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A PRELIMINARY PROPOSAL OF A LAYOUT OF SEISMIC STATIONS IN THE ČSM MINE, CZECH REPUBLIC

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Abstract. While a local network of seismic stations was established gradually in the western part of the Karviná part of the Ostrava–Karviná Coal Basin, its eastern part has not been monitored reliably at all. Therefore, it was planned to build a local microarray in the mine ČSM with the aim of reaching better conditions to detect and record even weak seismic events induced by mining operation in this mine field. An optimum layout of the sites of observation chosen in advance is searched. The first step to this problem was based on an analysis of the influence of inaccuracy in arrival time of P–wave determination. To estimate qualitatively resulting inaccuracies in localizing approach applied, error figures for two different accuracies in arrival times determination and coincidence criteria were computed.

Keywords: seismic monitoring, induced seismicity, Ostrava–Karviná Coal Basin

1. Introduction

The construction of seismographic stations in the eastern part of the Ostrava–Karviná Coal Basin started in 1977, being concentrated firstly to the mines where the risk of a frequent occurrence of rockbursts was evident, i.e. to the mines Doubrava, Dukla, ČSA and Darkov (formerly 1. Máj) which were the most hazardous ones. Later, a small monitoring array (3 one–component stations) was established in the mine 9. květen as well as an experimental seismic array (6 three–component stations type PCM–3) in the mine Lazy (Knejzlík et al., 1992). All the seismographic stations operating within the local network were equipped with the universal geophysical instrumentation type UGA or with the PCM–3 system. In addition to this local network, a regional monitoring system was erected which surrounds the whole mining area and which consists of 10 three–component stations equipped with the system of Lennartz Electronic, Germany.

In the past, a solitary seismographic station was operated on the surface in the mine ČSM. This station was equipped with a three–component self–triggered seismograph having only an analogue record. At present, in the area of the mine ČSM, there is situated one station of the regional network. This station was erected at the same locality where the solitary surface station existed in the past, as shown in Fig. 1.

The single near surface station, even though it works within the framework of the regional network, is unable to provide a reliable and compatible information of seismic events induced by the mining. Moreover, due to increasing frequency of more intensive mining–induced seismic events, the management of the mine ČSM asked the Coal Research Institute to perform an analysis of a layout of stations to be situated in the mine take. A system of 10 one–component seismic stations equipped with vertical seismographs was anticipated. Positions of 15 sites of observation for erection of the monitoring system mentioned above were chosen in advance according to the mine–operational situation. In the course of model calculations, two different errors in P–waves picking, two triggering criteria and various combinations at maximum of 10 seismic station distributions creating the local microarray were taken into account.

2. General Comments on the Mine Field

2.1. *Structural Characteristics*

A complicated block–type structure of the Ostrava–Karviná Coal Basin as a whole is defined by the presence of many faults with different throws and dips. These tectonically delimited blocks were used as elementary units in the planning of the layout of the individual mines in this region. Based on the knowledge of the geological and structural situation, each mine take was divided into several tectonic blocks. In these tectonic blocks, individual coal seams are being mined gradually.

In Fig. 2, a schematic tectonic situation is given. Through the mine field, three very expressive tectonic faults are passing, i.e. the Stonava, Albrechtice and Těšín faults, being generally oriented in a south–north up to southeast–northwest direction. The mine field itself is further disrupted by an expressive fault "X" passing almost along the northern limit of the mine field and by several more or less important faults denoted "A" through "G" and the Olše fault which are oriented approximately in an east–west and/or northeast–southwest direction, reaching throws between 2 m (the "B" fault) and 85 m (the "E" fault).

In Fig. 3, a vertical profile crossing the mine field in the east–west direction along the A - Ȧ line (see Fig. 2) displays basic geological–structural units, i.e. the overlying Miocene sediments, strata of detritus and red beds, coal seams, tectonic faults and the safety pillar of the shaft.

2.2. *Induced Seismicity*

The layout of the seismic stations belonging to the local network did not enable, due to the eccentric position of the ČSM mine field in comparison with the other active mines, to detect and localize reliably weak seismic events originating in the mine ČSM. Nevertheless, the first intensive event, which was recorded by the local network of seismographic stations, occurred here as early as in September, 1985, and its radiated seismic energy was estimated as $E = 10^5$ J (Knotek and Vajter, 1986). Later, 3 seismic events characterized as mining shocks, the energies of which were defined as $8 \cdot 10^4$, $1 \cdot 10^5$ and $5 \cdot 10^5$ J, were recorded during 1987. Due to the fact that

FIG. 1. Seismic networks in the eastern part of the Ostrava–Karviná Coal Mine District. 1 – local network of the seismic stations, 2 – the PCM–3 experimental microarray, 3 – regional network, + a solitary surface station, A – Á line (see Fig.3).

in 1988, the regional network mentioned above started to be operated, the number of the recorded seismic events increased gradually in the following years, while the energy threshold of the recorded events decreased. Then, one station of the regional network was removed from the original site of observation and installed at the site of the solitary surface station operated in the mine ČSM in the past (see Fig. 1). This displacement of the station enabled to detect reliably even weak seismic events. The increasing frequency of the recorded events and their energy range are documented in location plots and graphs of frequency–energy distributions investigated in the period of 1991 – 1995 (see Figs. 4 and 5).

