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LONG - TERM DEVELOPMENT OF SEISMIC MONITORING NETWORKS IN THE OSTRAVA-KARVINÁ COAL MINE DISTRICT

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ABSTRACT

This paper is devoted to a complex review of various monitoring networks operating in the eastern part of the Ostrava-Karviná Coal Basin. In the first place, there were systems for monitoring seismoacoustic emissions during coal extraction. Later a local seismic network was installed which encompasses partial arrays of seismic stations located in the individual mines underground. In addition, a special regional seismic network was established in order to ensure reasonable recordings of strong seismic events observed in this area. In 2001 an array was constructed with up to five surface seismic stations which monitor manifestations of rockbursts due to imposed dynamic loading on existing buildings at selected sites. Recently, a quite new monitoring system of accelerometers began operating, the purpose of which is to check the effects of rockbursts on surface structures. Using the output data of all monitoring systems, different graphs were constructed, which can faciliate geophysical interpretation of geodynamic processes in mines.

KEYWORDS: Ostrava-Karviná Coal Basin, seismoacoustic and seismological monitoring, geomechanical service

1. EARLY EXPERIENCE WITH SEISMIC MONITORING IN ORE AND COAL MINES

The first experience closely connected with the operational applicability of seismoacoustics and seismology in the process of solving problems related to rockburst occurrence in Czechoslovak mines was obtained during the activity of seismic networks operating in coal and ore mines, in the Kladno and Příbram regions (Central Bohemia), respectively. This good experience guaranteed the operational applicability of seismoacoustics and seismology also in the Ostrava-Karviná Coal Basin (OKCB).

The seismoacoustic station „Příbram" for underground experiments was established in 1962 in the ore mine Anna near Příbram, and later a new system consisting of four channels was installed there. The first results of observations in hard rocks threw light on the behaviour of rock mass under stress-strain conditions characterized by response in the form of increasing seismo-acoustic radiation either before or after rockburst, or after blasting operations (Šimáně, 1964 and 1966). In the same ore mine district, a temporary seismological station, provided with a short period vertical seismometer aimed at recording local seismic events for a detailed study of local seismic activity, was in operation at the 15th level (h ≈ 380 m below sea level) in the Prokop mine within the time period 7/1961-7/1962.

Some attempts to use seismoacoustics and seismology for research into rockbursts in coal mines in the Kladno region, however, started almost at the same time as the activities in the Příbram region. The first seismic station in this area was set up in August 1960 (Buben, 1962) which was followed by the construction of a seismic network in 1963. This network included three or four surface stations, which provided the approximate locations of rockburst foci (Holub and Tobyáš, 1963 and 1964; Buben, 1967). If the seismoacoustic method is applied *in-situ,* sensors record the trends of the disintegrating process of rock mass in the nearest zone of working. The decrease or increase of the number of recorded seismoacoustic impulses then indicates the instantaneous stress-strain condition of the rock mass in the neighbourhood of the locality under consideration.

Comprehensive information dealing with all activities in the mines near Příbram and Kladno up to the year 1966 is represented in the monography „Investigation of rock pressures by means of geophysical methods" by Riznichenko et al. (1967).

2. SEISMIC MONITORING SYSTEMS IN THE OKCB

2.1. *SEISMOACOUSTIC MONITORING*

The coal extraction in the Ostrava-Karviná Coal Basin historically belonged and still belongs to the hazards in mines which are associated with rockburtst occurrence. The number of coalfaces and drivages endangered by rockbursts are rather less now than roughly 20-30 years ago. The obligation of the

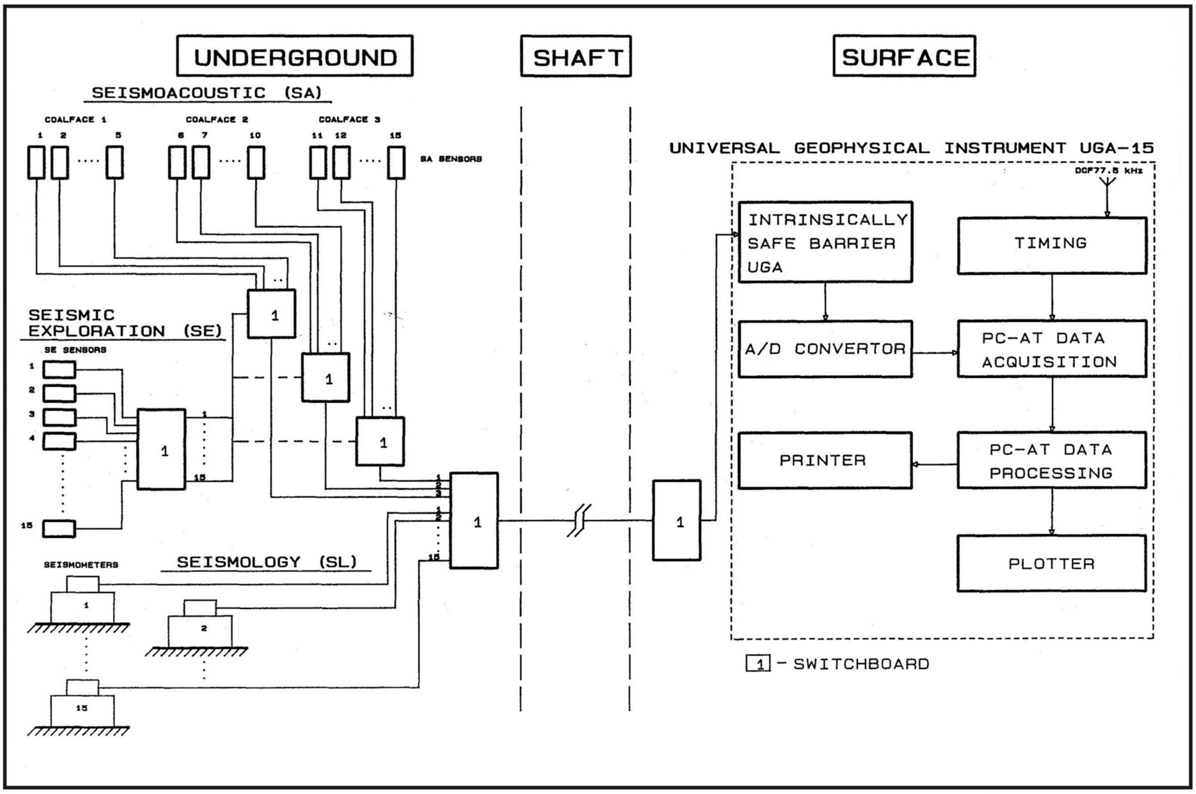

Fig. 1 Operational overview of the UGA-15 instrument.

Ostrava-Karviná Area Mines in monitoring the manifestations of rockbursts at the time forced them to establish a Geomechanical Service in the separate mines, which had to monitor the geomechanical situation in the mines on a current basis and ensure that preventive measures were taken in endangered workings.

It is common knowledge that the efficiency of forecasting rockbursts and applying active preventive measures against their occurrence depends on the state of knolwedge of the on-going process of origination in the focus as well as of its evolutionary phases. The essential information related to prognosis and prevention issues has usually been obtained by observations *in-situ*, by analysis of the current situation underground, by geomechanical estimation of rock mass and otherwise.

