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STATISTICAL METHODS FOR INTERPRETATION OF MINING TREMORS

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ABSTRACT. In this lecture, the results of monitoring and processing of seismic induced phenomena from Kladno rockburst region are presented. More detailed were analyzed the following tasks: the relation between maximum seismic energy and the sizes of active layers, the possible explanation of the shape of the magnitude frequency relation. Perspective methods and the most important problems for the next future research are drafted.

INTRODUCTION

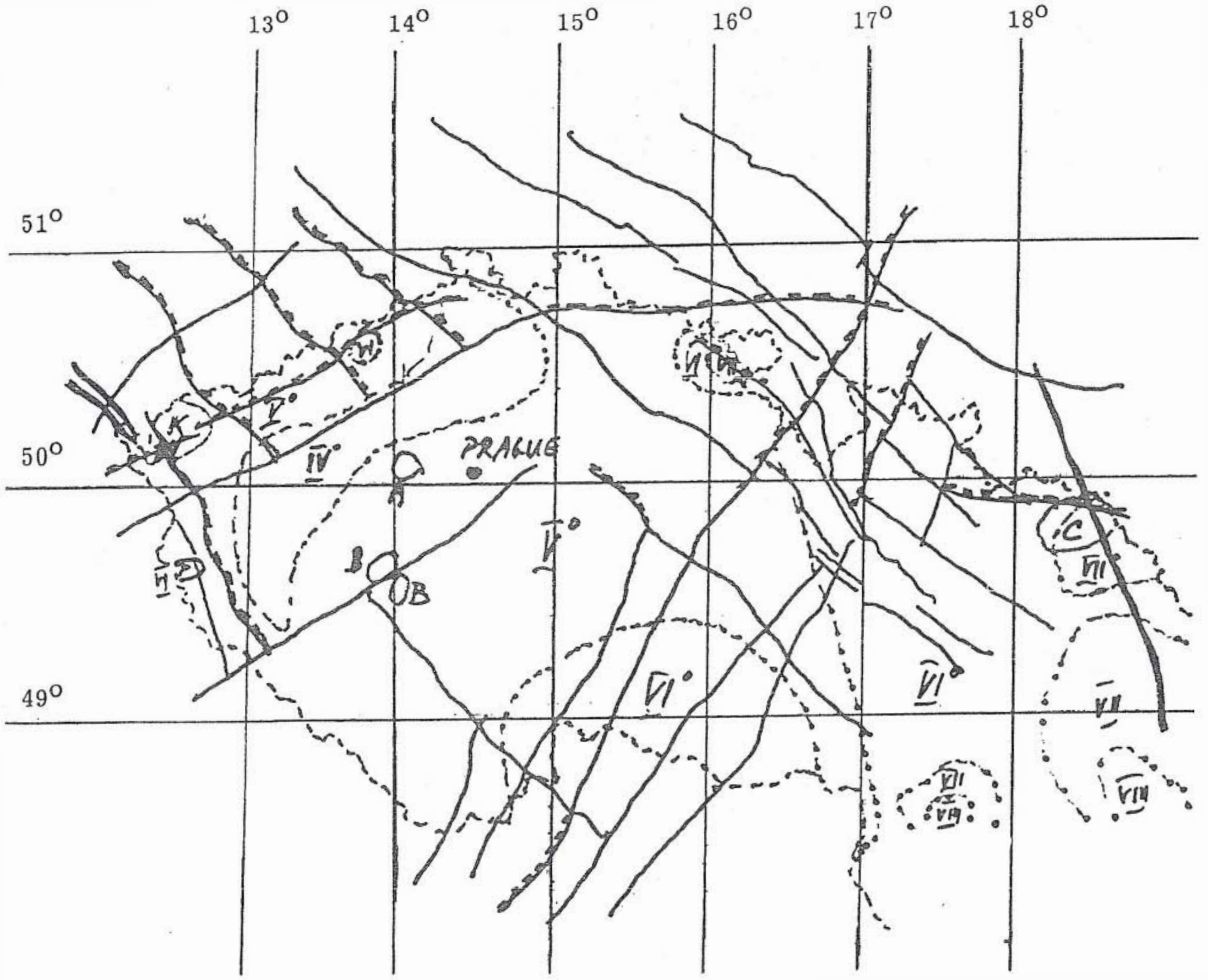
Systematical investigation of rockbursts in Kladno coal region, was performed since 1960, when the station Vinařice was installed there; the seismic event continuos monitoring has been running up to now.