As seen in Fig. 4, during the years 1991 and 1992, foci of seismic events were located prevailingly in the 2nd and 3rd tectonic blocks and along the line passing between both these blocks. During 1993 and 1994, a reduced number of more

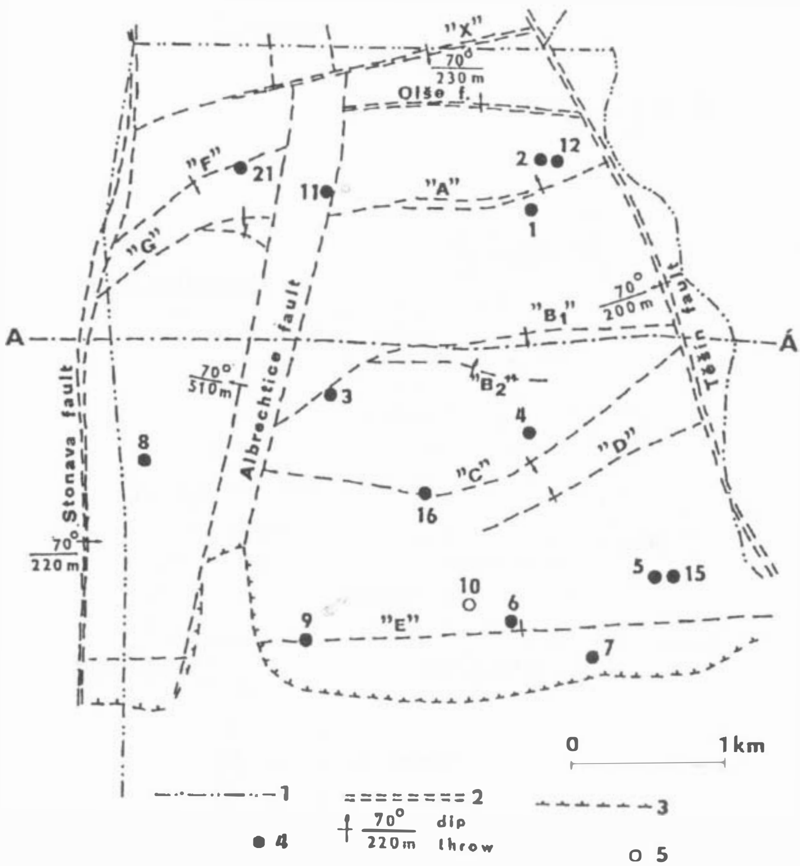

FIG. 2. Schematic sketch in the ČSM Mine. 1 – demarcation of the mine field, 2 – tectonic faults, 3 – boundary of red beds, 4 – underground stations, 5 – existing solitary surface station and A – Á line of the vertical cross section in Fig.3.

intensive events was located in tectonic blocks Nos. 0 and 1, which data are gathered and processed as a unique block of data and the results are attributed to the tectonic block 1, as seen in Fig. 4. During the same time interval, an evident clustering of foci in the 3rd block as well as a new focal region near the western boundary of the Stonava fault and the 4th tectonic block occurred, which was probably induced by the mining in a longwall in the neighbouring mine. The rest of the foci were attributed to mining activities in different areas of the mine. Foci determined in 1995 created two marked clusters in the 2nd and the 3rd tectonic blocks, while in the 1st block, five seismic events were recorded, the released energy of which reached the value up to $2 \cdot 10^5$ J approximately. According to the frequency–energy graphs in Fig. 5 which correspond to identical time intervals, the rate of the recorded seismic events increased during 1991 and 1992 up to 110 and 156, respectively. On the

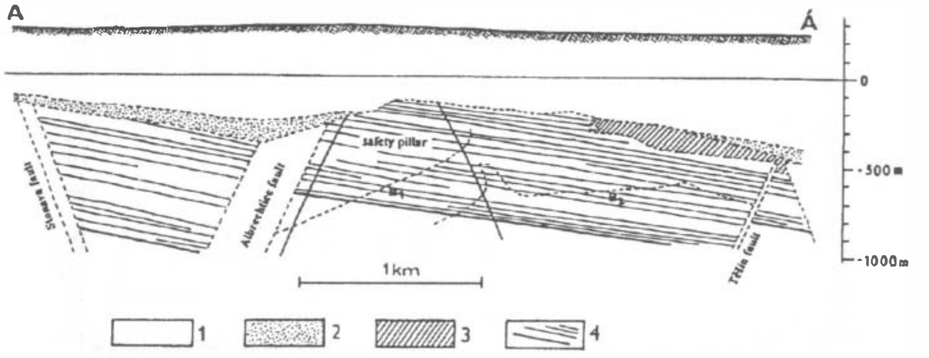

FIG. 3. Vertical cross section across the mine along the line A – Ȧ. 1 – overlying Miocene sediments, 2 – detritus, 3 – red beds and 4 – coal seams.

other hand, after the above mentioned displacement of one station of the regional network to the mine ČSM, the rate of the recorded seismic events was 390 in 1993 and 393 in 1994. In 1995, the rate of seismic events decreased to 282 but, in contrast to it, a number of events having an energy of about 10^5 J occurred.

It is assumed that after the construction of all the planned seismic stations, the rate of the recorded seismic events having an energy of $E = 10^2$ to 10^3 J will probably increase. Thus, the frequency–energy distributions have to be calculated for a wider energy span, i.e. for a span with a minimum energy threshold of 10^2 J.