The seismoacoustic method (SA) is one of the geophysical methods applied investigating the permanent process of rock mass deformations occurring due to the brittle fracturing of rocks. The seismoacoustic measurements in the Ostrava-Karviná Coal Field using stationary apparatuses were experimentally introduced in the Doubrava, ČSA and Darkov (former 1. máj) Mines, i.e. they started first with a delay of about 10 years compared with the experiments in the coal mines near the Kladno region as mentioned, e.g., by Staš et al. (1974 and 1974a), Knotek (1979), Knotek et al. (1982 and 1983). The monitoring of seismo-acoustic activity was recorded by an eight and twenty channel devices which were created by the computer controlled electronic system SAMS and SAIS (Dlouhý, 1979 and 1980), the acquisition, processing and assessment of the SA data, being carried out in a laboratory on the surface. Seismoacoustic high frequency sensors (geophones) SA-5 with frequencies $f \approx 70$ Hz - 2 kHz, situated undergroud, were connected with the system SAIS by means of special transmission cables, and an intrinsically safe barrier which must fulfil the Czechoslovak Standard for gassy mines. The SA sensors were anchored in boreholes having a depth of approx. 4 m situated roughly in the middle of the seam. The seismoacoustic emission was recorded by the SAIS apparatus by two pairs of sensors; boreholes were drilled for each pair from the main gate, on the one hand, and from the ventillation gate into the coal seam, on the other. The distance between both pairs of geophones along both parallel gates amounts to approximately 40-100 m. These twenty measuring channels enable to monitor the SA activity of 5 endangered coalfaces whose four geophones were distributed on a plane. The essential parameter investigated was the „dynamic frequency“ which corresponds to the number of oscillations within the SA seismic signal which exceeds the preset comparison level.

The diagrams, tables and analogous records, obtained in this manner, served as the input data for evaluating seismoacoustic monitoring in direct correlation with the proposed, realized and estimated measures of the rockburst prevention scheme applied in that particular mine section, based on normal and/or anomalous development of the SA activity (Knotek, 1979). For some details of the methodology of preparation and assessment of these data, we refer the reader to several papers, e.g., Knotek et al. (1983), Holub et al. (1987), Kořínek and Kalenda (1987), Kořínek et al. (1989), dealing with the problems discussed in this paragraph. Partial results of specific parametric measurements of the natural and induced seismoacoustic emission of the rock mass in the coal basin of Ostrava-Karviná are available in papers by Kalenda et al. (1992); Kalenda and Slavík (1992); Číž et al. (1999).

The latest model of geophysical digital instrumentation was denoted UGA-15 and is applicable to seismoacoustics (UGA-SA), seismology (UGA-SL) and seismic exploration (UGA-SE), the scheme of which is displayed in Figure 1. In principle, this apparatus is able to serve three coalfaces and five sensors for each, because a different measuring base is applied, i.e four geophones are situated in the coal seam used before, and morever, one geophone is placed in a 4 m deep hole drilled into the roof above the coalface as shown in Figure 2. This array enables to differentiate SA impulses originating either in the seam or in the roof, which is important when a location map is constructed. The different positions of foci (coal seam vs. roof) displayed in the plane can be quickly separated by different colours, thus making it easier to interpret the measured data. Unlike the

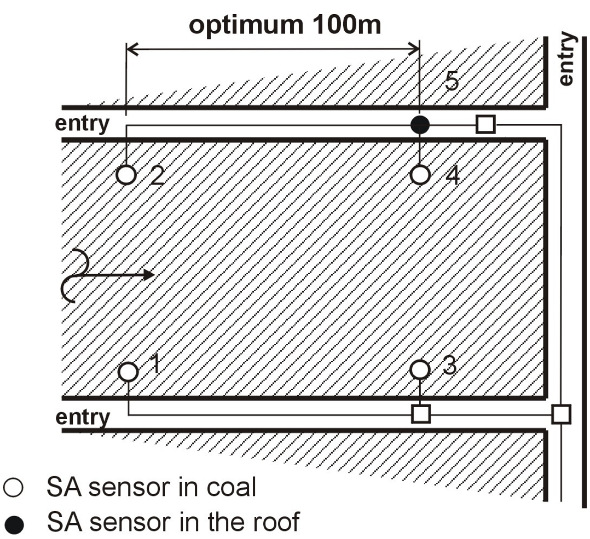

Fig. 2 Measuring base for underground continuous seismoacoustic measurements.

original parameter, the „dynamic frequency“, was fulfiled by two parameters in the software for the UGA-SA apparatus, i.e. the frequency and the relative energy value. Another important information is to estimate normal and anomaleous development of the SA activity, because the interpretation of data requires the knowledge of the basically balanced state of the rock mass with a minimum of radiated SA impulses. But once the rock mass is under the influence of increasing stress, the loaded massif induces increasing SA activity, which is a symptom of material disintegration sometimes massive.

Apart from the long-term stationary observations as mentioned above, also short-term seismoacoustic measurements have been regularly performed by means of portable indicators, e.g., MOW and/or MDSA (Dlouhý, 1979 and 1980; Macek, 1987; Trávníček et al., 1979; Trávníčková and Trávníček, 1992) almost in all mines of the OKCB as well.

Finally, it should be pointed out that for reliable approaches in computing procedures and correct data interpretation when the UGA-SA is used, some recommendations are described in the Methodical instructions. Moreover, these instructions are a part of the appropriate documentation of UGA-SA.

2.2. LOCAL SEISMOLOGICAL NETWORK

The necessity of constructing a local seismic network in the OKCB occurred after the strong rockburst which occurred in the Doubrava Mine on April 24, 1974. Nevertheless, after lenghty proceedings and recommendations (Rudajev and Svoboda, 1976; Rudajev et al., 1978) the final proposal for establishing this network was accepted. The original proposals for the distribution of the individual stations in the eastern part of the OKCB were first based on the assumed "lifetime of the workings" endangered by rockbursts. Based on an extended and more accurate project, an optimazation of the local network was performed by Kijko (1982) and a study of localization accuracy was carried out by Jech et al. (1986); Holub and Fiedler (1989) a little later. From the viewpoint of the needed low level of seismic noise at the seismic stations, those were prevailingly situated into the mine shaft pillars as an optimum solution due to the low seismic noise there.

Selection of suitable site for the surface seismic station was based on measurements of short-period seismic noise level, the results of which are described by Buben and Rudajev (1976).