It should be stressed out, that the seismological research in Czechoslovakia was performed not only in the above mentioned Kladno coal basin (west Prague), but also in the Příbram ore mine region, which is situated some 40 miles south-west of Prague. The excavation in Příbram mine openings reached the level 1600 m under surface, what was the deepest excavation level in Europe in the time.

This situation is shown in Fig.1 in which also the other rockburst regions in the Czech Republic are denoted, namely Ostrava-Karviná coal basin, which belongs to the South section of Upper-Silesian coal basin. The lager, Northern part of the said basin extends over the South border region of Poland. Also here an intensive rockburst research is being carried out in the last decades, as being demonstrated in the contributions of Polish colleagues.

The bold lines in the picture represent the deep tectonic fault locations. The more detailed characteristics of all the rockburst regions of Poland and Czech Republic are given in this symposium Proceedings: Acta Montana (special issues); Publs.Inst.Geoph.Pol.Acad.Sci (special issues).

As concerns the international collaboration in geophysical research of rock stress field distribution and its variations and of rockburst occurrence, close contacts has been made with Polish and Russian specialist. Selected results obtained together with the colleagues of the Moscow Institute of the Physics of the Earth supervised by Ju.V.Riznichenko and performed namely V.Mjachkin and S.Vinogradov were formulated in common monograph (Riznichenko et al, 1966).



A – Kladno
B – Příbram
C – Ostrava-Karviná

K – West Bohemian region of seismic swarms

Roman numerals denote epicentral intensity I_0

FIG. 1

The continuous cooperation with the Polish specialists has been intensively carried out in the last 30 years. Every year common Czech–Polish workshops have been organized, alternatively in Poland and Bohemia. The papers presented in these workshops were summarized in Polish and Czech geo-periodicals as their

Topical Issues (Acta Montana: No 22, 32, 38, 50, 55, 61, 71, 75, 81, 83, 84, 88, 89; Publs.Inst.Geoph.Pol.Acad.Sci.: No 47, 67, M1/97, M2/123, M3/134, M5/155, M6/176, M8/191, M10/213). Their copies are still obtainable in the Institute of Geotechnics Prague. Unfortunately, some of the papers are presented in Czech or Polish languages only.

The last meeting in the 1992 in Liblice by Prague had an international character and the list of participants is attached to the Proceedings of this symposium (Rudajev 1992).

Statistical research mining tremors

Let me now concentrate to the application of statistical methods in the rockburst study.

When applying the statistical methods for the induced seismic events evaluation the three fundamental viewpoints should be regarded.

Firstly, building up a proper physical model (or hypothesis) of mining tremor physics and of their occurrence. The scheme of the simple hypothesis of origin of mining tremor is shown on the Fig.2. Since the mining tremor should be understood as a result of a complex deformation process in the heterogenous structurally discontinuous, anisotropic rock massif variable in space and time, its occurrence explanation and possible prognosis assessments, can be hardly found by means of one method only, e.g. such as seismic record analysis. Namely, application of statistical methods should be aimed to multifactorial geo-data analysis.

