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# SEISMIC ACTIVITY DEVELOPMENT BEFORE STRESS CONDITIONED STRONG SEISMIC EVENTS IN JELŠAVA MINE

Pavel KALENDA[1) and Ivan POMPURA[2)

[1)Coalexp Ostrava, Kosmonautů 2,
700 30 Ostrava–3, Czech Republic
[2)SMZ Jelšava

Abstract. All significant events registered by continuous seismic monitoring system at the Jelšava magnesite mine during the period from July 17,1993 to August 1,1995 are described in the paper.

The anomalous seismic development preceding significant geomechanical events on the background of normal seismic activity was discovered on the basis of seismic data acquisition. Criteria for prediction parameters of the slope of Benioff's sum graph and criteria for number of seismic events at the time window were found on the same seismic data.

Necessary conditions for successful monitoring and prediction of these abnormal geomechanical events were discussed. Sufficient density and sensitivity of the base of sensors, homogeneous massif and on–line data processing in real time were determined as necessary conditions for successful prediction.

## 1. Introduction

An extraordinary event having occurred at the Jelšava deposit in 1991 resulted in collapse of the roof in the uppermost chamber of the Dubrava part of the deposit causing a surface crater with dimension approx. $150 \times 100$ m and $50-70$ m deep. Because this happened by pure coincidence on a holiday, no casualties were registered (see Fig. 1 and 2).

The monitoring system UGA 15 was installed in the area of the neighbouring chamber of similar dimensions in 1993. This system allowed us to study the induced seismicity in more details. The purpose of continuous SA monitoring was to localize seismic events, to determine their energies and to define the seismic modes of individual areas with adequate accuracy, especially in parts of Mikova chamber.

After a year's trial operation and after finding
separate anomalous seismic activity on the background of normal seismic mode and to indicate long enough in advance hazardous states of the rock massif induced by stress alterations [Kalenda, Pompura 1996], we analyzed and determined prediction parameters, their limit values and we also analyzed the anomalous development seismic activity before the occurrence of a main event. In this paper there is a description of the analysis of anomalous development of seismic activity before

FIG. 1. View of the Dúbrava abyss from the south

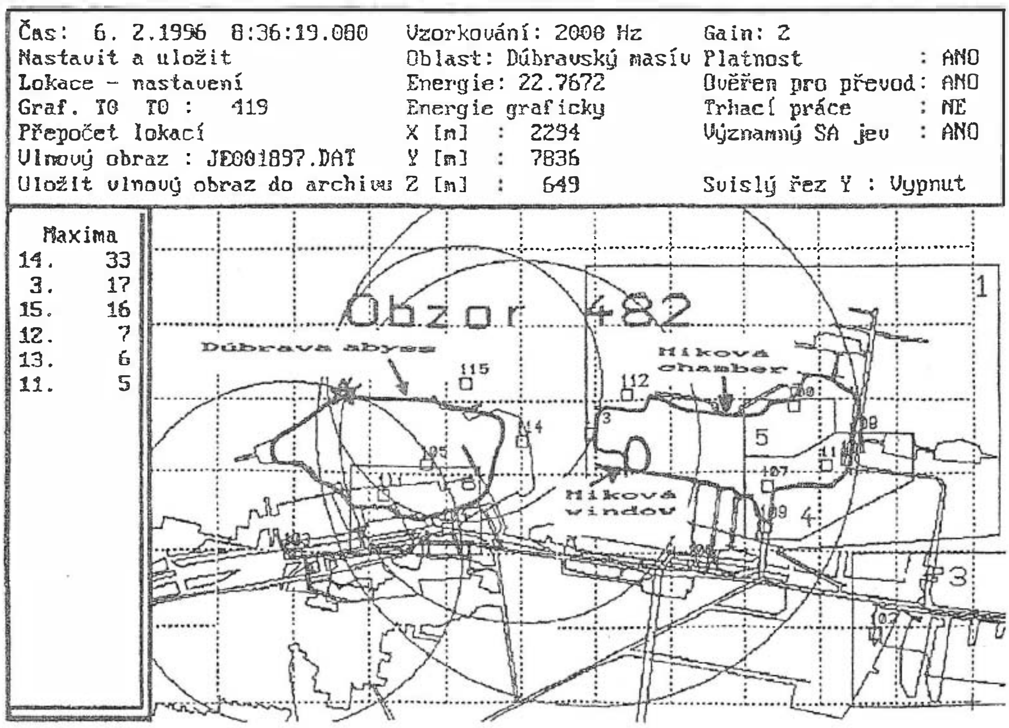


FIG. 2. Localization map of stone fall (more than 1000 m$^3$)

the main event and the estimation of its magnitude depending on duration of the anomalous seismic activity.