The first station which was put into operation as part of the co-operation with the Mining Institute of the Czechoslovak Academy of Sciences in Prague was the seismic station erected on the surface in the area of the 1st May Mine in 1977 (Trávníček and Holečko, 1980). Regardless of some problems with a relatively high level of noise and disturbances generated by traffic and machinery operating on the surface around this station it put on very important role during the

Fig. 3 Development of local seismological network up to the year 2000.

establishment of local seismic network. Therefore, it was shifted underground in 1981 due to surviving undesirable vibrations. At that time, i.e. till the end of 1981, further stations were installed underground and on the surface. The analogue instrumentation used at these underground stations was very simple, i.e. vertical short-period seismometer VEGIK, galvanmeter and recording photopaper drum (Russian production) (Holub, 1983), while the surface stations were equipped with the ELSMO system, which recorded in the triggering regime and heat-sensitive paper was used as the recording medium (Horevaj, 1981). Substantial increase in the number of stations was to have been gradually achieved in the course of the project "Labour safety in deep mines in the Czechoslovak Socialist Republic", when as many as 18 experimental channels of the DSLA digital apparatus were to have been manufactures (Bigos and Novotný, 1983; Bigos et al., 1988). When proposals for this measuring system being prepared, some demands had to be fulfilled, e.g., reliability and credibility of recorded seismic signals, objectivity of determined parameters, fulfilling of conditions of intrinsical safety because the mines in the OKCB are gassy mines. The device consists of an electronic seismological A/D convertor including an intrinsically safe barrier which separates the vertical seismometers SM-3 installed underground from the processing units in the surface geophysical laboratory. The internal time control was synchronized by time signals transmitted by DCF 77.5 kHz transmitter. The basic parameters were: input sensitivity 12 μmV – 5mV, amplification max. 74 dB, frequency range 1.5 – 20 Hz and sampling frequency 100 Hz.

When the five seismic underground stations began to operate (1981)in the Doubrava, ČSA and 1st May mines (see Fig. 3), the individual arrival times of P and S-waves and their maximum amplitudes,

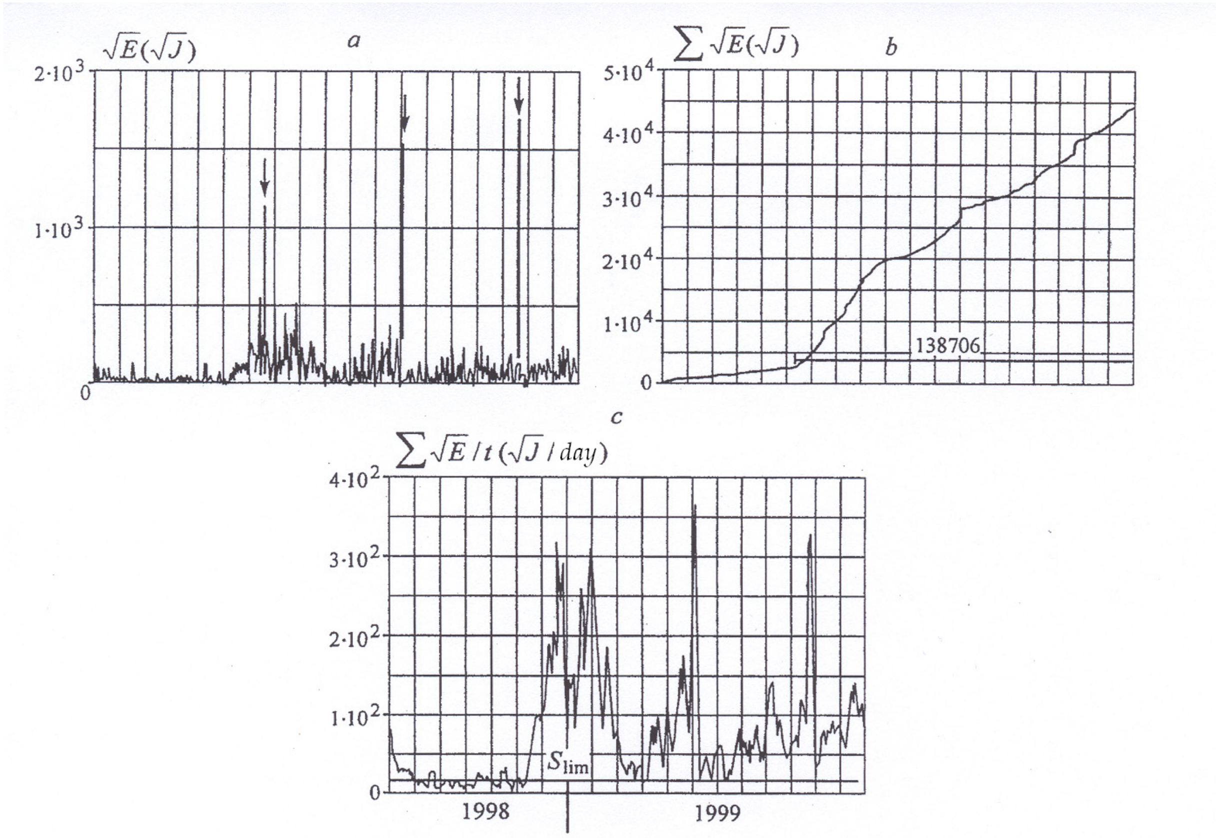

Fig. 4 Seismic activity displayed like time series (a), Benioff graph (b) and its derivative S (c). Strong rockbursts are in (a) denoted by arrows, time period of coal extraction is displayed in (b) by a straight line.

interpreted on analogue seismograms, were sent to the operational centre at the ČSA Mine using phone lines. Preiliminary localization was determined using izochrones $t_S - t_P$ (s). Later when the number of stations increased, then the preprocessed data were transmitted by means of Internet connection. During this stage of the local network, data acquisition, their preprocessing and preliminary evaluation underwent an essential reorganization in the following way. For each mine, the individual seismic stations were represented as a seismic array, the data of which were preprocessed there. Consequently all data from the individual mines were transmitted to the operational centre in the ČSA Mine for complex processing and interpretation. Basic and derived parameters of mining induced events resulting from detailed analysis at that time were as follows: a) arrival times and displacement amplitudes of P- and S-waves including their maxima, b) focus positions of foci (X, Y, Z and T_0), c) location plots using appropriate SW, d) amount of seismic energy subsequently released Es (J) is estimated and the square root of the energy ($\sqrt{E}$) is calculated for displaying the time series of the individual events and/or for constructing the Benioff diagram ($\sum\sqrt{E}$) and its derivative ($S = \sum\sqrt{E}/t$). Based on continuous monitoring of seismic activity, Benioff diagrams were constructed, in which each change in seismic radiation increase or decrease of activity is noticeable. Moreover, with the aid of the derivative of the Benioff diagram, the very important parameter S was obtained, which is usually used in detailed analysis of dangerous stress conditions in a rock massif (Vajter et al., 1989; Holub et al., 1991) However, all efforts leading to the improvement of temporal prognosis are questionable Three function mentioned before are displayed in Figure 4. In the system of preventative measures, sometimes camouflet shotfiring in the roof above the coalface were carried out in order to disintegrate hard rocks in the overlying roof. The efficiency of explosions (η) is then defined by the formula $\eta = E_S / (K \times Q)$, where E_s represents the amount of the released seismic energy in (J) which was determined experimentally from seismograms and Q is the mass of explosives in (kg), where coefficient K=2.6 by Holub (1985) and coefficient K=2.1 by Koníček (2009) were derived.

Existing efforts to apply the results of seismological observations of rockbursts were later aimed at, e.g., demarcating seismic active areas and at investigating the development of seismic activity in these areas, which usually was displayed in the location plot. This means that these observations contribute to the improvement of the local prognosis of hazard occurrence of rockbursts.

