Evidence of active tectonic movements in Krušné Hory Mts. (NW Bohemia)

Údaje o současných tektonických pohybech Krušných hor (Czech summary)

(7 text-figs.)

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Two decades of deformation monitoring in the forefront of the ČSA Mine at the toe of Krušné Hory Mts. (NW Bohemia) accumulated a large amount of data. Different monitoring methods were used primarily to assess mining effects upon the stability of adjacent mountainous fault slopes, and to secure safety in the mining operations. Two survey galleries driven into steep hills of Jezerka and Jezeří, opened an insight deep into the massif of crystalline rock, and into its behavior during a relatively long period of deformation. Evidence about horizontal creep, and of several episodic events of about half-a-year duration has been obtained. Some of them were due to mining, other of natural origin only. These have had apparently no connection with seismicity. In the period after the year 1991 there are clear indications of episodic movements that can be interpreted only as of natural tectonic origin. The movements include slope uplifts, as well as strain changes in the marginal zone of the mountains.

Key words: Krušné Hory Mts., Bohemia, active tectonic movements, crystalline rock deformation, monitoring of deformations

Introduction

The problem of stability of mountainous slopes in the forefront of the ČSA open pit mine in the North Bohemian brown coal basin (Marek 1981, 1994; Rybář 1983, 1987; Rybář – Zmítko 1987; Zika et al. 1993) called for a decision to organize extensive monitoring of the forefront slope areas in the eighties. The monitoring covered partially sedimentary rocks of the basin, partially hard crystalline rocks of the mountains, where more sophisticated monitoring methods had to be applied to detect even small displacements. At the time when monitoring started mining operations were fully under way in the basin. Therefore, the original natural slope deformation state prior to mining could not be defined and calculations largely accepted an assumption that the massif was in a stabilized state without any horizontal tectonic pressure (Mejzlík – Mencl 1981, Košťák – Kudrna 1991). First objective of the monitoring in the crystalline was to register any possible tendency for slope sliding due to deep instability. As a possible direct effect of the unloading caused by mining at the slope toe, shear plane formation and block loosening in the depth or at the surface, was expected to be detected.

The monitoring system became the principal element of the emergency plan of the mine concerned – „Mine of the Czechoslovak Army" – so called „ČSA Mine". A large amount of data from very diverse sources of monitoring was collected during a period of about fifteen years, and put to different archives. This raised the idea of evaluating the data finally in a higher complexity.

Findings pertinent to the sedimentary rock strata of the marginal zone of the basin directly affecting mines, is going to be published separately (Rybář – Košťák 1998). This work deals with evaluation of data pertinent to the behavior of hard crystalline rock, which forms the major core of the massif.

The investigated area represents a marginal zone of Krušné Hory Mts. from Jezerka and Jánský Hills to Jezeří Castle (Fig. 1). The analysis of results, oriented to long-term effects had to consider two observation periods, not fully compatible: before and after the year 1990. Main results are based on data from the second period, when monitoring procedures were better standardized. Yet, even those from the first period are important, giving background to the resulting view.

Methods providing basic source of data

Main data contributions come from the following monitoring facilities:

A) Two survey galleries Jezerka and Jezeří equipped with three precise geophysical Earth tide tiltmeters modified to check deformation tilts in the massif (Skalský 1996).

B) Check of axial length increments in the galleries using precise tape extensiometry. The increments were registered on a series of selected sections approx. 10 to 15 m long, and covered the full length of the galleries (Händl 1996).

C) Precise surface leveling on a track Mikulovice-Jezeří. The track comes through the marginal zone of the mountains (Kalvoda et al. 1994, Vilímek 1996).

D) TM71 three-dimensional extensiometric measurements in superficial slope fissures to check fissure opening and shearing (Košťák 1990, 1993).

E) High precision long-distance measurements between strategic rock tops in the marginal mountainous zone using an electro-optical instrumentation (rangefinder – Kern Mekometer), (Jakubec 1991, 1996).

Obtained results have practical as well as scientific aspects. The main result concerns deformations in the marginal crystalline zone of the mountains.

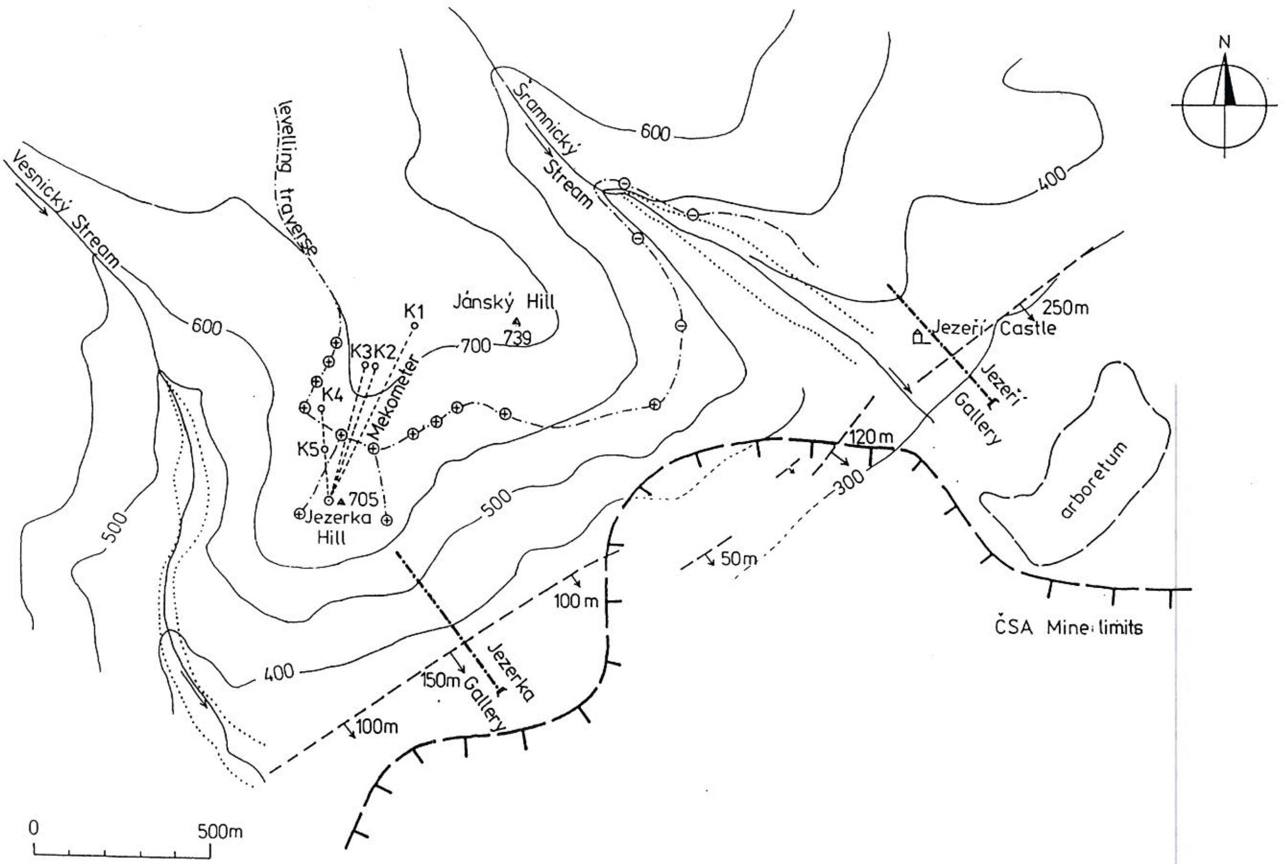

Fig. 1. Situation of the monitoring area.