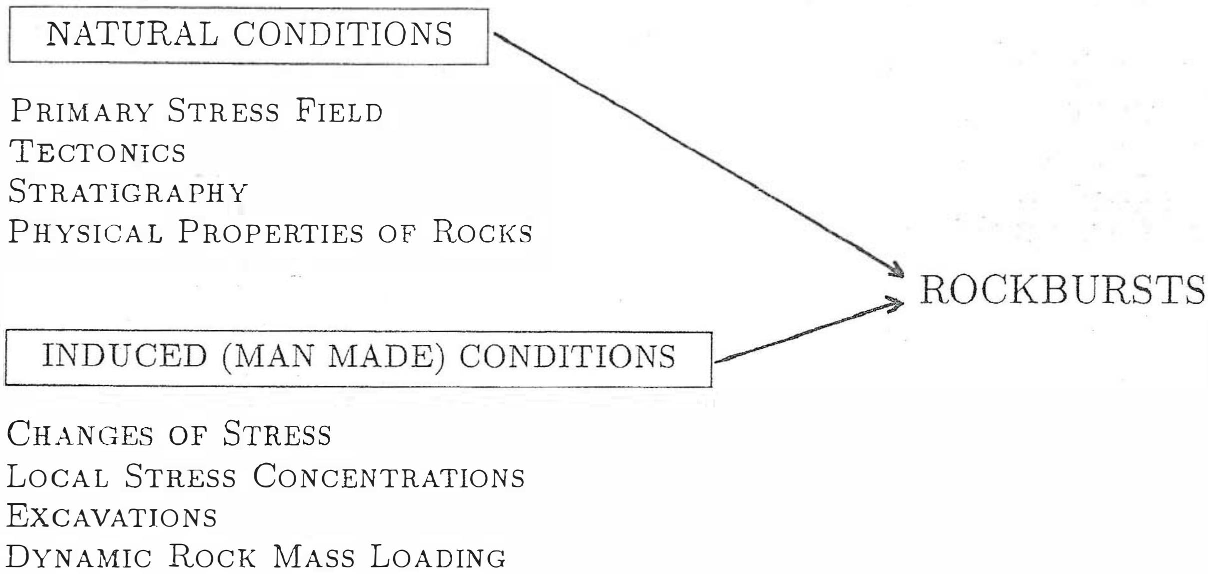
Secondly, the completeness and homogeneity of initial data should be satisfied in maximum degree. By the homogeneity, not only space/time uniformity of rockburst series should be understood, but also the family of foreshocks and aftershocks of the event related to the main shock should be distinguished according the Benioff pattern, see Fig.3. It follows from these figures, that the cumulative number of events does not fit the above condition of homogeneity.

At last, the proper application of statistical methods data evaluation and physical interpretation of the results should be searched for, that is

- determination of seismicity parameters, such as seismic energy release in time,
- energy-frequency distribution,
- space time foci clustering,
- energy range (of the pulses released) determination,
- determination of the maximum possible magnitude (energy) in the region in question (seismic hazard assessment),
- short time prediction of individual strong rockburst occurrence.

In the following selected results obtained from the statistical processing of geodata from rockbursts endangered regions of Czech Republic will be demonstrated.

The flow of seismic energy, such as shown in the figure 3, confirms the non-stationary processes in the rockburst foci. This non-stationarity results from both, rate and way of mining excavation and the local physical-tectonical properties of focal region. The re-distribution of the tectonic stresses may be described as a change



The limit stress-strain state implicates the new properties of rocks:

a) changes of transfer functions:
   - elastic waves – V_P/V_S
   - elmag. waves – attenuation frequencies

b) changes of rock mass structure:
   - new cracks the origin of which is accompanied by acoustic emission

Fig. 2

of the stress tensor component. In this process the mutual orientation of the main stress components, namely these of shear and tensile ones, versus the prevailing space orientation of primary faults is of the highest importance. For illustration of the importance of the primary stress distribution, the differences in the seismic activities in the individual sections of Kladno coal mine region is presented in Fig.4. Here the hatched area denotes the region of the rockburst occurrence. The points denote the position of mines. The induced mining tremors foci are situated exclusively in the sediment sandstone strata into which tertiary volcanic effusions penetrated. It is related to the encreased horizontal stress components what can be understood as a predisposition. In Kladno region it was observed that after termination of mining excavation, the rockburst occurrence died out completely within 1 month.