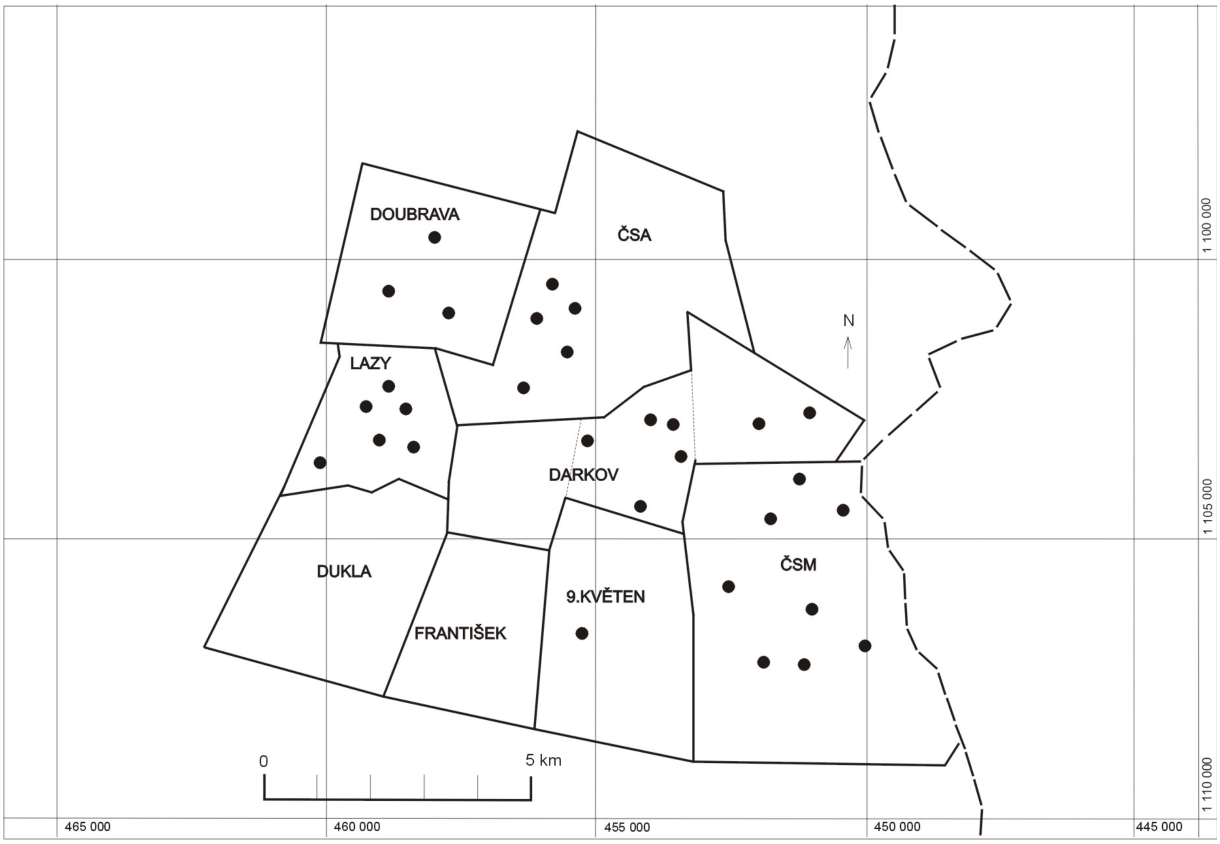

Fig. 5 Up-to date distribution of seismic stations included in the local seismological network.

After the complex assessment of the seismic data, they were sorted and sent back from the operational centre to the appropriate mines for subsequent application, e.g., within the preventative measures scheme, investigation of cumulation of seismic event foci, seismic activity development and its response to the behaviour of the rock massif, etc. Up to 1989 a large number of results of investigations dealing with induced seismicty occurring in the Ostrava-Karviná hard coal deposit were obtained and published. For some essential information dealing with local seismological network and problems connected with the manifestations of induced seismic events, we refer the reader to some papers worth consideration, e.g., by: Knotek and Holub, 1980; Trávníček, 1980; Knotek et al., 1982; Keclík and Trávníček, 1982; Holub et al., 1988; Slavík et al., 1989; Trávniček et al., 1990; Kalenda et al., 1991, 1991a and 1992a. Since 1989 a common database including data of local and regional network was created where all recorded seismic events were stored and subsequently used for further mathematical assessment and geophysical and/or geomechanical interpretation.

A new type of digital apparatus UGA-15 was designed in 1991, i.e. a **u**niversal **g**eophysical **a**pparatus which was put into experimental operation within a short time (Kalenda, 1991). As was mentioned in Chap. 2.1, the UGA-15 apparatus, in principle, offers three possibilties of its application, i.e. for seismoacoustics in connection with SA geophones, for seismology using a short-period SM-3 seismometer (Russian production) and SA sensors for geophysical survey. During the years 1991-1993, the installation of the UGA-SL was finished in the Doubrava, Dukla, ČSA, Darkov and 9. květen Mines and finally the last apparatuses and seismometers for the ČSM Mine were also put in place. The individual stages of construction of the underground and surface parts of the local seismic network are displayed in and Figure 3 and the last configuration, i.e. present state is shown in Figure 5**.** Compared all the stages up to the year 2011, some changes in the configuration of stations are obvious. These changes were made due to operational reasons, e.g., closure of the mine, advance of the coalface headed towards the near zone of the seismic station, causing an increasing level of seismic noise. Sometimes the monitoring instrumentation was needed in another area which was under seismic risk.

Some results of seismological observations have been often applied in practical application. Two examples are displayed in Figures 6 - 7**.**

All SW packages used in the DSLA apparatus were later modified for the UGA-SL in order to ensure the continuation of the database after 1989 and, moreover, this database was extended due to the incorporation of data from the regional seismic polygon. At the end of 1993, the task „Complex HW