Fundamental findings

The most important findings (Rybář–Košťák 1998) have been derived from data found in the two galleries Jezerka and Jezeří, and supplemented by observations in the marginal zone of the mountains (Fig. 1). Individual findings are related to the used methods of monitoring.

A1. Geophysical tiltmeter – station Jezerka 2, was located deep in the crystalline of Jezerka gallery. It indicated tilts to S direction persistently (Fig. 2). From 1987, during nine years of monitoring the tilts reached a total of up to 42". As a matter of fact, they have overgrown seven times the limit value set originally as an alarming limit for Jezerka, without apparent slope damage. These tilts can be seen quite significant, not to say extreme. Yet, although being generally downslope, they tilt S, i.e. do not follow exactly the dip orientation of the slope, which is SE.

A2. Geophysical tiltmeter – station Jezeří, was located at the end of the gallery of Jezeří Hill, deep in the crystalline of Jezeří gallery. It shows persistent tilts, also. However, contrary to Jezerka 2, these are oriented to SW (Fig. 2) being considerably lower. From 1982, during fourteen years of monitoring they reached a total of 10" only, i.e. significantly less than that found at Jezerka.

A3. Geophysical tiltmeter, station Jezerka 1, located in a gallery zone of subsurface crystalline shows several periods of tilt reorientation clearly affected by superficial debris movement. Tilts are within limits of 20" during a period of twelve years of monitoring (Fig. 2).

B1. Tape extensiometric measurements in the two mentioned galleries show significant extensions near the surface indicating superficial debris slope movements, which developed into slow shearing of the galleries, directly observable as steps in the floor. Besides, a shallow zone of the crystalline behind the shearing planes became gradually loosened, which was observed by extensions in the gallery axis even behind the shearing planes.

However, deeper in the massif, i.e. beyond 150 m (gallery stationing) to its end, typical detailed extensiometric diagrams are those of Figs 3 and 4, showing a general process of long-time shortening.

Although relatively low, the shortening is persistent, with one conspicuous episodic exception, found during a period of 1994. The extensiometric measurements were quite systematic and regular in both the galleries – twice a month almost in all sections after 1990.

B2. Tape extensiometric measurements in the two mentioned galleries indicated an episode of exceptional deformations. The episode took place in 1994, and it was characterized by primal acceleration of compression followed by sudden extension, and then back to the original process. In diagrams it looks like a wave of an impulse. The impulse was registered during the same time

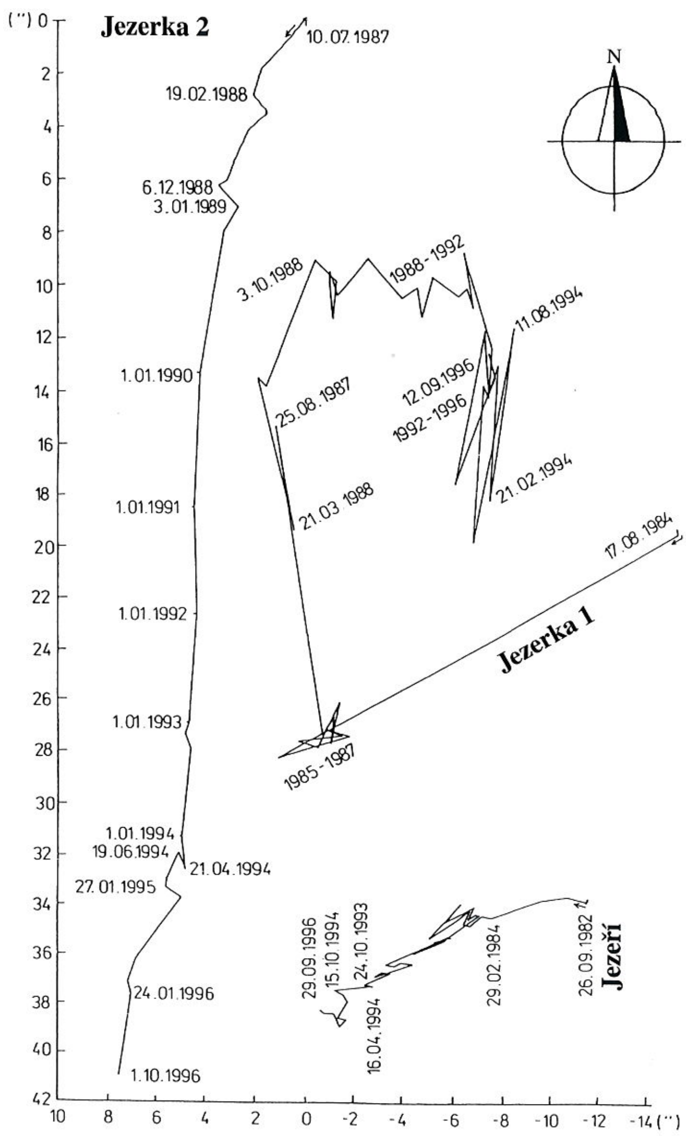

Fig. 2. Hodographs of tilts as indicated by geophysical tiltmeters in Jezerka and Jezeří galleries. The diagrams express time sequence of oriented deflections from the vertical. Tilts (deflections) are measured in angular seconds (1" = π/180/60/60) along two axes: N–S, W–E.
Jezerka 1 – superficial zone of the crystalline; Jezerka 2 – deep in the crystalline; Jezeří – deep in the crystalline (After Skalský 1996).

period at Jezerka and Jezeří at all deep gallery sections simultaneously. Averaging the result of all sections deeper than 150 m, and calculating horizontal strains in the massif, one obtains diagrams of Fig. 5.

C. Geodesy. Precise leveling in the marginal zone of the mountains, performed in years 1984/1989 twice a year, and in 1990/1995 once a year indicated several different behavioral zones.

The top zone of Jezerka Hill (in plans usually marked as Jezeří 707 m) registered uplifts by 1 to 4 mm per first 6 years, i.e. during the first period of leveling. Later, measurements show the same tendency. The top zone contains one point with deep stabilization showing a trend fully compatible with other points of shallower stabilization. The most intensive uplifts were found in points laying most closely to the slope edge, in the highest part of the fault slope, where chances of rock block sliding are generally excluded.

The second zone is located ENE from the first one. This second zone produced subsidence or neutral variations of movement. It represents a different tectonic block. This subsidence appeared on slopes of the Šramnický Stream, and reached a total of 11 mm in the first 6 years. However, slope movements could not be excluded here. Then, there is a third zone farther to ENE showing no trends. These points are located deep in the valley of the Šramnický Stream and close to Jezeří Castle.