## 2. DATA PROCESSING

The seismic monitoring at Jelšava deposit is running in usual way. There are three seismometers SM–3 (101, 102, 103) located in the neighbourhood of Mikova chamber and the area of interest has dimensions of about 800 × 500 × 200 m and there are 13 pcs of seismoacoustic sensors (100, 104 – 115) installed on five horizons, 390 – 500 m above s.l. [Kalenda, Pompura 1996]. The density of those sensors and their sensitivities enable to register all the events from the area of interest with energies from about 0.5 J.

The events are automatically localized with accuracy of about 20 m, their energies are evaluated and consequently, all the blastings according to reports from the mine are marked into the file, thus confronting the waveforms. All the evaluated events are stored in databases for blastings and natural events. From the databases for natural events it is possible to compile Benioff's sum graph and a number of events in a sliding time window. Mechanisms of natural events are not determined. For all the analyses it is possible to select events only according to areas or energies. The graphics enable to monitor changes in in the number of events and the values of seismic loading (sum of roots of energies) in squares sized 20 × 20 m.

A number of following significant geomechanical events was registered during the monitored period from 17.7.1993 – 1.8.1995:

- 13.10.93 – loosening of a block in the chamber's roof together with an anchor
- 23.–25.10.93 – loosening of a block in the southern part of the chamber after destructive blasting
- 7.11.93 – gravity breakdown of the scrap interchamber pillar, i.e. "leg" and break–through of interlevel panels
- 16.–17.1.94 – crumbling of the sides of the Dubrava abyss and movement of mass surrounding the "leg"
- 16.10.94 – breakdown of a block in the south–east corner of the Mikova chamber
- 15.2.95 – breakdown of a "groin" in the eastern part of the Mikova chamber

The above given events were reported earlier [Kalenda, Pompura 1996] and here is a list of newly registered events:

- 24.4.95–13.6.95 – seismic activity in the eastern block of the Mikova chamber
- 28.7.95 – events in the south–east side of the Mikova chamber plus a significant event
- 6.2.96 – falling down of a block from the Dubrava abyss (see Fig. 2).

## 3. DISCUSSING THE OBSERVED RESULTS

There are periods of anomalous seismic activity which can be well seen from Benioff's sum graph (see Fig. 3). The bend in the slope of Benioff's sum graph from 1.8.1994 is connected with the change when setting the parameters for energy calculation. The anomalous seismic development before the event of 15.2.1995 can be seen best, when the breakdown of the groin in the side of the Mikova chamber took place as a result of stress rearrangement. More than 1500 m$^3$ of rock was put