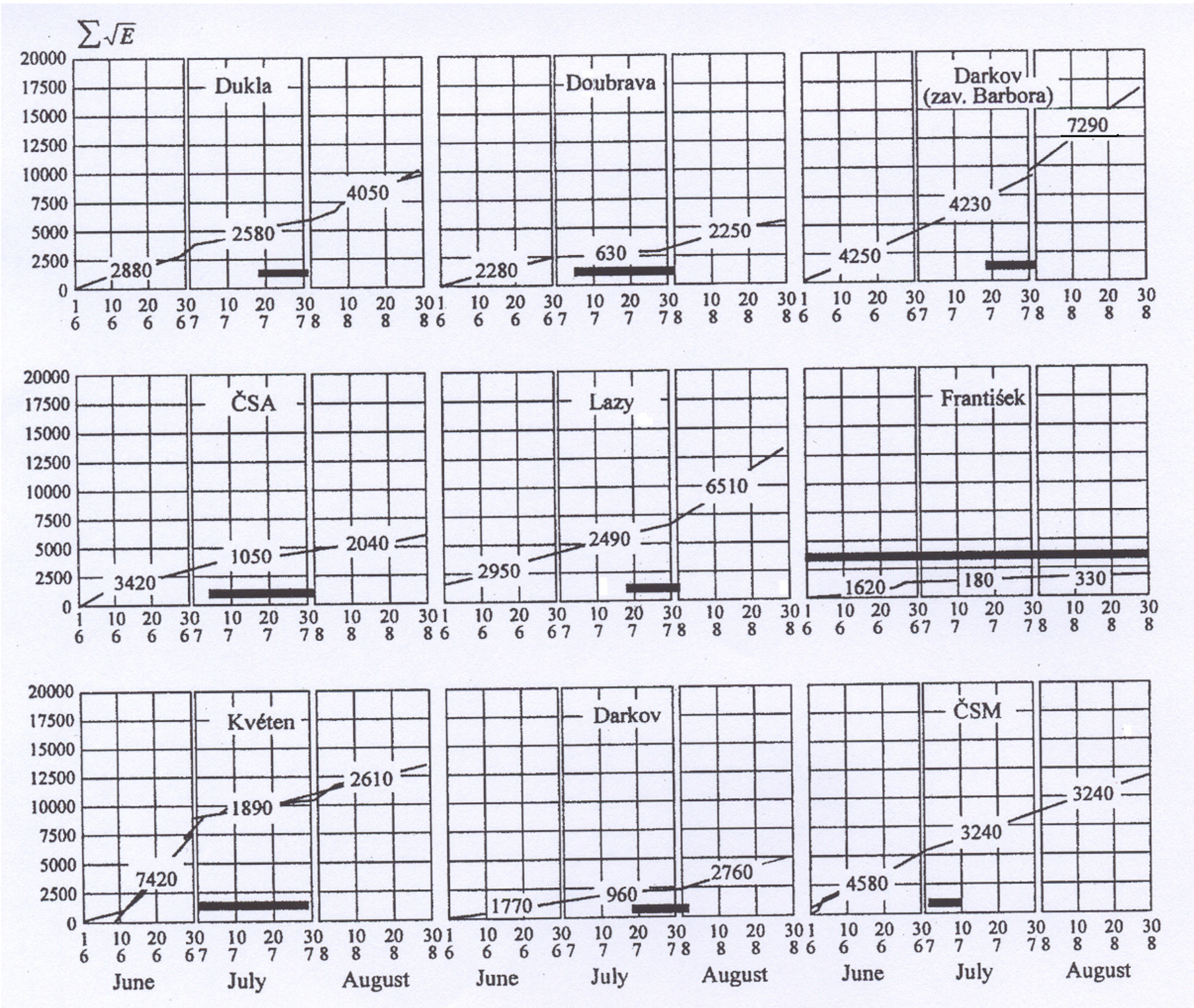

Fig. 6 Benioff diagrams with monthly slopes during summer season when the coal extraction was temporarily suspended due to vacations; the thick line denotes the time duration of interruption.

and SW equipment of the seismological centre and its link with individual collieres of the Ostrava-Karviná Coalfield ” came to an end, and its results were considered to be positive (Slavík, 1993). The UGA-SL was innovated as concerns HW and necessary arrangements of SW within the time interval 2008-2010 (Suchanek et al., 2008).

2.3. LOCAL EXPERIMENTAL SEISMOLOGIACAL NETWORK IN THE LAZY MINE

The Lazy Mine (former A. Zápotocký Mine) has not been mentioned till now and, therefore, some issues related to this mine will be presented shortly. Since this mine differs from the other mines due to its status, its array was not originally included in the local seismic network of the OKCB. Originally it was selected for testing the development of a new highly sophisticated digital instrumentation and appropriate SW as part of an experimental mining monitoring array operated by the Mining Institute of the Academy of Sciences of the Czech Republic (Gruntorád, 1990; Gruntorád et al., 1992). The final stage of this network consisted of three surface stations equipped with three components of short-period S-5-S seismometers ($T_0 \approx 5.0$ s) and telemetric PCMT/Tx transmitters and of five underground. The underground stations were equipped with SM-3-JB seismometers ($T_0 \approx 2.0$ s) which ensure intrinsical safety needed for apparatuses operating underground. A special PCM3 data acquisition apparatus was constructed for recording raw data. Other technical details of the whole system, i.e. data acquisition, digital data recording and interpretation are given by Knejzlík et al., (1989); Knejzlík, (1990); Knejzlík, (1992) and Knejzlík et al., (1992). The distribution of the individual seismic stations is displayed in Figure 8 where underground and surface seismic stations are denoted by different symbols.

The operation of this experimental network under the auspice of the Mining Institute ASCR

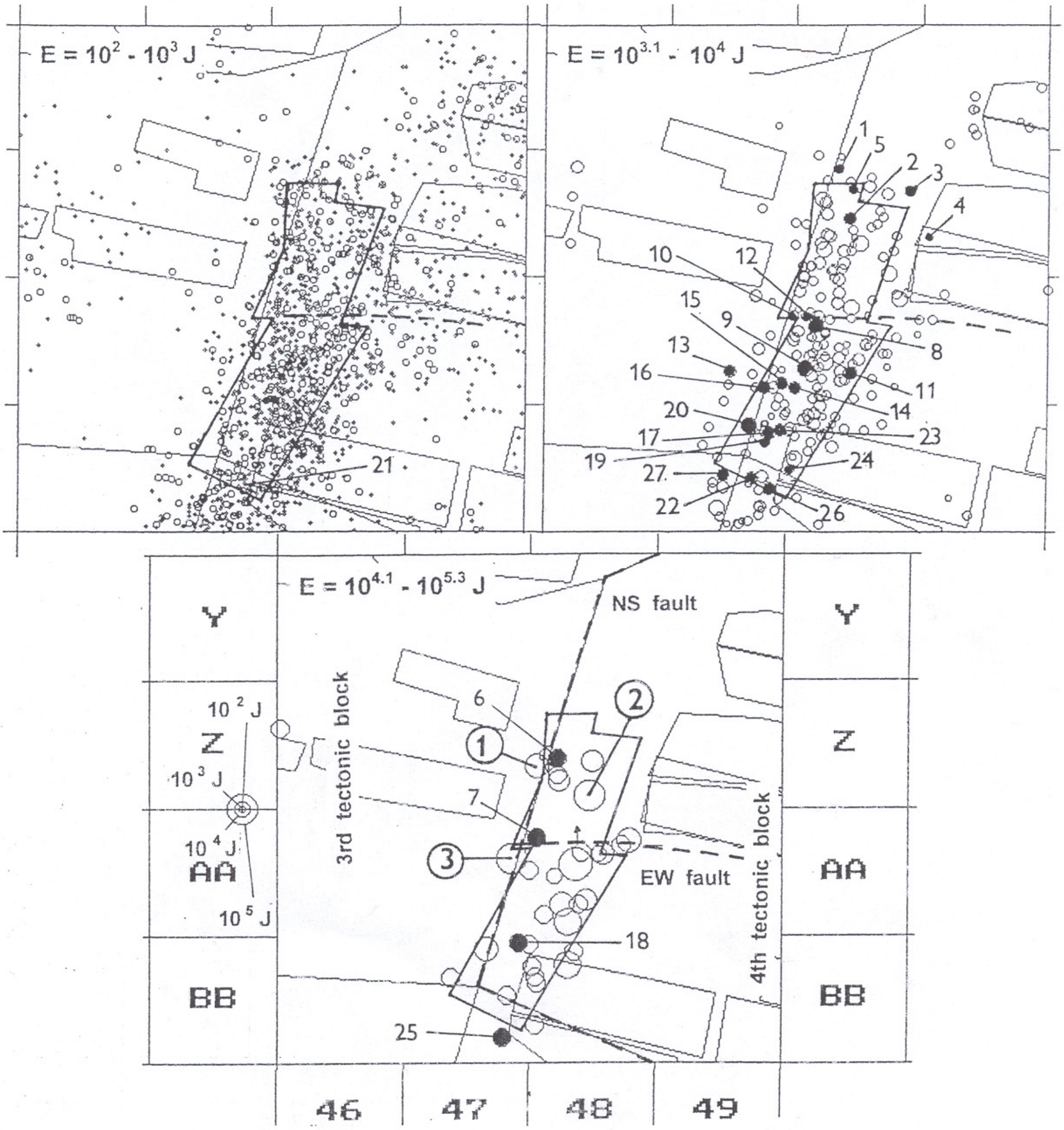

Fig. 7 Location plots of seismic events induced by mining of the longwall (○) and by large scale torpedo blasting operation in the roof (●); in the upper left corners ranges of released seismic energy are given.