The situation differs considerably in the Příbram ore mine region, in which the deposits are almost vertically arranged. Here, after termination of mining activities, following 3-years period was characterized by the absence of any local seismic event. In this period, however, the underground water level climbed from 1500 m under the surface up to 800 m level. These changed the friction conditions along the

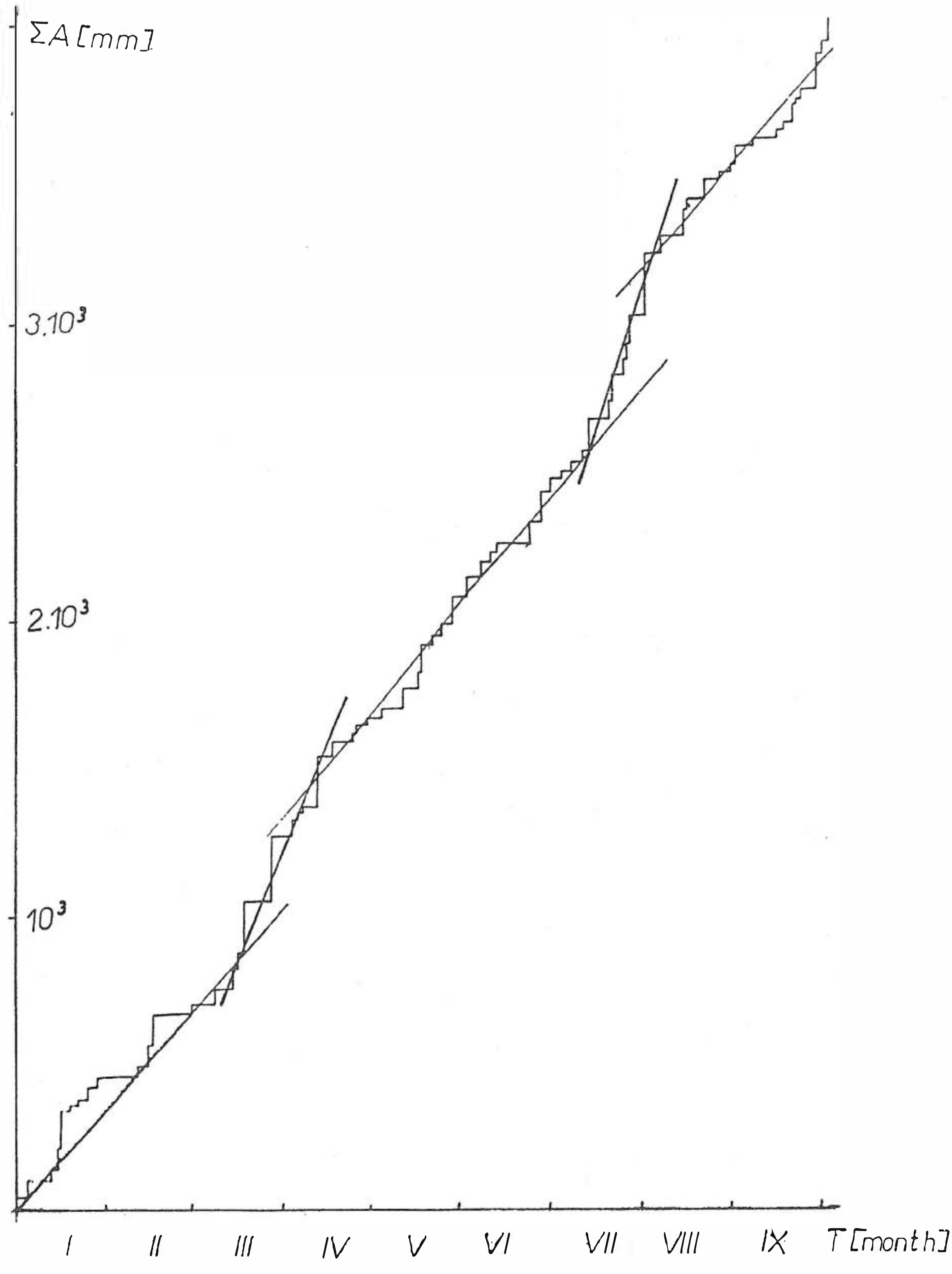


FIG. 3

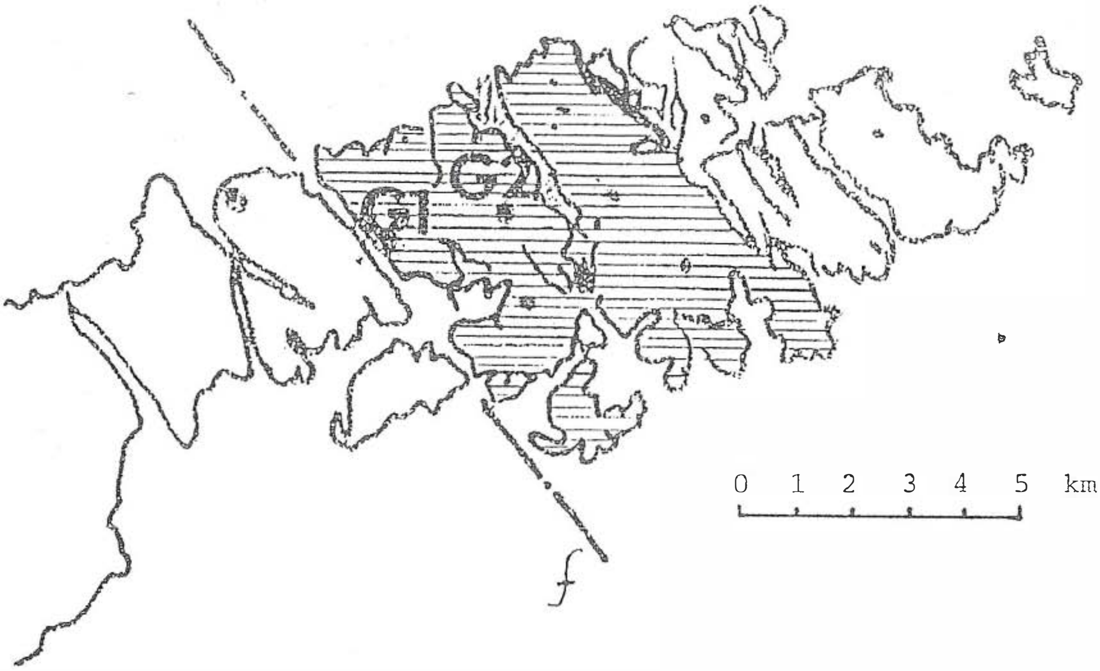


FIG. 4

dislocations of the rock massif what resulted in occurrence of 3 strong rockbursts having the magnitude M_L equal to two.

As concerns the energy/frequency distribution mining tremors ($\log N = A - \gamma \log E$) it was found that the parameters of this empirical function were variable in time and they were dependant on the structure of rock massif and amount of seismic energy released. In Fig.5 the pattern is shown, which is typical for the Kladno rockburst region. This pattern is important for the prognosis of strong rockbursts occurrence; therefore, it is analysed more in detail: the completeness or not-completeness of initial seismic data was tested from the view-point of its reliability. It was found by means of numerical model, that in the case of non-sufficient amount of events, for example $N = 100$ the random walking of A and γ parameters of this distribution may occur. This phenomenon can influence substantionally the shape of distribution course. The details can be found in the paper by Buben and Rudajev (1992). Except of the above limiting cause the shape of the distribution curve depends also upon the parameters of the rockburst initiation. Kijko at al (1985) explained the bimodality of distribution curve as a result of the fact that two rockburst localities with different mechanism of foci were mixed in. Special discussion on the magnitudo-frequency distribution can be found in Lasocki (1992a).