There were exceptional and episodic periods. From fall 1988 to spring 1989 points in all the zones sudsided by 2 to 3 mm, and later after spring 1990 all the points were uplifted to the original positions or even higher, so that the original uplifting trends appeared to continue.

All reported movements are related to reference points deeper in the mountains.

D. TM71 three-dimensional extensiometric measurements in a superficial slope fissure close to the top of Jezerka Hill indicated three exceptional episodic deformation periods represented mostly by vertical and/or horizontal shears in the fissure (Košťák – Avramova-Tačeva 1993). First such a period occurred from September 1984

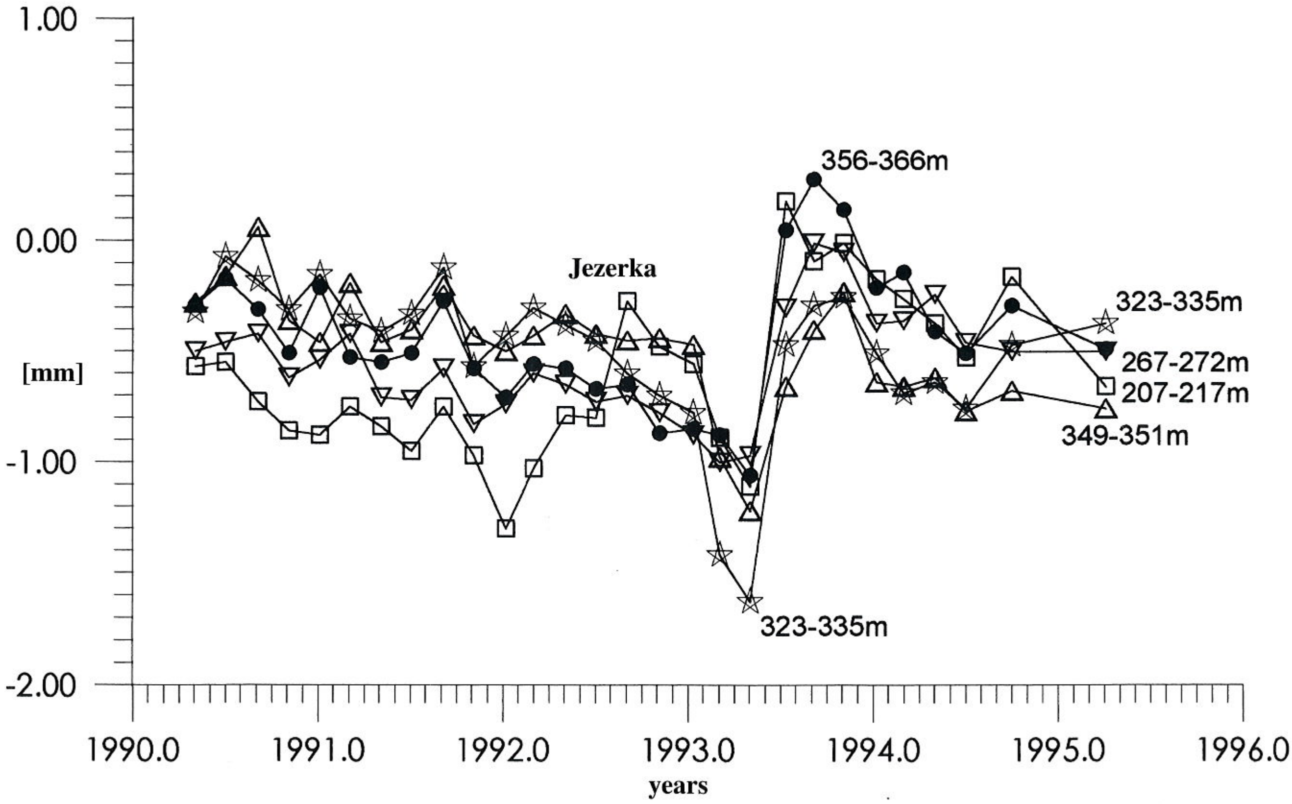

Fig. 3. Variations in length in five typical deep sections of Jezerka gallery after the year 1990.

to April 1985, and deformations appeared later to be reversible. The second period occurred from December 1987 to April 1988, and deformations of up to 1 mm appeared permanent. The third period occurred from December 1993 to April 1994, the reaction was weak and reversible.

Registration frequency was close to two months, i.e. higher than of other monitoring methods applied in the Jezerka Hill top zone. Regarding that, recognition of the timing of the deformation episodes with the use of TM71 was more precise and even easier than with most other methods before 1991.

E. Electro-optical long-distance measurements using Kern Mekometer ME 3000 investigated segments between five points in the mountainous marginal zone and the cliff peak of Jezerka Hill, behind the fissure mentioned above (D). The points are located in a zone between the cliff peak and the top of Jánský Vrch Hill. Measurements were performed twice a year from 1986 to 1991, then disconnected. A single measurement check was performed in November 1996, and repeated in 1997. Results of fall measurements (seasonal fall/spring variation has been observed) are shown in Fig. 6.

Originally, there was a general tendency to find negative increments; all the segments became shorter at the end of 1989, when an extreme in negative values was registered. [The period corresponds to the second exceptional period registered by TM71 (D)]. This picture seemed to be reversed between 1989 and 1991. [The period corresponds to the period of extreme vertical movements registered by precise leveling (C)]. After a period when no measurements were made (1991–1995) a new picture comes out from the last two measurements of 1996 and 1997. There is a clear establishment of succession of points regarding distance, which is completely opposite to the state before the break. The points were numbered from the most distant point K1 to K5, the closest one to the basin. The farther the points from the marginal cliff peak the lower the absolute value of length decrease in the respective segment. The most distant points K1 and K2 show even small increments of length while the nearest points continue to show decreasing values.

Obviously, observation frequency was not satisfactory to check details but there is an apparent behavioral change with a certain analogy to timing of episodes given by D (TM71) and C (precise leveling) at the end of eighties.