terminated at the turn of 1992 and 1993. Subsequently array was incorporated into the local seismological network which required the unification of all replaced the PCM3 apparatuses. At present this array is operating as part of the local seismological network.

2.4. REGIONAL SEISMOLOGICAL NETWORK

The occurrence of the extraordinary strong rockburst on April 27, 1983 in the ČSA Mine was the essential reason for erecting a modern regional monitoring system. The released seismic energy of this rockburst was estimated at $E \approx 10^{10}$ J or $M = 3.75 \pm 0.5$ (CSEM) which was recorded at many European seismic stations, almost up to a distance of 2000 km (Trávníček et al., 1987). During the process of evaluation, it was found that the quality of the analogue records of this extremaly strong event was very poor; the records are, in the sense of their intesity, so to speak overloaded and their interpretation, namely amplitude maxima, was doubtful (Klíma et al., 1986). Therefore, it was considered that only digital instrumentation can guaratee records of high quality with regard to suitable frequency band and dynamic range. Competitive bidding among

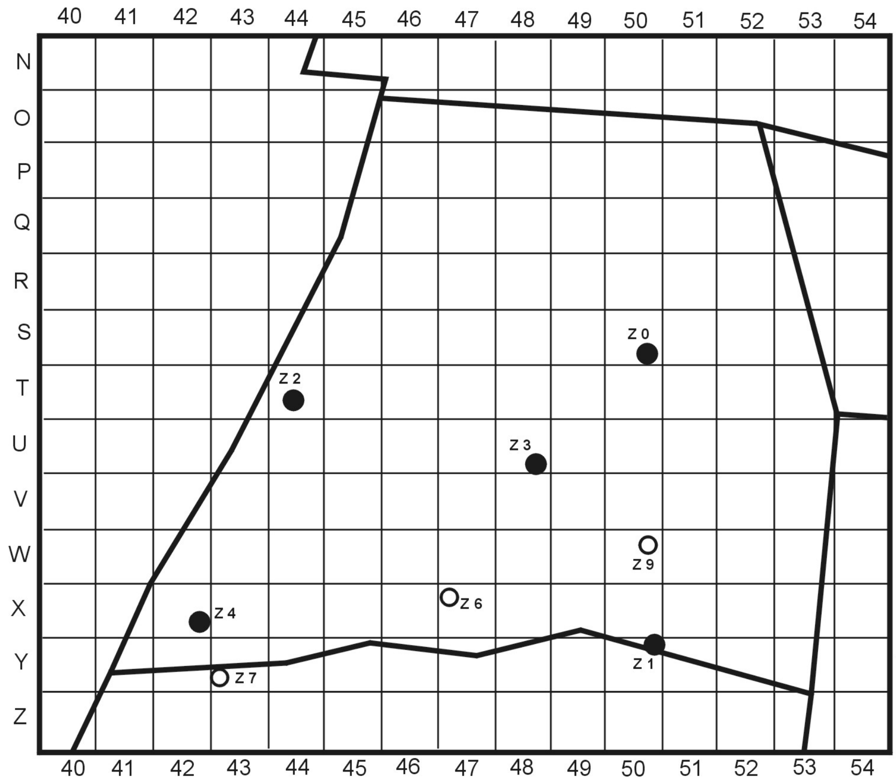

Fig. 8 Local seismological network in the Lazy Mine where surface (○) and underground (●) stations are placed.

seismological instrumentation companies was opened. Finally, the company Lennartz Electronic GmbH won this competition.

During the following time period, some preparatory activities started, e.g., the selection of sites for seismic stations, geological survey of these localities, drilling holes for adjustment of oriented seismometers, performing tests for radio transmission and, moreover, a large amount of further admistrative activities was needed. Nevertheless, the first part (5 stations) of the regional network was launched in 1987. As for the essential contribution of this monitoring system, three basic tasks were expected to be solved:

- continuously to observe all seismic events from the Ostrava-Karviná and Frenštát regions, including events of both natural and man-made character,
- to ensure reliable link-up of all existing networks in the investigated area,
- to gather homogeneous experimental material for detailed research into the seismic regime on a local scale and to clarify the mechanism of rockburst origin.

The working version of this new monitoring system was called the Regional Diagnostic Polygon (RDP), later it was named briefly the Seismic Polygon (SP) which was set up as an indispensable supplement of the local seismological network and, moreover, it represented a connection between the local and the Czech national seismological network.

The first step in establishing the SP was an array consisting of five stations described by Konečný (1989), further stations being gradually set up between 1988 and 1991; the present state-of-art of the regional array is displayed in Figure 9**.** The regional monitoring system consists of seismic stations equipped with tri-axial short-period WDS-202 sensors ($f_0 \approx 2.0$ Hz) which surround the whole mining area. Six of them are placed in shallow boreholes ($h \approx 30$ m), three are installed underground, and the last one is located in a short gallery of the seismic station Ostrava-Krásné Pole (OKC) approx. 30 km away from the centre of the coal field.

The recording device works within the frequency range of $f = 2 – 32$ Hz (the upper limit is restricted by filtration) and the parameters of this device correspond to recording of local seismic events. The site of observation also includes an A/D convertor, mixer of all three channels and transmitter. The dynamics of the recorded seismic signals is about 120 dB. Due to the rugged topography, the relay station was situated at the top of the Beskydy Mts (Lysá hora), whence transmission of seismic data to the laboratory in Green Gas DPB in Paskov was guaranteed. The receiver of the coded time signals from the DCF transmitter 77.5 kHz (Germany) is