The shape of the distribution curve (Fig. 6) can be also affected by the rock massif structure and the size of rockburst active volume. Occurrence of the weakest events ($M_L \leq 0{,}5$) is related with the size of rock grains and intergrain cracks the most numerous events given by the distribution curve corresponds to the level of characteristic tremor energy in a given area. The section of the distribution pattern

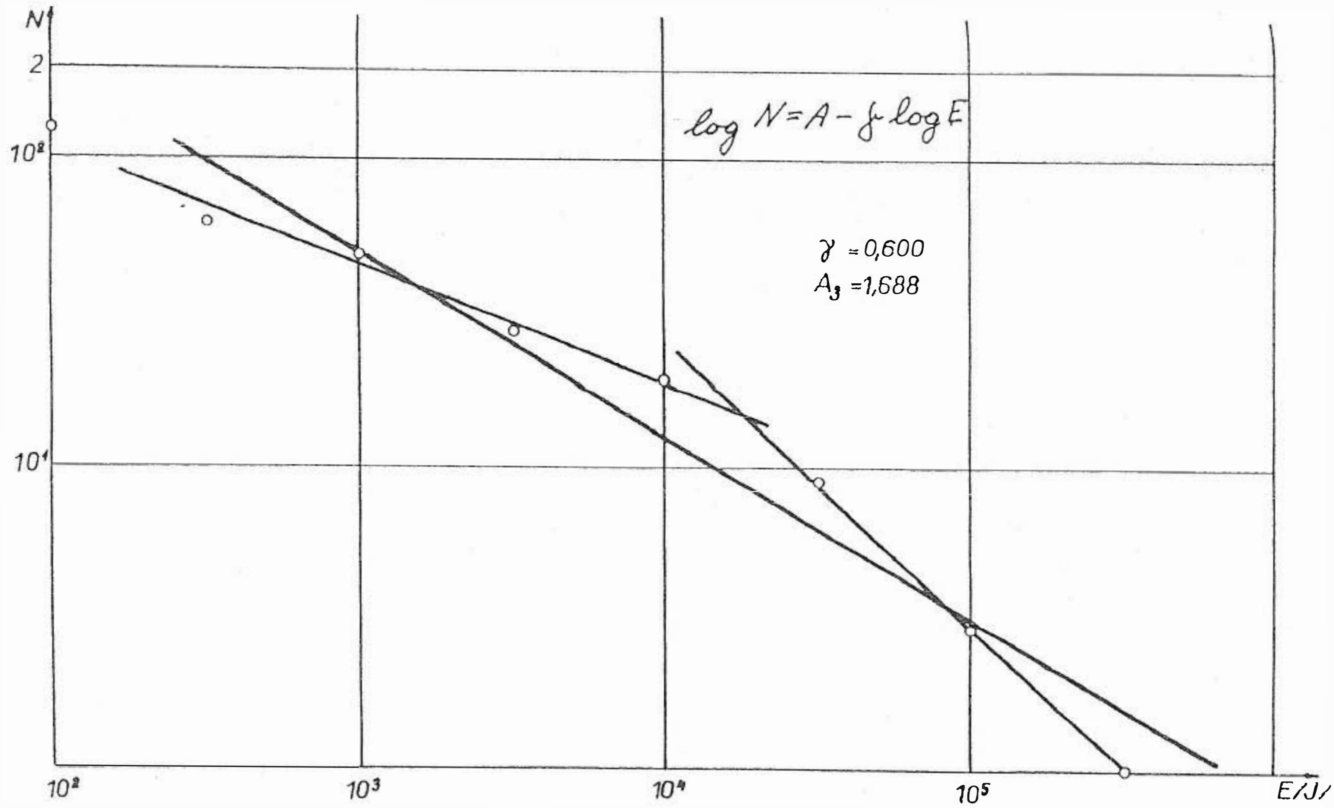


FIG. 5

(for the strongest events, $M_L \geq 1{,}5$) is limited by the thickness of the seismoactive stratum.

Complex analysis of rockbursts resulted in the conclusion that value E_{max} primarily depends on the focus volume, which can be, in the first approximation, simulated by a sphere with radius R, e.g. using modification of the inverse Sharp model (Fučík, Rudajev 1979).