Remarks to the interpretation of data

There is a general call for having more than one measurement point and more than one method to avoid ambiguity in the interpretation of results. Therefore, the highest

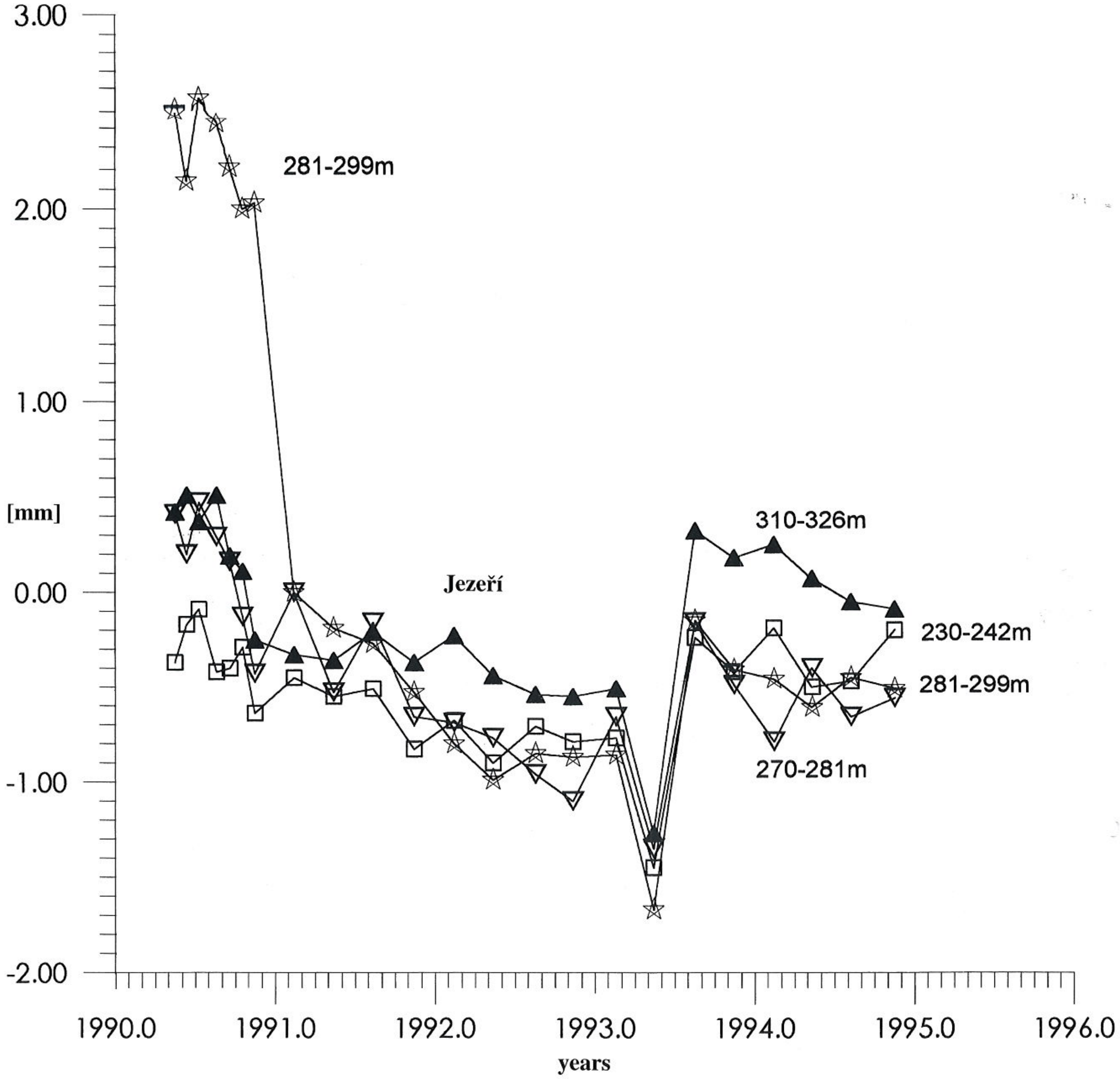

Fig. 4. Variations in length in four typical deep sections of Jezeří gallery after the year 1990.

weight should be given to the results obtained from the galleries, notably to the findings B1 and B2, which are obtained from a considerably large series of points covering two long and distant galleries in their full length deep in the massif. Data of many other methods were obtained with a low frequency of measurement or even occasionally, and could not be checked directly by parallel observations. Such results can be considered as supplementary only.

There were several periods, when the mine authorities asked for the data to be interpreted. The process of mining came through different stages regarding mining advance when different individual factors prevailed. Thus, the complex picture of the dynamics in the mountains came out only gradually with increasing time span and amount of data.

The interpretation which follows has to proceed first dealing with individual reactions one after the other, and only then to bring the identification of the dynamical process in the massif in its complexity. Since final interpretation must try to consider all the important findings in a concerted view, it was just the unexpected and even some seemingly contradictory findings which limited chances for alternative explanations of events, and excluded thus some misleading interpretations. In any case, it appeared obvious, that a general interpretation of findings in such a large scale monitoring experiment should not be made too early, otherwise conclusions might later become questionable. In this case the period necessary to obtain well interpretable data would not be less than ten years of observation.

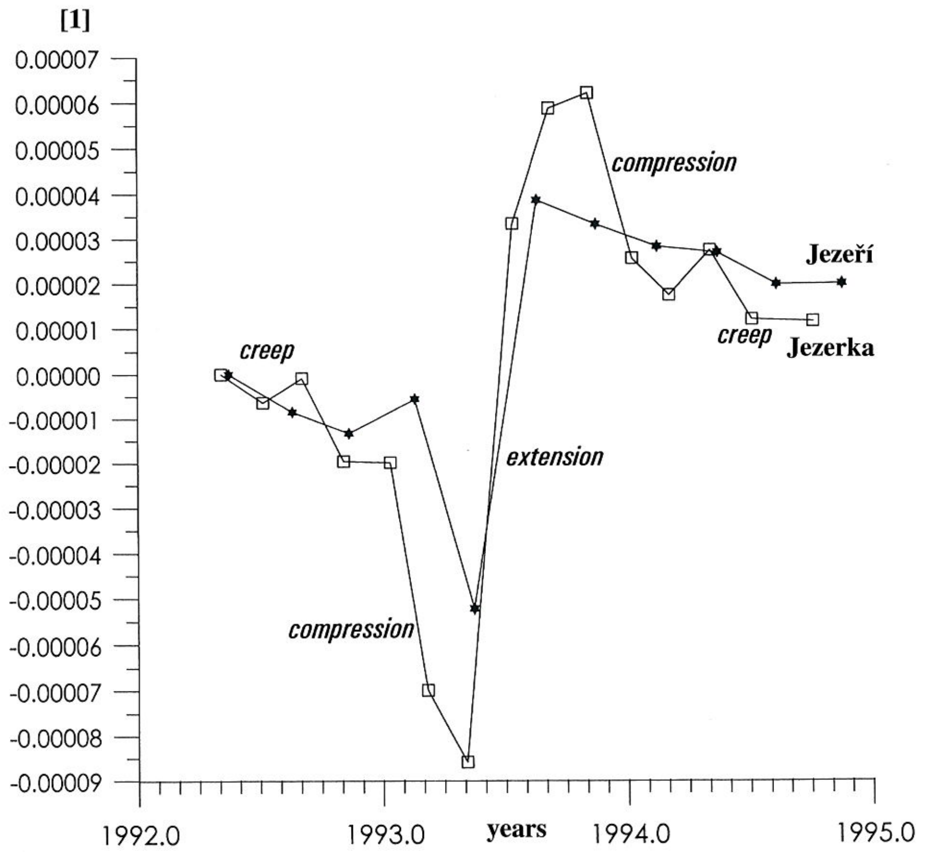

Fig. 5. Parallel development of horizontal strains in Jezerka and Jezeří galleries during the exceptional event of the year 1994.
Creep till the end of 1993; increased compressive strain till May 1994; extensive strain till September 1994; reestablishment of horizontal compressive strain (Jezerka) till January 1995; back to creep thereafter. Measurements done by precise tape extensiometry and horizontal strains averaged for more than 200 m long sections deep in the massifs of Jezerka and Jezeří.

