose. Crack gauging is an important tool of field surveying which allows for environmental control and new apprehension of processes affecting territories in intensive development.

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RECENTNÍ POHYBY SKALNÍHO MASÍVU ZKOUMANÉ NA ÚZEMÍ BULHARSKA A ČESKOSLOVENSKA

Blahoslav Košťák a Elka Avramova-Tačeva

Dlouhodobá měření pohybů na poruchách skalních masívů umožňují charakterizovat stabilitní poměry svahů a zvolna probíhající procesy hlubokého porušování. Kromě svahových gravitačních procesů byly zachyceny i deformační účinky otřesů seismického původu a projevy současné tektonické aktivity. Měření poskytlo údaje, na jejichž základě lze odlišit tyto jednotlivé procesy a účinky a v návaznosti na geologický průzkum posoudit současné chování masívu.