This dependence was described by relation (Buben, Rudajev 1992)

$$\log E = C_1 \log R + C_2 \, .$$

Parameter C_1 depends on the geometrical shape of the focus. In the case of a sphere, $C_1 = 3{,}3$. The value of C_2 depends on elastic moduli, on the strength of rock and also on coefficient p describing the transformation of deformation energy W to energy E_s of seismic waves, $E_s = p.W$.

The values of C_2 for various estimates of transformation coefficient p are given in the following table

$p\%$	10	1	0,1
C_2	1,54	1,2	0,87

For geomechanical moduli of rock mass in the Kladno coal mine radius R of the

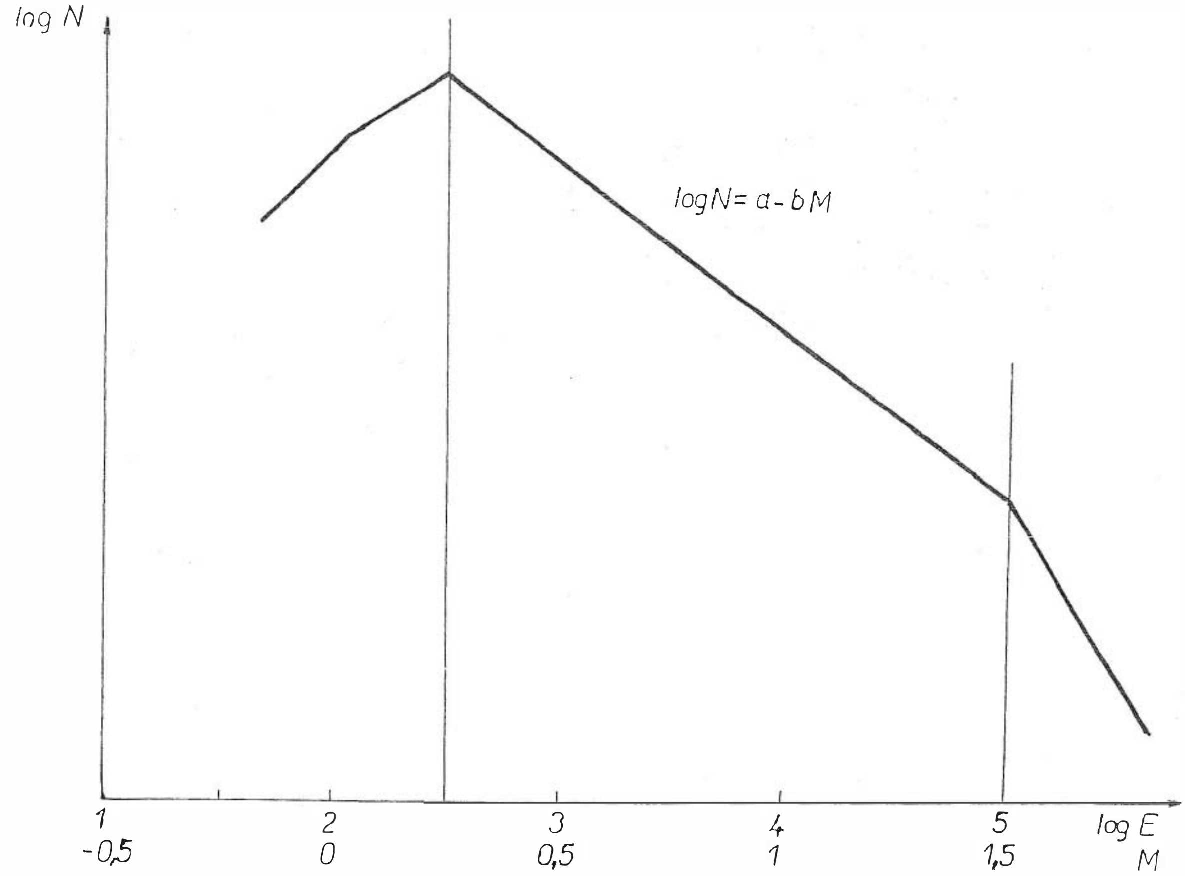


FIG. 6

focal volume sphere for $K_{max} = 6{,}2$ ($M_L = 2{,}0$) should have the value $R = 27$ m. Assuming a focus volume of elliptical shape with axes $a = b = 3c$, then for maximum rockburst energy $K = 6{,}2$ the value of the axis are $a = b = 39$ m. The superstrata of the coal seam are formed by cretaceous (claystones and sandstones). The rockburst foci it has been found that they mostly occur in a brittle, relative strong sandstone. The thickness of this layer is about 44 m. This seems to be in good agreement with the value which is given above. Empirically, the analogous relation was confirmed also for the Ostrava-Karviná coal region (Kalenda 1992)

$$\log E = -0{,}56 + 4{,}29 \log h \qquad \text{[Joule,m]}$$

Here h denotes the thickness of the overlying active layer. The discussed relation was obtained using the third Gumbel distribution for estimation of maximum energy. By this the difference between the values of the coefficients 2,3 and 4,3 respectively for both discussed regions can be explained.

The questions of prediction of individual seismic events in time, however, (even the multichannel statistical methods are used), are not completely solvable, in general. The largest obstacle is the non-stationarity of the seismic energy release. The stationarity is preserved only for individual sections of the pattern (Fig.3). The most important sections of diagram, however, demonstrate the non-stationary character of the process. Up to now the most frequently utilized methods of time series extrapolation based on the predictive errors minimalization, which are mentioned in Rudajev (1993), seem not to be quite sufficient.

At present a complex research in the isolated rockburst region of Kladno is carried out with the aim, firstly, to establish the proper physical model of rockburst occurrence, secondly, to elaborate the methods of rockbursts prediction, and finally, to define and verify the measures of the rockbursts consequences mitigation.