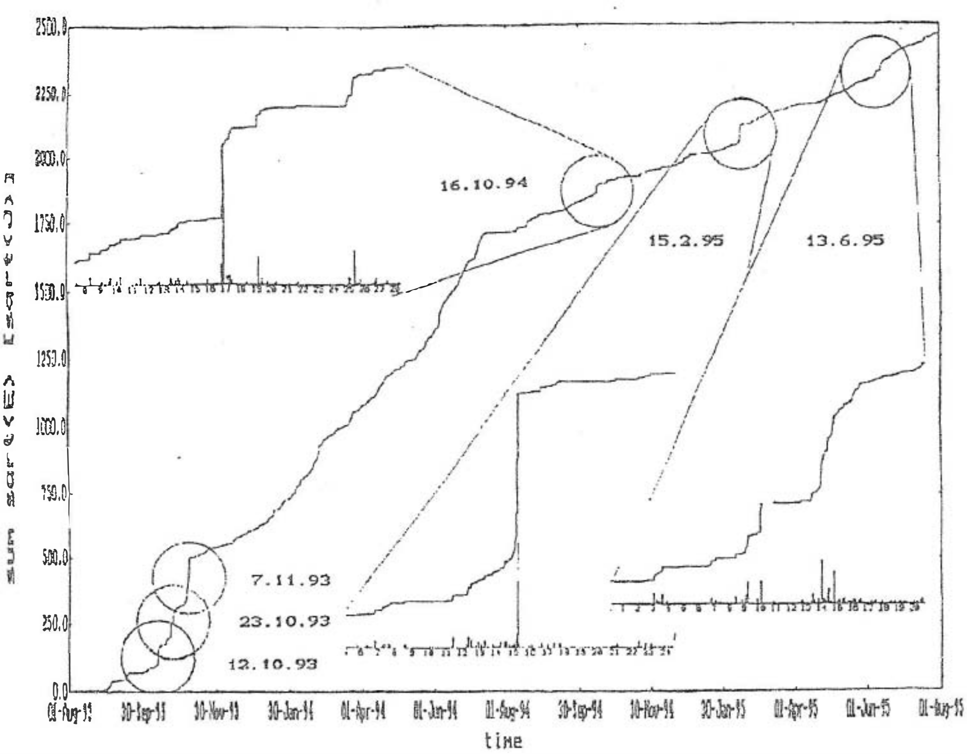


FIG. 3. Benioff's sum graph

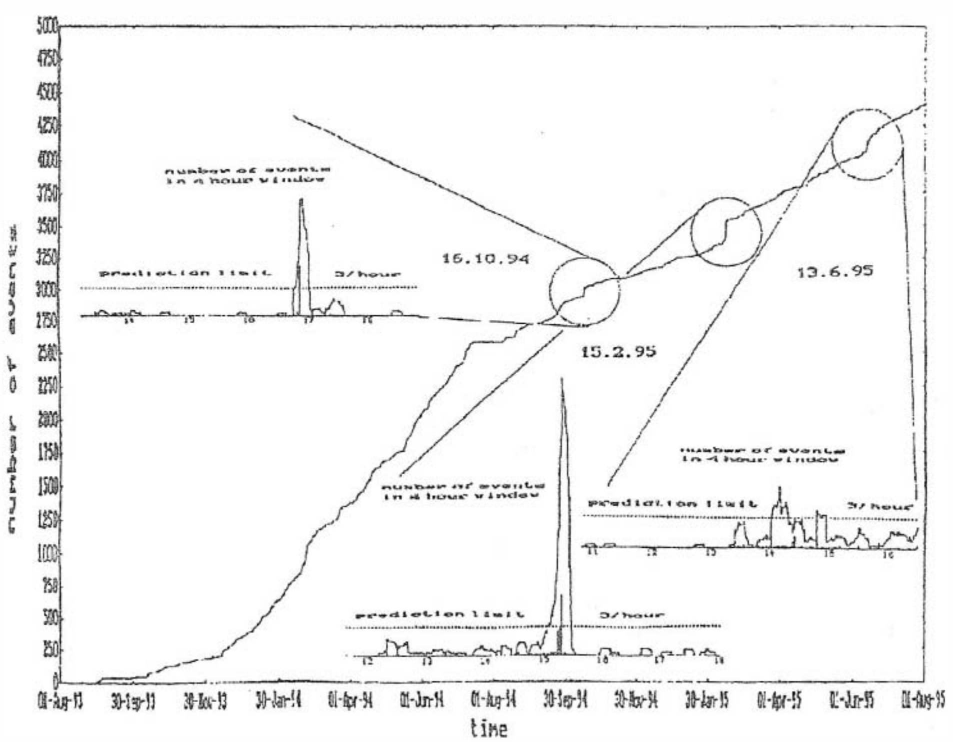


FIG. 4. Cumulative number of seismic events

into a motion during the main event. Gradual growth in frequencies and energies of individual seismic events was mostly apparent before the occurrence of significant ones.

The limit slope of Benioff's graph in 4 hour's sliding window was initially evaluated to the value of $2\sqrt{J}$/hour. This was done on the basis of data processing for all monitored period. At this value there was no "release" of any anomalous development which was so far discovered and, on the other hand, there was a minimum number of false warnings.

The anomalous seismic development is even more apparent from the graph showing the accumulated number of events (see Fig. 4). It was confirmed that so far, before every significant event which had destructed the rock massif due to stress changes and exceeding the strength limit, we could observe the growth in frequency of relatively small seismic events in given area and this had happened a few hours in advance.

The prediction limit for a number of events in 4 hour's sliding window was initially assessed to $2-3$ events per hour according to the area. This parameter responded better and sooner to anomalous development than the slope of Benioff's sum graph. The mutual combination of both parameters, expressed as the slope of Benioff's sum graph in the window of six consequent events which had minimum of false predictions and did not release any of the significant anomalous development, seemed to be ideal (see Fig. 5). Only those developments were released or registered late, which had main events with low energies or which took place as a result of gravitational collapse due to lack of stability, but not as a result of exceeding the strength limit of the rock.