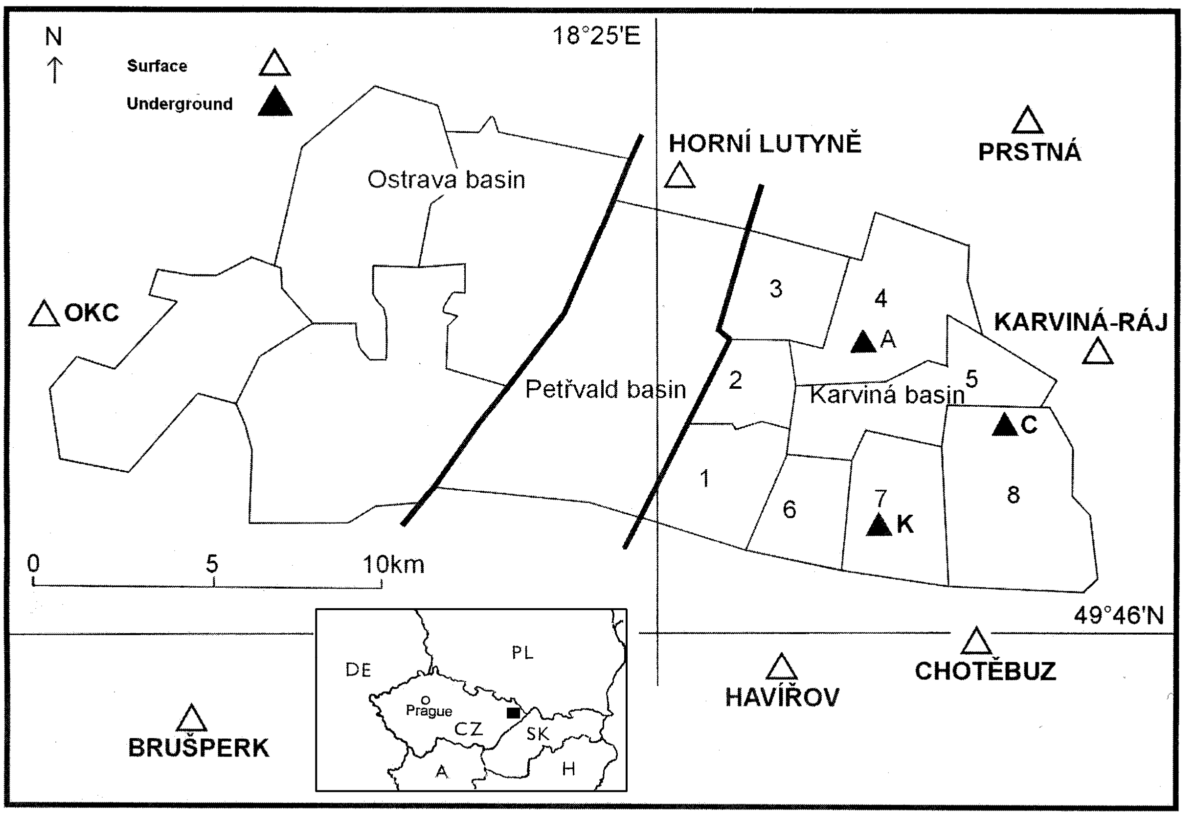

Fig. 9 The lay-out of stations of the Seismic Polygon in the Karviná basin; station situated on the surface (△) and underground (▲); position of the Czech Republic in the middle of adjacent European countries is displayed in the lower part of this figure.

located at the Lysá hora, where preprocessing of seismic data and signal mixing is performed. Subsequently selection of seismic events based on triggering conditions was performed and finally are transmitted from Lysá hora to the Green Gas DPB centre in Paskov. In this way data sets are prepared and simultaneously are ready for interpretation in laboratory where common database of local and regional monitoring systems is kept and available since 1989. Recently, some devices were innovated and/or replaced by new ones and, therefore, changes in arrangement of the individual apparatuses could be made.

The basic software for the SP was purchased from Lennartz Electronic GmbH but was partly modified and/or substituted in order to conform to the requirements for reliable functioning of the whole system, i.e. on-line monitoring of seismic events, acceleration of data interpretation, preparation of graphic outputs, to connect the SP to the local seismological network using computer network of Ostrava-Karviná Mines, a.s. (mutual connection is in operation since the year 2002), maximum automation of all precedures, programs for visual interactive evaluation of wave trains, foci localization, spectral analysis, etc. (Knotek and Holub, 1991). Recently innovation of some program packages for the Seismic Polygon has been finished (Suchanek et al., 2008).

A large number of examples of the output data of the Seismic Polygon and local seismological network have so far been widely used. These data often represent an important part of various publications and, therefore, some examples of practical data application of both networks are the objectives of the papers mentioned above. As for the Seismic Polygon, many unpublished reports from discussions, which dealt with this issue, have been gathered. Other reports are published in various scientific journals, mostly in Czech, e.g., Knotek et al. (1990), Trávníček et al. (1990 and 1991), Kaláb et al. (1992), Holečko et al. (2007), Holečko (2008), Koníček and Mořkovská (2008), Trávníček and Mekiňa (2008), Kubica et al. (2010). Less papers, dealing generally with the investigation of induced seismicity, have been published in English, e.g., Kaláb (1991), Kaláb (1992), Kaláb and Knejzlík (1995), Holub (1997 and 1998), Holečko et al. (1999), Petroš and Holub (2003), Holub (2006) and Holub et al. (2011). Finally, we must stress that only a small part of the material has been presented in this chapter and, therefore, we apologize to all who have not been personally mentioned.

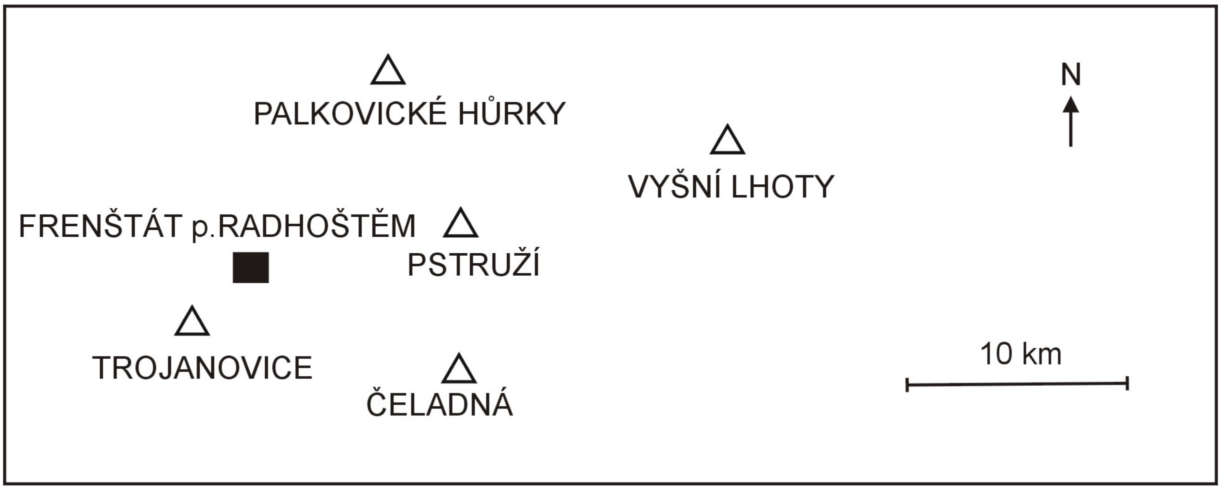

Fig. 10 Distribution of seismic stations of the polygon Frenštát. (SPF).

2.5. SEISMOLOGICAL POLYGON NEAR FRENŠTÁT (SPF)

The proposed Regional Diagnostic Polygon in the Ostrava-Karviná Coal Basin, consisting originally of 15 seimic stations, was later divided into two parts. The first part (10 stations) was described in Chap. 2.4 above, while the second part (5 stations) denoted as SPF, was in operation in the wider vicinity of the town of Frenštát near the mountain Radhošť, where two exploration shafts were under construction as mentioned by Kaláb (1992).