The methods of rockburst analysis would utilize the results of laboratory tests, namely as for the acoustic emission from loaded rock samples. Classification of the rockburst source mechanism would also respect the non-linearity of process which is related with variable rupture velocity. The first result obtained in this field indicate the suitability of non-linear approach namely for more accurate determination the focus size and the focus energy density. A special attention will be paid to the detail investigation of properties of rock massif and also to the excavation advance as related to the space/time rockburst occurrence.

Conclusion

Let us return to the Czech-Polish meetings. In this Workshops on Mining Geophysics the following questions were namely discussed:

(1) Location of mining tremor focus. At present for solving this problem the tomographic methods are used repeatedly. This approach includes not only determination the geometrical coordinates and the time of origin; this method also made the velocity model of rock massif more correct.

(2) Secondly, an effort was made to determine the focus energy; here we had to face difficulties connected with the fact, that we had only the seismic signals for our disposal recorded in short epicentral distances, equal to several wave-lengths. These signals of relatively high frequency interacted with local tectonic disturbances and inhomogeneities. All this resulted in the occurrence of anisotropy of signal propagation. Also, the non-point size of mine tremor foci and the polarization of the seismic energy release in short distance should be taken into account and respected.

(3) Finally, the mine tremor mechanism was investigated. We have proved and verified, that expect the shear displacement also the implosive and tensile displacement components can exist in seismic foci. At present the spectral content of seismic waves is analyzed from the view point of non-linear processes occurring in seismic foci under special stress condition. We intend to make a try to utilize these non-linear methods for prediction of mine tremors occurrence. To solve this problems not only initial seismic data, but also various coseismic phenomena and the parameters of technological methods will be utilized (Aksenov at al 1992).

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Statistické metody interpretace důlních otřesů

Vladimír Rudajev

Uvedený příspěvek je v podstatě přednáška, která byla ústně proslovena na III. Mezinárodním symposiu "Rockburstsand Seismicivity in Mines" v Kingstonu (Canada) v srpnu v roce 1993. Jelikož se tento text podstatně liší od příspěvku, uvedeného ve sborníku citované konference, je účelné, aby byl presentován širší veřejnosti.