3. APPROACHES TO THE CHOICE OF SUITABLE LAYOUT OF SEISMIC STATIONS

3.1. *Method of Estimating Localization Accuracy*

The automated localization method used in the pre–processing of the data from the individual mines operating within the seismographic network in the Ostrava–Karviná Coal Basin is based on a simultaneous determination of P and S and/or M arrival times as well as of the origin time t_0 which is calculated for each seismic station according to the formula (Holub et al., 1989)

$$t_0 = (v_P t_S - v_S t_S)/(v_P - v_S)\,.$$

Using this approach, any further shifting of foci to the centre of gravity of the estimated seismic network has not been expected while Cete (1979) reported that due to the iterative approaches usually some gradual shifts of computed foci to the centre of the network were observed.

On the contrary, it has been generally accepted that the errors in determining the source parameters have been caused, in principle, by two reasons. The first source of errors is the inaccuracy in P–waves picking while the second source of errors is the unsufficient knowledge of seismic wave propagation velocities (Kijko and Slezak, 1979).

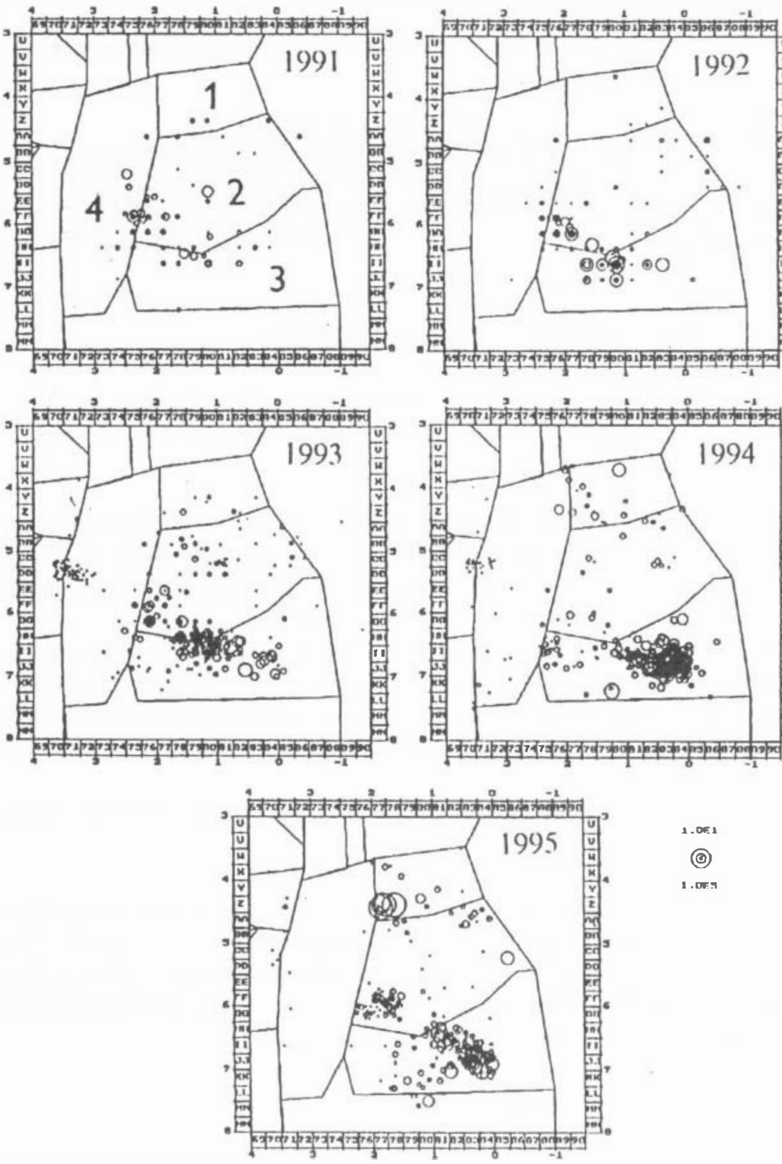

FIG. 4. Location plots of seismic events observed during 1991–1995 time period.

Our method of estimating the influence of inaccuracy in P wave picking and different coincidence criteria resulting to the localization accuracy is based on a modelling procedure which is characterized by the following steps and assumptions:

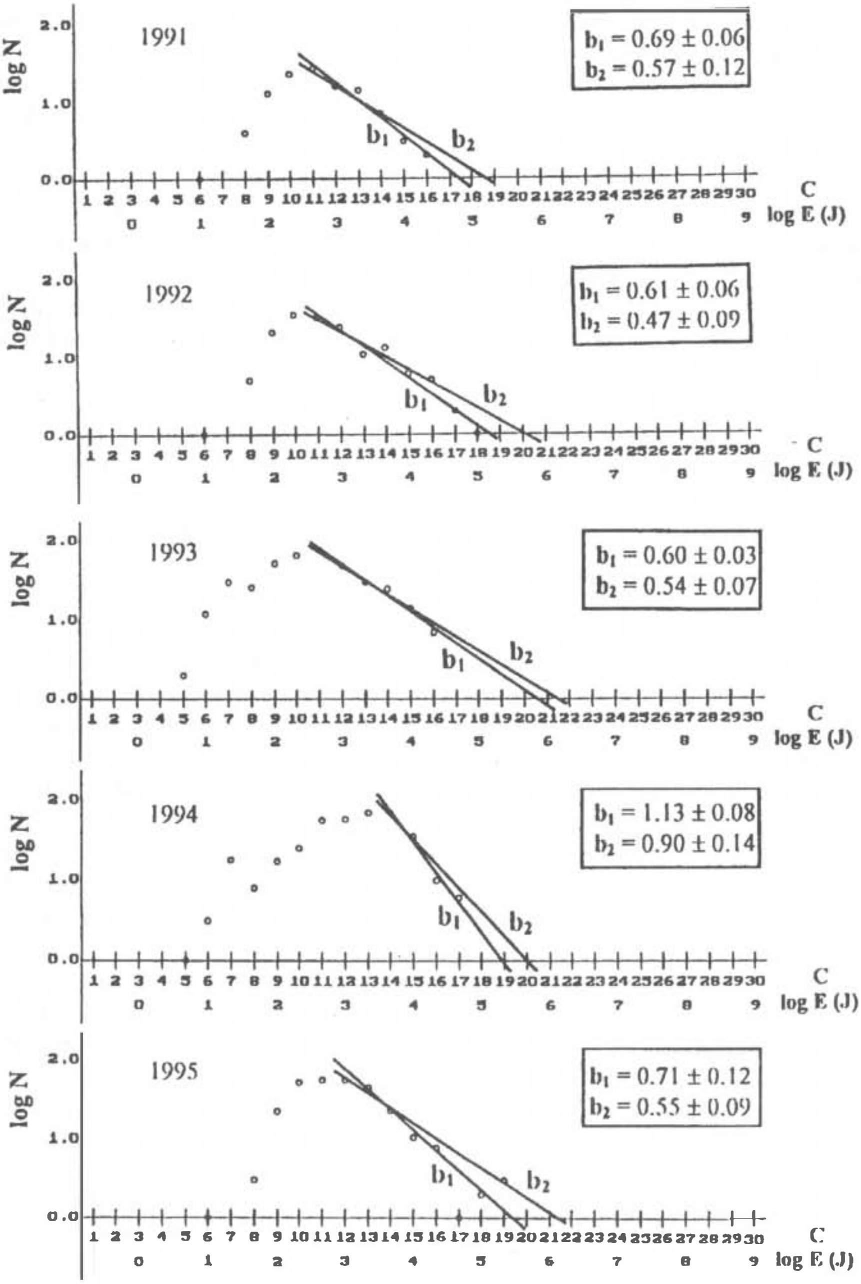

FIG. 5. Frequency–energy distributions of observed seismic events during 1991 – 1995. b_1 and b_2 were calculated by using the least square method and maximum likelihood method, respectively.

1. the variant of the accepted layout of seismic stations is the starting model where the position of the stations is defined by their coordinates (x, y, z);

2. the velocity characteristics of the medium are known, i.e. propagation velocities of P–waves depending on the properties of the medium are known and they correspond to the velocity model used (see Holub et al., 1995);

3. the picking of arrival times of P–waves allows a prescribed inaccuracy. In our conditions, two different inaccuracies of determination of P–wave onsets are assumed, i.e. $\triangle t = 30\,\mathrm{ms}$ and $\triangle t = 50\,\mathrm{ms}$, which corresponds, at a sampling frequency of 250 Hz, to a sampling rate of 7 and 13, respectively;

4. a minimum number of sites of observation $n = 3$ or $n = 6$ which comply with the coincidence criterion based on the prescribed accuracy of detection of the first arrivals, was chosen;

5. a grid of points of intersection with a step of $\triangle x = 1000\,\mathrm{m}$ and $\triangle y = 1000\,\mathrm{m}$ and an origin of the coordinate system were introduced;

6. for each point of intersection of the rectangular grid, the relevant error figure is determined as follows:

- for each position of seismic stations and the points of their intersection, epicentral distances are calculated;
- around each point of intersection of the grid, a polar grid in 24 azimuths, i.e. with a step of 15 degrees, is created, along which limiting points are defined. These limiting points meet the condition that the deviation between the arrival time of P–waves calculated for the appropriate point of the rectangular as well as polar grid, is less, for all the chosen seismic stations, than the prescribed error in picking the first onset. The limiting points are determined using an iterative algorithm where the initial distance between the points of the polar and rectangular grid is reduced to a half, if the error determined at all the stations considered is less than the preset error. On the contrary, the distance will be twofold, if the error is greater. After attaining the required accuracy of calculation, this iterative algorithm is completed;
- seismic stations in close neighbourhood of the points of intersection of the rectangular grid are selected from the set of seismic stations depending on the number of detecting stations (3 and/or 6). In the course of the calculations, this number of stations is maintained. It corresponds to the required sensitivity of the network. For 3 stations, the maximum attainable sensitivity is obtained, if the calculated localizing error corresponds to the localizing error of seismic events having a minimum, i.e. threshold energy. By this procedure, the recording ability of a network consisting only of 3 seismic stations situated in close neighbourhood, is defined. From this statement follows that more intensive seismic events will display a better localization accuracy at the same locality, because they will be detected by a higher number of stations of the network.