The best predictable events were of 13.10.1993, 16.10.1994 and 15.2.1995. The limit values of both parameters (slope of Benioff's graph and number of events) were exceeded at the event of 15.2.1995 for more than 3 hours before the main event and moderate growth of activity had been taking place a few days sooner (see Fig. 3). The limit values at the two remaining events were exceeded before the main event, but this period was so short that it was impossible to inform the miners about the anomalous state (see Fig. 3, 4). This can be explained by a relatively small volume of rock subject to destruction. At the disastrous event in 1992, when the Dubrava abyss came into being, the increased activity had been observed at least two days before.

Benioff's sum graph with cleared background, which was determined within the span of $1-3\sqrt{J}$ during the period from 1.8.1994 (see Fig. 5) was used to determine the anomalous development of seismic activity occurring before the main event. Reading the normal slope of Benioff's graph was performed individually according to requisite seismic activity before an event in given time. The value of $2\sqrt{J}$/day for the event of 15.2.1995 was accepted as a normal slope of Benioff's sum graph and the value of $1.2\sqrt{J}$/day was accepted for the event of 16.10.1994.

On the background of normal noise after substracting the trend of Benioff's sum graph there is an evident development of anomalous seismic activity. At various noise suppression (compare Fig. 7a–c) it is possible to observe that the anomalous Benioff's graph of the event of 15.2.1995 has ideal exponential form after substract-