Creep in crystalline rock

Finding B1 – continuous slow decrease in gallery length – can be interpreted simply as creep due to a state of horizontal compression along the longitudinal gallery axis. The result is parallel with findings A1 and A2 – continuous tilts with persisting orientation downslope. It can be interpreted mechanically as creep manifested by tilts due to shear strain in the two respective blocks of the mountainous massif.

Quantitatively, creep in the galleries (as measured by tape extensiometry) is manifested by decrements in length of about 1.5 to 3.0 mm per 200 m and year horizontally, along gallery axis. The strain level is of the same order in both galleries, and in a long-range view it reads

$\varepsilon = -1{,}7.10^{-5}$ per year.

The last fact is somewhat unexpected regarding the high tilt rate difference between the two galleries (finding A). Jezerka shows 6.5 higher tilt rate than Jezeří in spite of Jezeří being structurally weaker than Jezerka. Obviously, the explanation is to be found in relatively different situation of the two galleries, and even the tiltmeter stations. Jezerka block is higher, under uplifting effects, and fully backed by a huge massif while Jezeří block appears to be more isolated from the mountains, and the structure allows for faster relaxation. Orientation of the tilts is influenced by local structure, slope orientation, and morphology. Jezeří tilts are oriented to Šramnický Stream valley, i.e. to SW, while Jezerka tilts are oriented to S, which represent generally a downslope movement, skew to the slope gradient.

That can be seen in connection with the most prominent structure in this mountainous area, i.e. with the dome of Hora Svaté Kateřiny. Due to an uplifting dynamics in the core of the dome, creep rate will be governed by internal movements of it, and the rate will be at the same level in both the blocks, Jezerka and Jezeří. On the other hand, Jezerka block can be seen under considerably higher local stress state than that of Jezeří.

Downslope tilts are likely to be seen as due to mining. However, finding of negative strain in the galleries is hardly compatible with it, being opposite to all expectations, and showing an active rather than a passive stress state. It is rather due to an active pressure coming from the mountains, and the fact that horizontal strain in both the galleries is almost equal calls for an idea of a deformation process that strains the massif from the depth, independently of the mountainous morphology. Impacts of mining operations reach the two structurally uneven galleries from different directions, and timing and level of such effects must be considerably different. Therefore, mining operations can be hardly blamed for the evidenced horizontal strain, which is rather of tectonic origin. A conclusion can be drawn therefore that presence of a pressure of tectonic origin with a significant horizontal component has been indicated in the massif.

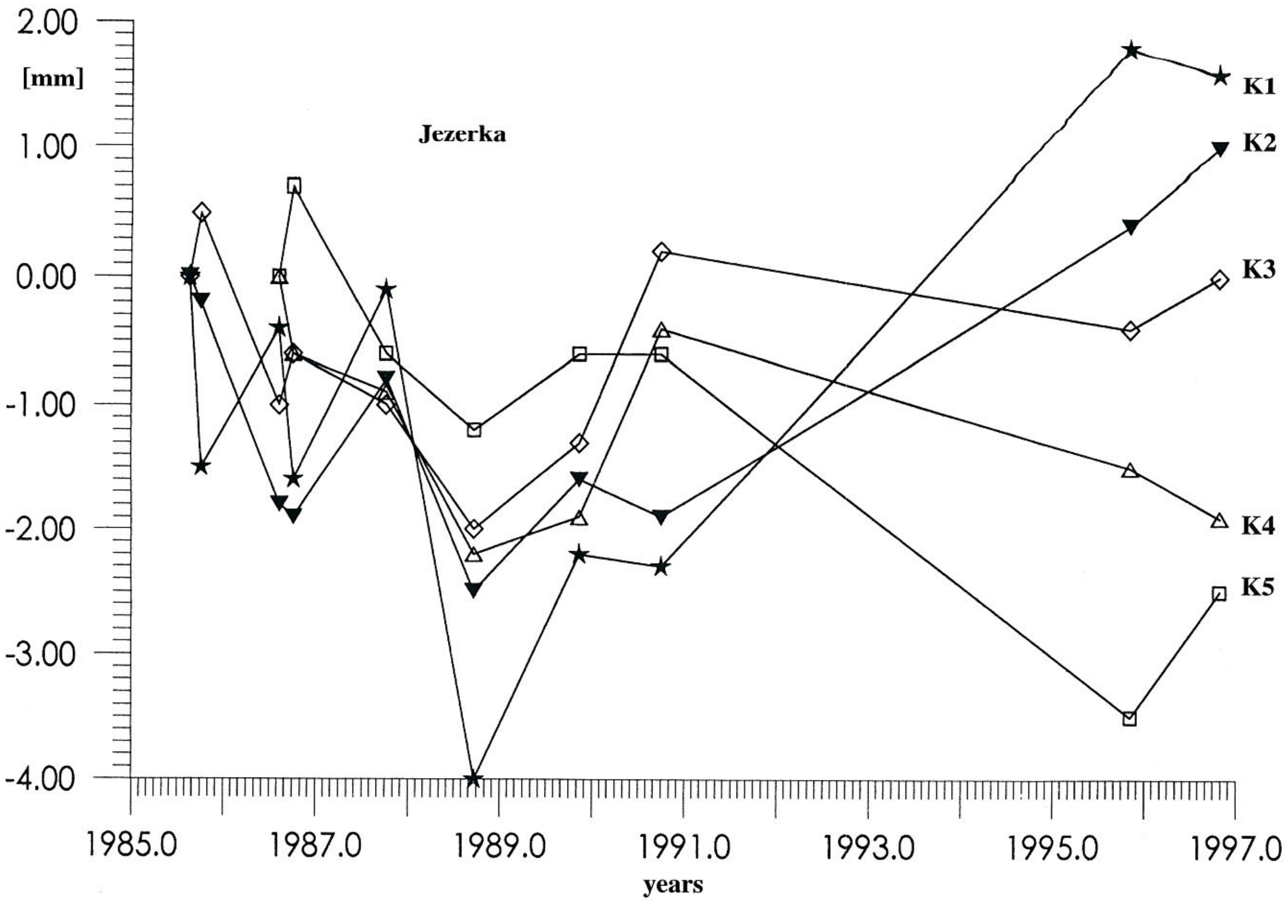

Fig. 6. Development of long-distance variations between one of the top cliffs above Jezerka gallery, and five peak points (K5–K1) towards the mountains (Jánský Hill 739).
Measurements done by Kern Mekometer (Electro-Optical High Precision Distance Meter). (After Jakubec).