3.2. *Variants of the Solution and Their Analysis*

For the proposed procedure of estimating the inaccuracy of localization due to errors in the determination of reliable arrival times of P–wave as well as for the determination of the number of seismic stations simultaneously detecting these arrivals, four variants of the layout of the sites of observation were proposed. Before starting model calculations, the primary number of 9 underground stations was expanded by one surface station (No. 10) situated at the locality of the existing solitary surface station (+277 m m.s.l.). According to our assumptions, this station ought to contribute to a more precise knowledge of velocity characteristics in the area of interest which would help to a more reliable determination of foci depths.

Our decisions on velocity characteristics of the medium were based on an updated knowledge of the medium derived from the local seismic network, i.e. a direct P–wave velocity in the subhorizontal plane at the 4th level (−630 m m.s.l.) $v_P = 4.200\,\mathrm{ms}^{-1}$ was assumed; in the vertical direction, $v_P = 2.700\,\mathrm{ms}^{-1}$ as a maximum. For the surface station, data were reduced similarly, i.e. according to the dependence of the emergence angle of seismic rays at the seismic station in the corresponding directions, at velocities $v_P = 4.000\,\mathrm{ms}{-1}$ and $v_P = 2.500\,\mathrm{ms}{-1}$, respectively (see Holub et al., 1995).

The values of $\triangle t = 30\,\mathrm{ms}$ and $\triangle t = 50\,\mathrm{ms}$ were prescribed for any inaccuracy in determining the time of arrival (in which values any possible negative factors are included). At the sampling rate of 250 Hz, this inaccuracy corresponds to the rate of 7 or 13 samples, respectively. It can be assumed that the actual accuracy in determining arrival times will be higher.

For the criterion of coincidence, two possible variants were designed. The first variant assumes simultaneous detection of a seismic event at three stations, while the second one supposes a simultaneous detection at six stations as a minimum.

The basic network configuration consisting of 10 sites of observation is shown in Fig. 6, the numbering of which is 1 through 10. Figs. 6 to 9 show the results of calculation of estimates of influence of possible inaccuracy in input time data ($\triangle t = 30\,\mathrm{ms}$ and $\triangle t = 50\,\mathrm{ms}$) and in the rate of coincidence criterion (3 and/or 6 stations) at a reference z–level of −630 m m.s.l.

After examining the possibility of such a change in the layout of the sites of observation which, from an operational point of view, would be a more realistic layout and which would also contribute to an improvement of the accuracy of localization, three proposals of the layout of the stations were examined additionally. A schematic representation of the layout of the sites of observation within the mine take is shown in Fig. 2.

The following combinations of localities were tested:

variant No. 2 : 3, 4, 6, 7, 8, 9, 10, 12, 15 and 21 (Fig. 7),
variant No. 3 : 3, 4, 7, 8, 9, 10, 11, 12, 15 and 16 (Fig. 8),
variant No. 4: 3, 4, 7, 8, 9, 10, 11, 12 and 15 (Fig. 9).

The distribution of seismic stations as mentioned above and their error figures are given in Figs.6 through 9. All results obtained during the solution of the problem are characterized by a concentric arrangement of error figures, with their centre