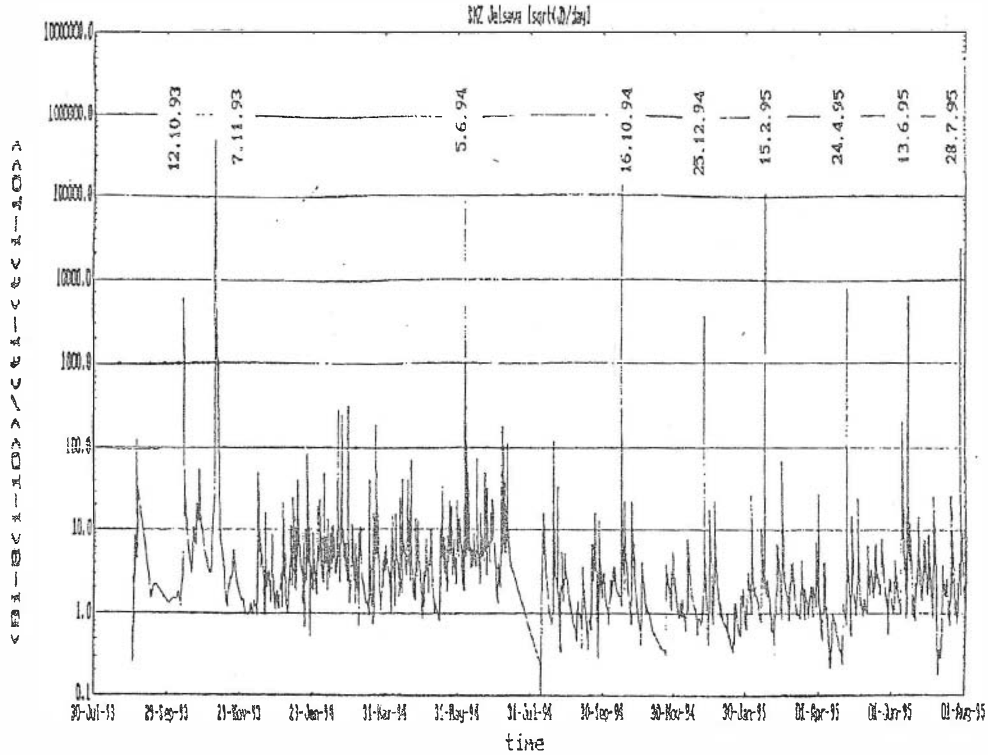


FIG. 5. Benioff's graph slope for 10 events

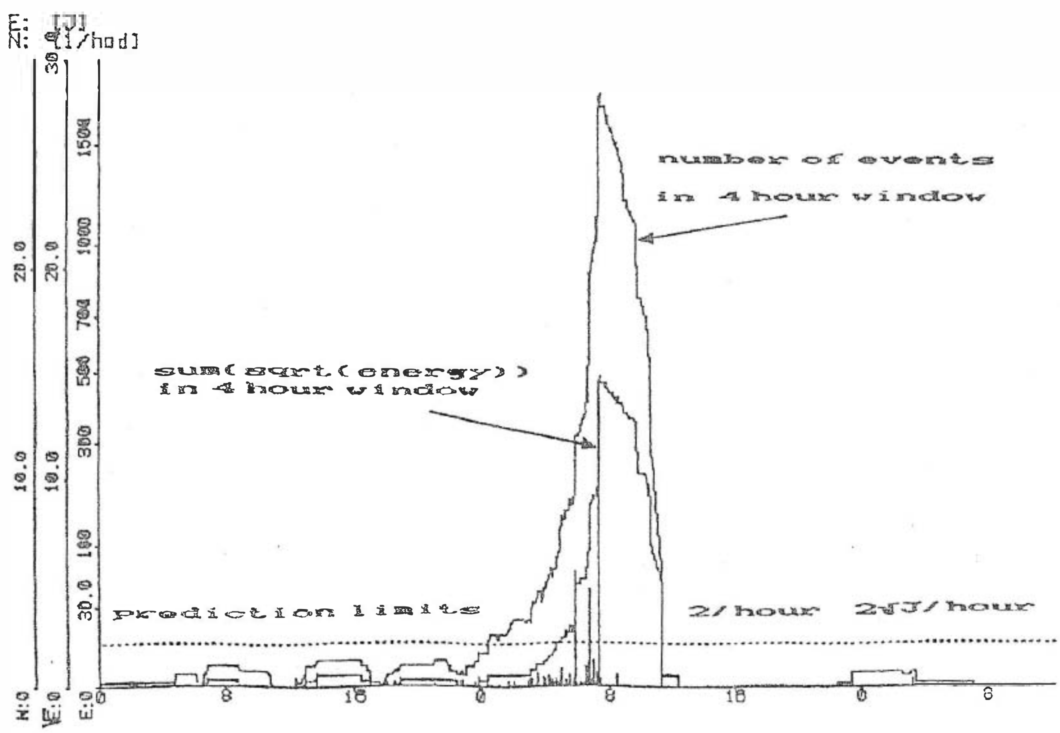


FIG. 6. Prediction parameters graph

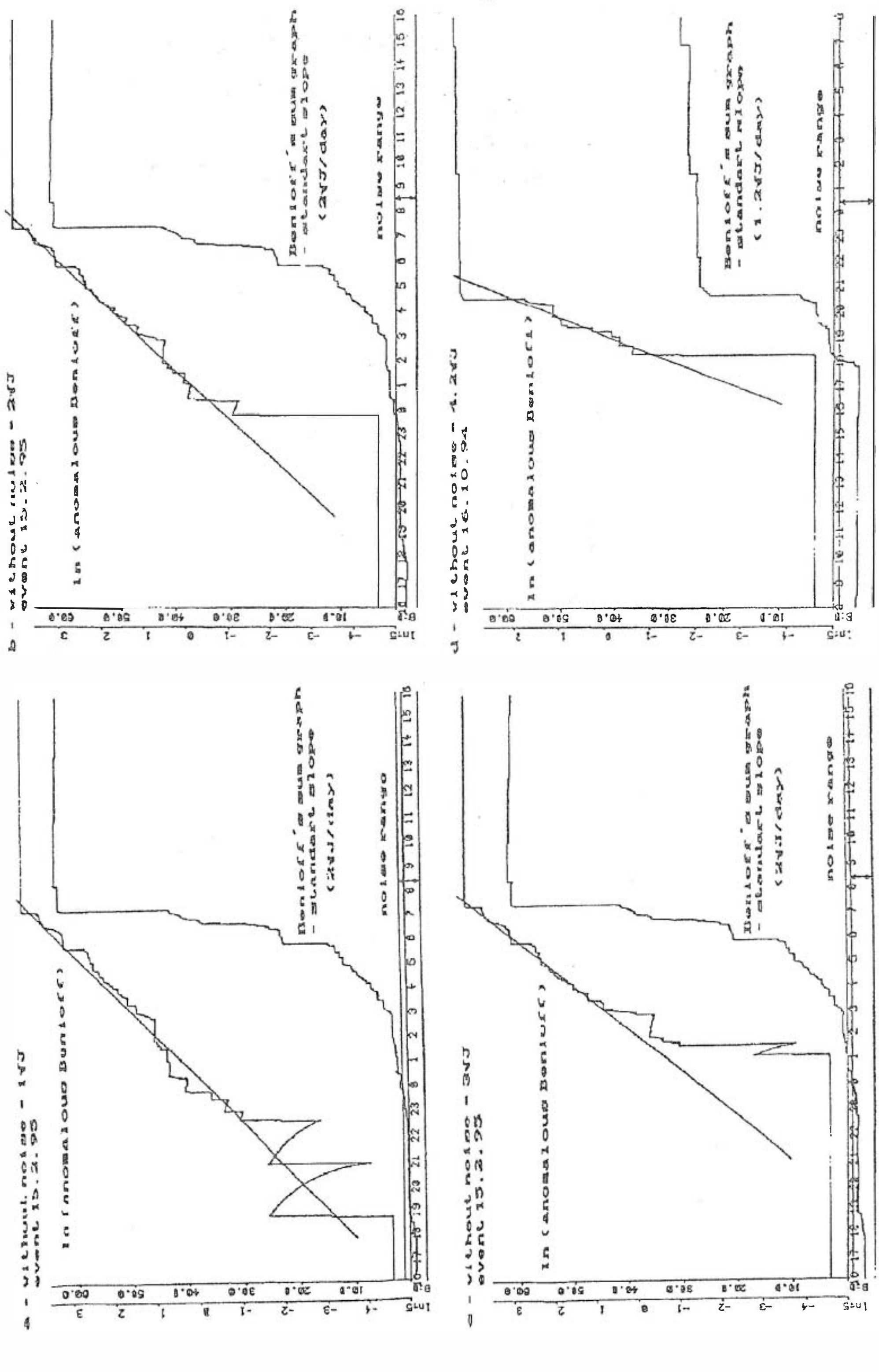

FIG. 7. Seismicity development before main event

ing the level of accidental noise. After substracting low level noise the initial part of the graph is very irregular, after substracting anomalous signals the initial part of anomalous development is not consistent with its final part (see Fig. 7c). Then all the seismic activity for the period of about 14.2., 18:00 to 15.2.1995, 7:30 can be considered as a show of a single process with unified dynamics and development which was terminated by a main event emitting the biggest energy and resulting in destruction and disintegration of the whole block of massif.

However, if we had monitored all period from about 7.2.1995, we could have come to a conclusion that this whole period can be considered as anomalous in given locality and the whole anomalous process consists of individual partial processes. Similarly, it was so even in case of the other partial processes, as it is evident, for example, from Fig. 7d when the main event of 16.10.1994 was preceded by a few partial anomalous periods with the only climax.

Discovered developments of anomalous seismic activities correspond to theoretical hypotheses sample modelling as it was published [Dunegan 1996]. As necessary conditions to monitor anomalous seismic activity before the main event appear the following ones:

- sufficient density and sensitivity of sensors enabling thus to register events with energies a few orders over the corresponding energy of the main event is. For example, in case of the Jelšava deposit it is necessary to monitor seismic events with energies below 1 J, because the events with energies about 100 J are relatively dangerous due to affecting the volume 1000 $m^3$ of rock mass at minimum.