Uplift

Precise leveling (finding C) indicated uplift in mountains, at the marginal zone of Jezerka block. It seems that it could be again interpreted as an affect of mining. Unloading in the basin due to an enormous coal and overburden extraction is necessarily counterbalanced by pit bottom uplifts in a wide region. It is a well known effect observed regularly on mine pit bottoms. Such an effect should be present, no doubt, even in the investigated region. There is a question, however, whether the effect can produce marginal uplift in the nearby mountains, notably separated by a fault, and whether it is compatible with other observed phenomena.

The most obvious effect of mining to mountains is unloading at the slope toe. Here the toe looses its support, the mass moves in, and extension strains are expected to develop deep in the marginal mountainous zone. This is going to result in potential crack opening. Such a process was expected as a possible danger to rock slopes, calling forth monitoring of structural dilatation on the surface as well as in the galleries. Portal zones of the galleries near the slope surface proved such extensions, although related to slope movements. Deeper, as indicated, an opposite (B1) effect of persistent negative compressive strains has been found in the massif. In any case, slope toe unloading cannot induce the observed negative strains.

Regional reactions to the basinal unloading are questionable. Main uplifts are expected in the basin, while rock slopes moving down to close the pits. The two effects interfere, slope toe unloading comes to produce downslope tilts with deep horizontal extensions in the massif, while basinal uplifts are counterproductive to a certain extent. Observed tilts are downslope, and strains negative. Tilt observation contradicts the effect of basinal uplifts and negative strains contradicts the effect of slope toe unloading. The observation can be hardly explained without an additional external action, which would change the system. Such an action can be found in tectonic movements. It is considered therefore, that the main cause of the indicated uplifts together with horizontal contraction in mountains cannot be due to mining, and uplifts of tectonic origin have been indicated.

Episodic events

Three episodic events were registered by TM71 three-dimensional extensiometric measurements in a superficial slope fissure close to the top of Jezerka Hill (finding D). Two of them occurred prior to tape extensiometry investigations in the galleries, so that no comparison can be made. The last third in 1994 was observed in a full time coincidence with finding B2. No seismic effects were registered during the episodes (Tobyáš 1995). Obviously, the massif gets to an unbalanced state from time to time, which can be registered by small displacements. Such episodic movements proceed for several months until a new balance is found. Generally, such events can be induced by mining or can be of a natural origin, and need not be observed everywhere simultaneously.

Finding B2 – the pressure impulse indicated by the tape extensiometric measurement in the galleries is of special importance since the spatial extent of the observed phenomenon is so large that events could not be seen as local only. The two galleries were hit simultaneously at a distance of about 1600 m, and provided parallel and compatible deformation effects (Fig. 5). Mining operations advance in a specific spatial configuration uneven in respect of the two respective tectonic blocks where the galleries are located. On a first sight one can see that the spatial relation of the two galleries in respect to mine fronts is completely different, and a possible impulse from mining would reach the two galleries from different directions under different conditions. Therefore, it is hardly possible to see the event as a direct reaction to mining. The event of the year 1994 must have been natural. As an obvious conclusion, the registered deformational episode of 1994 represent a reaction due to active tectonic movements.

The episode allows to see even character of the reaction. The event started as a pressure impulse. The pressure came in strengthening the state that had produced creep. This supports the idea that both came from the identical source of energy. After a period of three months approximately, a reverse reaction appeared. It was a three month reaction of relaxation, after which again a new pressure impulse in another of three months period got to reestablish original conditions of continual creep. One can assume, that the relaxation period represented an instability period, when, due to local slips and failures in the structure, stability conditions in rock were going to be transformed, and new balance conditions had to be established at the end. However, there are indications that during the event rock reactions in galleries were mostly elastic, i.e. reversible, with similar reactions observed in competent and incompetent gallery sections.

It can be derived, therefore, that no real instability occurred in the gallery itself but the gallery reacted in an appropriate manner to a distant disturbance, the source being the same for both galleries. The resulting strain appeared a little lower after the event than before, which indicates that a certain amount of pressure was released during the event. This supports a view to see the source of the horizontal pressure distant, i.e. tectonic, opposite to a possible idea that the pressure comes just from rock own weight near the slope. Again, to avoid any discussions, let us stress that no seismicity was reported during the event, and the event was so slow that it cannot be seen dynamical in the common sense of vibration effects involving inertia.

Only one period like that of 1994 with such an episodic event has been observed in such a detail, yet. It proves the high value of the gallery systematic observations. The first event reported by the TM71 extensiometers (finding D) between September 1984 and April 1985 was possibly different, a reaction of rock release to mining. The second between December 1987 and April 1988 could be similar to that of 1994, yet no details were registered. If such events assumed periodical then an interval of 6 years would be indicated, at least. Serious variance in the quantitative effects and periodicity must be expected.

Additional evidence

The unique event of December 1994 was registered in the two galleries which are quite distant. Therefore, a vast marginal mountainous zone must have been affected. Neither precise leveling on the surface (C) nor high precision distance measurements (E) covered this period with a frequency that would allow to look for an appropriate effect in detail. However, inspection of Fig. 6 will find a strange rearrangement of the length increments at the end of 1996, and persisting to 1997, i.e. after the event. Obviously, it provides a supporting evidence, that a disturbance occurred during the time when the measurements were suspended.

The apparent rearrangement is likely to be a result of the event. It indicates that the disturbance was centered deeper in the mountains (perhaps in the dome of Hora Svaté Kateřiny), where the main relaxation appeared and even superficial length increments might develop. On the other hand, the pressure in the slope edge zone has reestablished more quickly. A special geophysical survey (Vybíral – Osykin 1995) indicated a tectonic zone between points K5 and K4 which is evident in the terrain morphology as a saddle. The tectonic zone separate Jezerka block from the mountains. Presence of such a zone can partially explain contractions, and more intensive uplifts at the edge.

Looking for possible evidence of the event in the tiltmeter diagrams (finding A), we will notice a disturbance of the spring 1994 in the diagram of Jezerka 2 station when, for the first time during tilt monitoring, the tilt turned there back to N for a while (Fig. 2). The tilt path diagram of Jezeří 1 displayed a serious increase of N–S skips in 1994/1995. Besides, tiltmeter Jezerka 1 produced an absolute long-term maximum of daily tilts just in 1994.

Such additional evidence brings findings A, B, C, D, and E to compatibility, and supports interpretation of the event as of tectonic origin.

Conclusions

Studies of long-term monitoring data of the Jezerka–Jezeří section of Krušné Hory Mts. have proved active tectonic movements, which are due to far field forces of unknown origin, located in the mountains, and are not bound to seismic events. The movements were evidenced as uplifts of Jezerka block (up to 1–4 mm per 6 years), distance variations between top cliffs of Jezerka–Jánský Vrch section (up to 4 mm per 6 years), persistent horizontal pressures in two investigated galleries with a pressure – relaxation event of the year 1994. Looking to an old stress measurement and persistent tiltmeter reactions principal stress in this mountainous section is mostly horizontal and oriented to N–S.