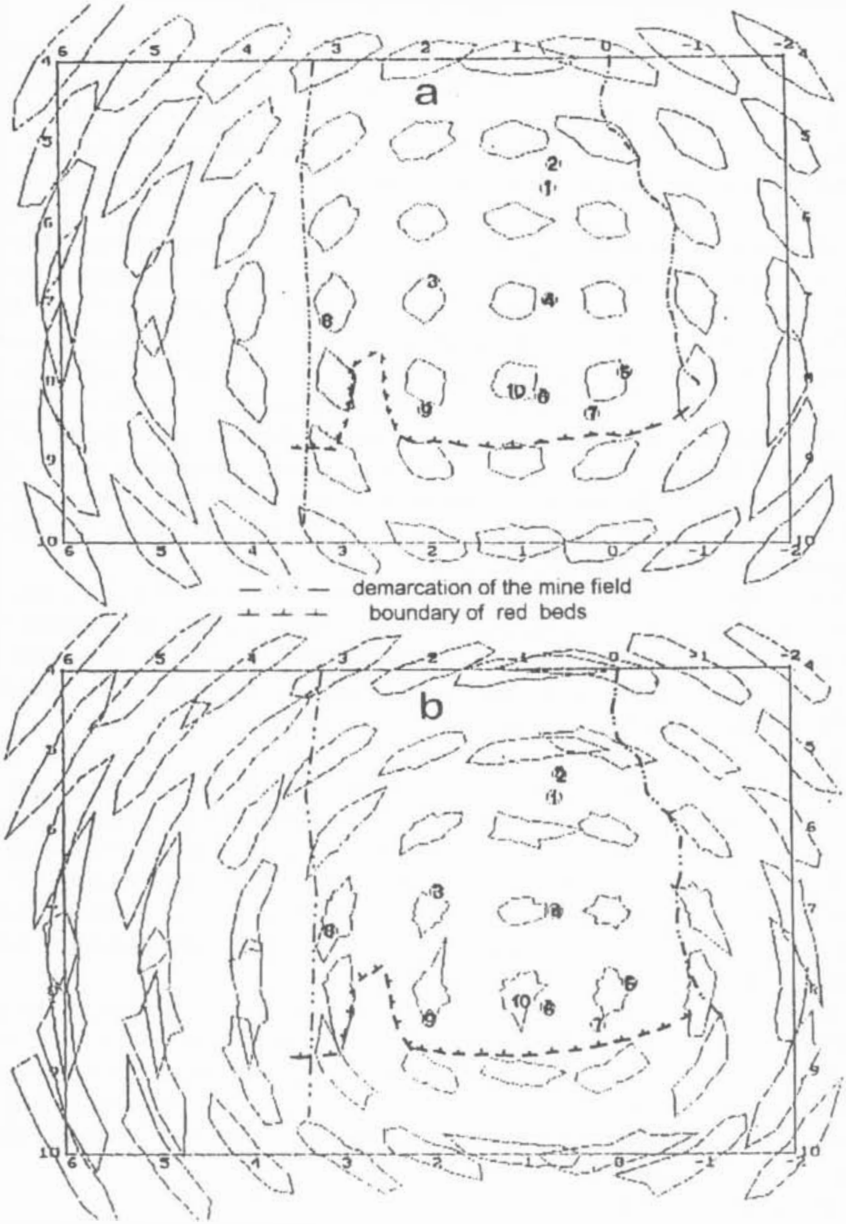

FIG. 6. Error figures for the original layout of sites of observation. a) $\triangle t = 50\,\mathrm{ms}$ and $n = 3$, b) $\triangle t = 30\,\mathrm{ms}$ and $n = 6$.

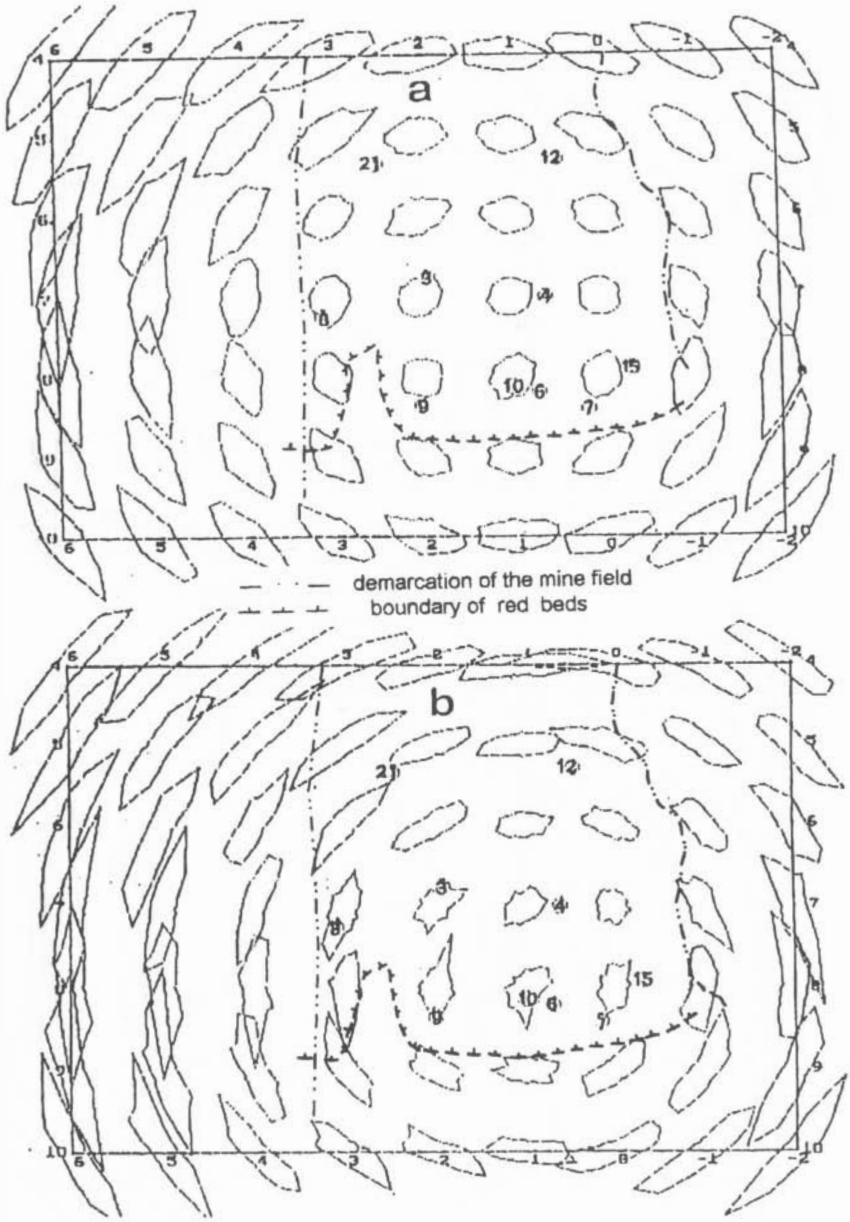

FIG. 7. Error figures for the 2nd variant of layout of sites of observation. a) $\triangle t = 50$ ms and $n = 3$, b) $\triangle t = 30$ ms and $n = 6$.