- relative homogeneity of the massif, because at the multicomponent geological construction of the massif both components have their anomalous developments at different stress levels and it is not trivial to separate seismic activities of both components as it is done in coal mines, for instance. Similar non–homogeneity can be observed in the case of wide tectonic fault areas.
- on–line registration and processing of seismic events, because the anomalous seismic development lasts from a few hours to days in conditions of the Jelšava deposit.

Geomechanical events caused by the loss of stability of rock blocks and their gravitational collapse even on a large scale will not be possible to predict, because they are not preceded by the seismic activity.

## 4. Conclusion

All the anomalous geomechanical events at the Jelšava deposit in a period of 17.7.1993 – 1.8.1995 were assessed and compared with results achieved from seismic monitoring. The anomalous seismic development preceding significant geomechanical events on the background of normal seismic activity was discovered on the basis of seismic data acquisition. Criteria for prediction parameters of the slope of Benioff's sum graph and criteria for number of seismic events at the time window were found on the same seismic data.

Abnormal development of seismic activity before significant geomechanical events was monitored and it was found out that this development was exponential by parts and had unified dynamics and therefore it was possible to predict what region would be affected next time as well as further continuation of that anomalous development.

Necessary conditions for successful monitoring and prediction of these abnormal geomechanical events were discussed. Sufficient density and sensitivity of the base of sensors, homogeneous massif and on-line data processing in real time were determined as necessary conditions for successful prediction.

On the other hand it will be impossible to predict the geomechanical events caused by the loss of stability and by gravitational collapse.

## References

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