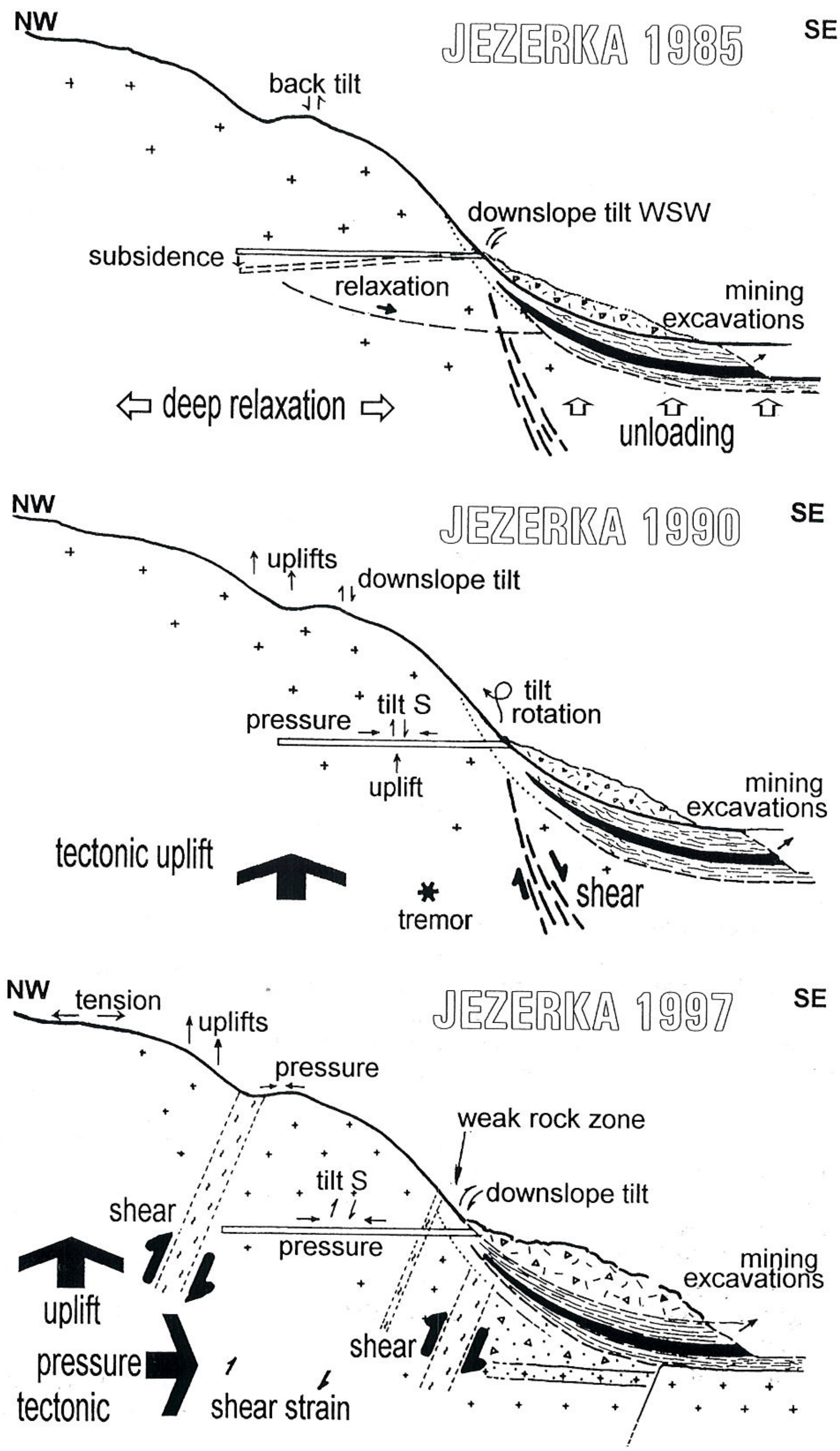

Fig. 7. Massif of Jezerka dynamics in compatibility with monitored deformation effects.
Three stages as evaluated in Jezerka schematic cross sections by 1985, 1990, and 1997. Stage 1985 – an early relaxation period due to unloading caused by mining; Stage 1990 – first indications of tectonic uplifts combined with mining effects; Stage 1997 – after the tectonic pressure event of 1994, function of deep fault structure estimated.

Tape extensiometric measurements in the galleries provided detailed data about rock behavior in the massif. Due to a persisting horizontal pressure the rock creeps by about 1.5 to 3.0 mm per 200 m. year. Besides, massif suffers by slow episodic tectonic shock events. The best evidenced movement of such a type is that of the episode of 1994, when both galleries Jezerka and Jezeří suffered deep in the crystalline simultaneously an elastic slow shock producing reduction in length (12.6 mm and 10.0 mm per 200 m respectively) followed by an extension (30.0 mm and 17.6 mm per 200 m respectively) at about 10 times higher rates than those of creep.

From the year of 1991 observed deep massif reactions have no apparent direct coincidence with present mining operations, which sounds perfect for mining authorities. On the other hand, local mines represent a serious disruption in the territory, and effects of mining are necessarily far reaching in space and time. At present, the observed effects of negative horizontal strains, uplifts, downslope tilts and episodic pressure shocks in the massif produce a compatible picture only as effects of active tectonic movements effective in a wide area of the mountains.

Not knowing the original and natural state of the massif prior to mining one cannot make appraisal of all possible future impacts of mining. Effects in such a territorial scale will probably appear delayed, and even obscure, including potential unexpected slope instabilities. Conditions under Jezeří Castle are rather complicated structurally and mechanico-physically (Marek 1994, Mühldorf 1992, Horáček 1994), and stress concentrations between structural blocks quite delicate. The section of Jánský Hill has no direct control. Impacts of mining can reappear. Monitoring will continue to be a necessary practice for safety reasons.

A schematic dynamics of Jezerka Hill, presented in three stages regarding time and volume of data, has been derived from monitoring. These are given in Fig. 7, which represent a generalization of the up to now observations.

Resulting effects in detail seem to be influenced seriously by the internal structure in the massif where diagonal planes may allow for shear strain, and therefore even for downslope tilts in connection with observed uplifts. Indication of active tectonic forces enforcing pressures in the marginal zone of the mountains supports an idea of a thrust with a main fault dipping steeply under the mountains rather than opposite, parallel with mountainous slopes, which has been a commonly accepted view till now.

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References

Händl, J. (1996): Situation report about ČSA Mine sidewall stability monitoring during first half-year of 1996 (Situační zpráva o výsledcích monitorování stability bočních svahů lomu ČSA za období I. pololetí 1996). – MS AZ Consult, s.r.o. Ústí nad Labem. (In Czech.)

Horáček, M. (1994): Comparison of survey gallery results between Jezerka and Horní Jiřetín in Krušné Hory Mts (Srovnání poznatků o průzkumných důlních dílech mezi Jezerkou a Horním Jiřetínem v Krušných horách). – Sbor. Geol. Věd, Hydrogeol. Inž. Geol., 20, 45–51. Praha. (In Czech, English summary.)