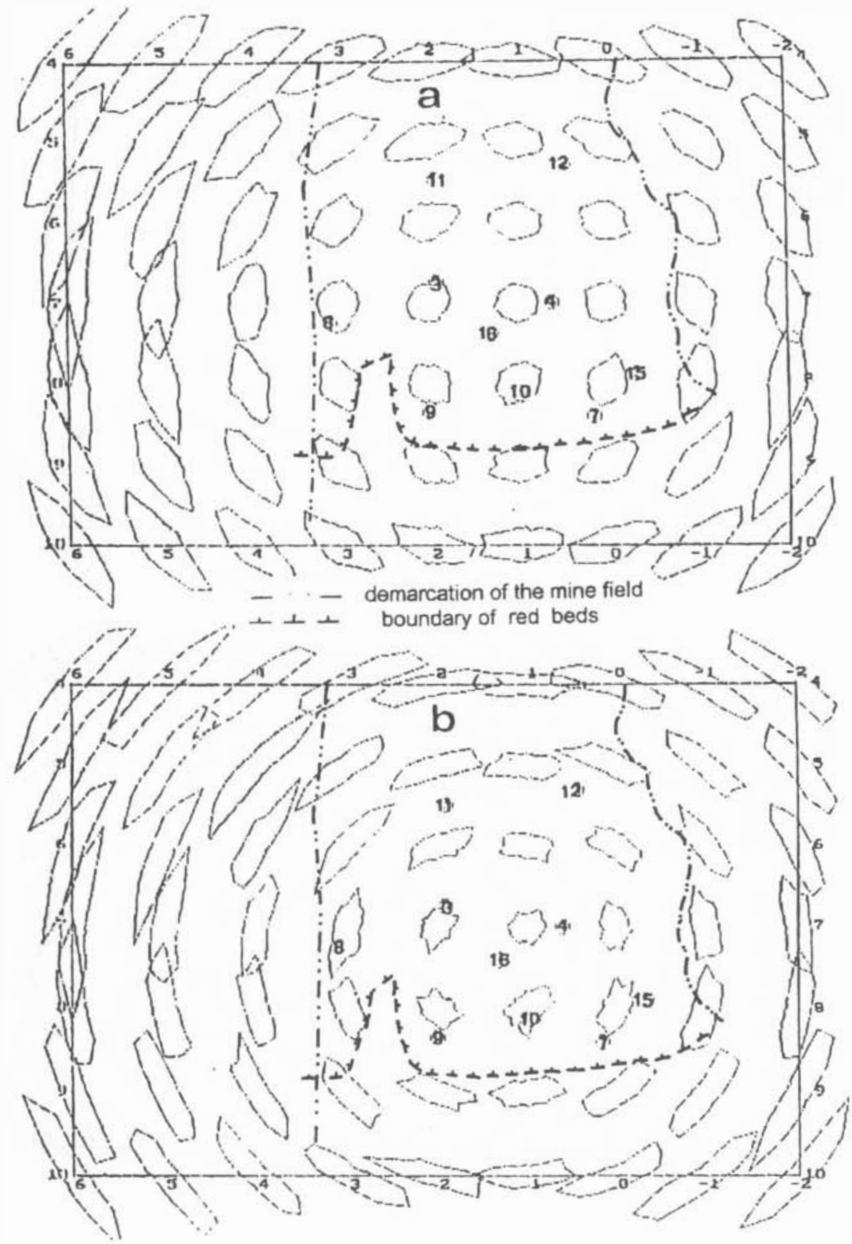

FIG.8. Error figures for the 3rd variant of layout of sites of observation. a) $\triangle t = 50\,\mathrm{ms}$ and $n = 3$, b) $\triangle t = 30\,\mathrm{ms}$ and $n = 6$.

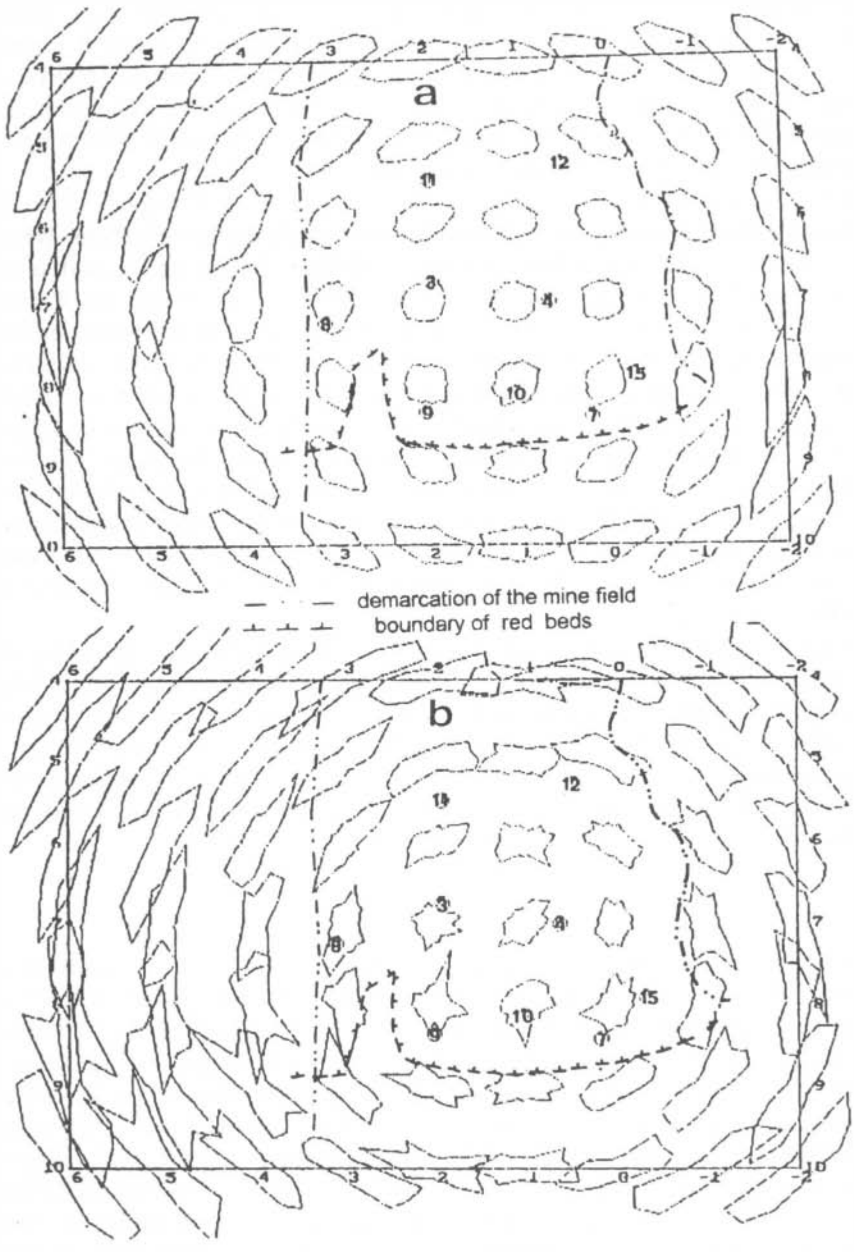

FIG. 9. Error figures for the 4th variant of layout of sites of observation. a) $\triangle t = 50\,\mathrm{ms}$ and $n = 3$, b) $\triangle t = 30\,\mathrm{ms}$ and $n = 6$.

in the gravity centre of the investigated network. This is entirely in agreement with basic principles of localization because this arrangement makes it possible to expect minimum errors of localization inside the network. With the increase of the distance from the centre of gravity of the monitoring array, the dimension of error figures in the direction of radius–vector remains the same, in principle, while in the perpendicular direction, a gradual elongation occurs.

When comparing qualitatively the results of the individual variants of the layout of the sites of observation, we find a considerable similarity among them. Nevertheless, according to the dimensionally defined criterion of error figures and according to the adequacy of mining and technological conditions, the variant No. 3 was identified as the best solution (see Fig. 8). But this variant exhibits certain differences in detail from the other variants, which result from the coincidence criterion applied. If this criterion is fulfilled using observations from three sites as a minimum and an inaccuracy of 50 ms in arrival times, error figures inside the 2nd, 3rd and 5th tectonic blocks of this mining field have almost a circular shape, the measure of inaccuracy being defined by their diameter. In contrast to it, if the criterion mentioned above is fulfilled using six sites of observation and inaccuracy in arrival times 30 ms, error figures are gradually onesidedly elongated in the direction from the centre to the margin of the monitoring network and, therefore, the error in this direction increases.

It can be generally stated that the measure of inaccuracy is defined by the dimensions of error figures in any direction from the centre of gravity. From this follows, in our view, that the variant No. 3 of the layout of the sites of observation will allow for a reliably monitoring of the 2nd, 3rd and 5th tectonic blocks. Nevertheless, *only during the operation of the accepted layout the monitoring system, the real localization accuracy can be tested, in particular by using of underground explosions with defined source coordinates.*

4. Conclusions

It was proved during a systematic investigation of the induced seismicity in the mines of the eastern part of the Ostrava–Karviná Coal Basin that seismic events occur frequently not only in the mines of the central part of the Basin, but also in the marginal parts of the area under investigation. This applies to the mine ČSM which is situated outside the existing local seismic network (see Fig. 1). Therefore, a preliminary proposal for the layout of the sites of observation in this mine was worked out. During this work, special attention was paid to both the analysis of the influence of the inaccuracy in the first arrival of P–waves picking and to the number of seismic stations fulfilling the prescribed coincidence criteria within the network. However, for a proper foci localization, the method for a laterally isotropic medium, which corresponds to the geological conditions in the Ostrava–Karviná Coal Basin as described by Holub et al.(1995) was applied.

From a qualitative evaluation of the character and the dimensions of error figures for estimating the inaccuracy of localization of rockbursts and other seismic events occurred in the mine field under consideration, the following conclusions could be drawn:

- the proposed configuration of the sites of observation according to the variant No. 3 (see Fig. 8) displays the best agreement with the operational demands,
- using a 15 channel instrumentation, a three-component seismic station could be established at the 2nd level of the mine ČSM (−380 m m.s.l.) while the rest of the stations would be equipped with vertical seismometers only,
- in all analyses described above, only the network of stations situated within the mining field of the mine ČSM was taken into account,
- error figures show a relatively great influence of inaccuracies in P–waves picking on the localization of hypocentres, especially in marginal regions, i.e. in areas of limits between two neighbouring mines. These localization errors could be reduced considerably, if input data from the planned local microarray in the mine ČSM could be used together with data sets of the operational seismological centre in the mine ČSA. It is obvious that for reaching a higher quality of the database of seismic events observed in the eastern part of the Ostrava–Karviná Coal Basin, a mutual exchange of data from the operational seismological centre in the mine ČSA and the planned local microarray in the mine ČSM will be required.

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