Jakubec, V. (1991): Report No 12 about Jezerka Hill stability (12. informativní zpráva o stabilitě vrchu Jezerka). – MS Vodohospodářský rozvoj a výstavba, i.p. Praha. (In Czech.)

– (1996): Rangefinder survey report from Jezerka Hill (Zpráva o měření délek na vrchu Jezerka). – MS Vodní díla – technickobezpečnostní dohled a.s. Praha. (In Czech.)

Kalvoda, J. – Vilímek, V. – Zeman, A. (1994): Earth's surface movements in the hazardous areas of Jezeří castle, Krušné hory Mountains. – Geojournal, 32, 3, 247–252. Dodrecht, Boston, London.

Košťák, B. (1990): Deformation development in Krušné Hory Mts. slope crystalline in the ČSA Mine forefront, and alarming limits (Deformační vývoj krystalinika krušnohorského svahu v předpolí lomu ČSA s ohledem na varovné stavy). – MS ÚG ČSAV. Praha. (In Czech.)

– (1993): Deformation effects on cracks in massifs and their interpretation. – Proc. 7th ICFL 93, Bratislava, A. A. Balkema, 169–174. Rotterdam.

Košťák, B. – Avramova-Tačeva, E. (1993): Recent rock mass movements investigated in the territories of Bulgaria and Czechoslovakia. – Acta Montana Igt AS CR, Series A, 4, 90, 7–24. Praha.

Košťák, B. – Kudrna, Z. (1991): Stability evaluation of high mountaneous slopes by a method of percolation theory. *In: J.- C. Roegiers*: Rock Mechanics as a Multidisciplinary Science, Proc. 32nd U.S. Symposium, Balkema, 811–820. Rotterdam/Brookfield.

Marek, J. (1981): Final report about engineering-geological survey regarding stability of the Jezeři Complex in the forefront of ČSA coal mine (Závěrečná zpráva o inženýrskogeologickém průzkumu pro řešení stability areálu Jezeří v předpolí uhelného velkolomu Čs. Armády). – MS Stavební geologie. Praha. (In Czech.)

– (1994): Engineering-geological mapping and geological conditions at the toe of Krušné Hory Mts. in Bohemia (Inženýrskogeologické mapování a geologické poměry v okolí úpatí Krušných hor, Čechy). – Sbor. Geol. Věd, Hydrogeol. Inž. Geol., 20, 23–37. Praha. (In Czech, English summary.)

Mejzlík, L. – Mencl, V. (1981): Report about stability calculations of Krušné Hory Mts. slope, Jezeří Castle zone (Zpráva o výpočtu stability části krušnohorského svahu v oblasti zámku Jezeří). – MS Technical University Brno. (In Czech)

Mühldorf, J. (1992): Physical-mechanical properties of the Krušné Hory Mts. crystalline (Fyzikální vlastnosti hornin krystalinika Krušných hor). – MS Thesis – kandidátská disertační práce, PřF UK v Praze, edited by AGE s. s.r.o. Praha. (In Czech.)

Rybář, J. (1983): Effects of open pit coal mining to slope stability at the toe of Krušné Hory Mts. (Vliv povrchové těžby uhlí na stabilitu svahů při úpatí Krušných hor). – MS ÚGG ČSAV. Praha. (In Czech.)

– (1987): Engineering-geological zoning of the outcrop area of North Bohemian brown coal basin at the toe of Krušné Hory Mts. (Inženýrskogeologická rajonizace výchozové partie severočeské hnědouhelné pánve při úpatí Krušných hor). – Acta Montana, 77, 3–63. Praha. (In Czech.)

Rybář, J. – Košťák, B. (1998): Open pit mining under Krušné Hory Mts. high slopes. – Proc. 8th Congress of IAEG and Environment, Vol. 5, 3027–3034, The Can. Geotech. Soc., Vancouver B.C.

Rybář, J. – Zmítko, J. (1987): Mine-geological conditions for open pit mine planning at the Krušné Hory Mts. toe and in the deepest central section of the basin (Báňsko-geologické podmínky rozvoje povrchového dobývání na úpatí Krušných hor a v nejhlubší centrální části pánve). – Hnědé Uhlí, 1, 7–30, Most. (In Czech.)

Skalský, L. (1996): 2nd quarterly 1996 tiltmeter report for stations Jezeří, Jezerka-1 and Jezerka-2 (Zpráva o výsledcích náklonových měření, provedených na stanicích Jezeří, Jezerka-1 a Jezerka-2 ve 2. čtvrtletí 1996). – MS GFÚ AV ČR. Příbram. (In Czech.)

Tobyáš, V. (1995): Seismic survey in SHR – Summarizing report 1982–1994 (Seismický výzkum oblasti SHR. – Souhrnná zpráva za období 1982–1994), MS GFÚ AV ČR, Praha. (In Czech.)

Vilímek, V. (1996): Interpretation of a new geodetic survey on the Krušné Hory Mts. fault slope (Interpretace nových geodetických měření na zlomovém svahu Krušných hor). – MS PřF UK. Praha. (In Czech.)

Vybíral, V. – Osykin, M. A. (1995): Survey of ČSA Mine slopes using PEE method (Meranie pol'a PEE na svahoch bane ČSA). – MS Sensor s.r.o. Bratislava. (In Slovak.)

Zika, P. – Rybář, J. – Avramova-Tačeva, E. (1993): Analogy in stability evaluation of high rock-cutting slopes. – Acta Montana IGt AS CR, Series A, 4, 90, 81–92. Praha.

Údaje o současných tektonických pohybech Krušných hor

Kontrolní sledování krystalinika Krušných hor v předpolí povrchového dolu ČSA poskytlo údaje využitelné jak pro zabezpečení důlního provozu, tak i pro zhodnocení deformačního chování okrajové oblasti hor v poměrně dlouhém období posledních dvou desetiletí. Štoly Jezerka a Jezeří, vyhloubené hluboko do masivu krystalinika ve zlomovém svahu poskytují přitom nejdůležitější údaje o deformacích. Ačkoli původní stabilitní úvahy nepředpokládaly účinnou horizontální napjatost v masivu, deformační měření ji potvrzují. Ve hloubce štol bylo zjištěno pozvolné zkracování a zkos, které svědčí o horizontálním tlaku. Rychlost ploužení v hornině dosahuje dlouhodobě $e = -1{,}7.10^{-5}$/rok, přičemž hlavní napětí je na Jezerce orientováno S–J, tj. kose ke zlomovému svahu. Přesná nivelace v okrajové části masivu Jezerky zachytila zdvihy řádově 0,5 mm/rok. V masivu proběhly rovněž několikaměsíční epizodické deformační události, které nemají vazbu na seismiku. Některé jsou následkem důlní činnosti, avšak jiné nelze interpretovat jinak, než jako následky současných přirozených aktivních tektonických pohybů. Zjištěná pohybová událost z prvé poloviny roku 1994 dosáhla rychlosti až desetkrát vyšší než dlouhodobá rychlost plouživého pohybu ve skalním masivu.