Five stations equipped with triaxial WDS-202 sensors (f_0 = 2 Hz) placed in shallow holes (h ≈ 30 m) were distributed within the area under investigation, as seen in Figure 10. While the HW for seismic monitoring of the southern part of the Ostrava-Karviná area was bought from the professional company Lennartz Electronic GmbH, the rest (data acquisition system, transmission and the data processing apparatus PCM3 and special software packages) was developed by researchers of the Institute of Geonics AS CR. The conception of the software was based on the possibility of interactive data processing. As regards the level of data interpretation, the compatibility of both parts of the Seismic Polygon was guaranteed (Toth, 1992; Knejzlík and Zamazal, 1992).

At the field stations, the analogue seismic signals were converted into a floating point code (10 bits mantissa and 4 bits exponent) which made the dynamic range of 120 dB possible. The sample frequency was 125 Hz and Miller´s code modulation was used for radio data transmission within the frequency band of 430 MHz via the relay station situated on the top of the Beskydy Mts, on Lysá hora (Mt.). The relay station was common till 2002 for data transmission from the individual stations of the local seismic network, for the stations belonging to SP Green Gas DPB, and it was also used for radio transmission between the top of the Lysá hora (Mt.) and the interpretation centre of the Institute of Geonics AS CR in Ostrava. The relay station is equipped with a data concentrator based on a micro-computer. The signals received from the individual seismic stations by radio receivers are transmitted to the decoders of Miller´s code receiver and, after decoding, they are stored in buffer memories. After transmitting the recorded data by radio to the interpretation centre, these are converted by means of a special program which makes it possible to prepare these data for further seismological analyses, e.g., waveform analysis, location of events which enables using the necessary data from five stations, spectral and particle motion analyses. Moreover, special programs for localization and focal mechanism determination of the individual seismic events, e.g. induced seismic events, local earthquakes and quarry blasts were added to the software (Kaláb and Knejzlík, 1995; Kaláb and Kunčický, 1996; Kaláb and Skácelová, 1999).

The original intension to monitor the seismicity induced by mining in the Frenštát Mine was abandoned, because mining was stopped there due to the complicated geological conditions and the tectonic pattern of this deposit. Nevertheless, during seismological observations some stronger seismic events from the OKCB were detected and localized, as well as seismic events caused by falling-in in the Paskov and Staříč Mines (Holub et al., 2002). A map of seismic foci localized by means of data of SP Green Gas DPB and by SPF is displayed in Figure 11 (see Holub et al., 2004).

2.6. SURFACE SEISMIC ARRAYS

Some seismic phenomena have been observed and felt by residents in the undermined areas for many years ago, e.g., (Kusznir et al., 1980; Westbrook, 1978; Mutke and Dworak, 1992; Dubinski,1996;

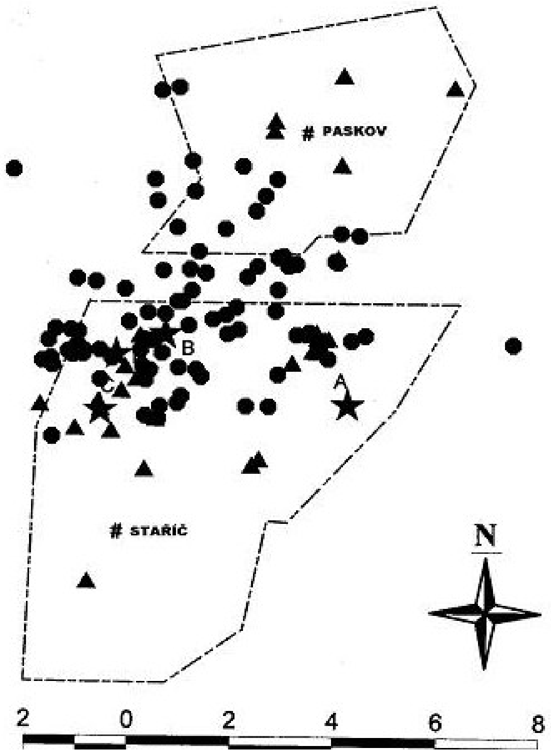

Fig. 11 Foci located by SPF network (●) or by Seismic polygon Green Gas DPB (▲) within the time interval 1992-2002, focal regions A, B, and C.

Kaláb et al., 2002). These tremors are characterized by shallow depth of focus and proximity to current mining activities, and if such a tremor **is** stronger, it is then felt strongly locally and sometimes is followed by more or less damages as described in detail for the Polish territory, e.g., by Kwiatek (1998). A similar situation occurred, e.g., in the 1980´s in the Dukla Mine, when coalface No. 16 212 was mined. At that time a series of events was localized by the local seismological network to the „higher roof", and most of them were followed by surface tremors felt in the environs of the shaft by mine employees and by residents living near the mine who often felt upleasant motions of the floor at home (Holub, 1997a). Considering that the undermined area in Ostrava-Karviná is relatively large and a large amount of coal and rocks has been extracted, further events and some damage to buildings on the surface could be expected.

This situation deteriorates the living environment for residents, especially when cracks appear in the walls of houses. Then the Department of Environmental Protection of the OKD (Ostrava-Karviná Mines) is asked for compensation. However, during the process of estimating the extent of damage according to Czech Technical Standard 73 0040, many problems usually have to be solved, above all the problem of proving objectively that this damage was caused by the particular mining induced event. In order to precede unpleasant negotiations, it was recommended to establish arrays of seismic sensors for investigating induced seismic activity at selected endangered localities as an objective solution. That is also the reason why false reports concerning apparent damage can be objectively excluded, and thus the municipal corporation has the possibility to justify and support the final decision as regards financial compensation.

2.6.1. ARRAY OF THE INSTITUTE OF GEONICS AS CR

Since nearly all the problems in the Ostrava-Karviná region are associated with coal mining, the Mine Authority deals with any damage, but together with other organizations, which are competent to deal with the effect of induced seismic events on surface structures, in particular residential buildings in the undermined area.

Institute of Geonics AS CR was asked by the Mine Authority to establish a seismic array in the endangered area, which could monitor and quantitatively classify the hazards of induced seismic events to the surface structures. After the reconnaissance of the area near the town of Karviná, several sites were found for constructing the requisite array. Four sites was selected for the first stage, i.e., ORL 1, ORL 2, DOU 1 and STO 1, which started in 2000. Afterwards, i.e. in 2003, 2004 and 2005 stations DAR 1, KAR 1 and STO 2 completed the whole array which is displayed in Figure 12. For more current information we refer the reader to, e.g., Kaláb et al., (2002); Kaláb, (2004); Holečko et al., (2006); Doležalová et al., (2008); Kaláb and Knejzlík, (2009), Kaláb and Lednická, (2010); Mutke, (2010). The seismic stations are equipped with SM-3 seismometers oriented according to geographical coordinates, i.e. horizontal components NS, EW and vertical Z , so that the total vector of particle motion in three directions can be calculated, if needed. Either PCM3-PC or PCM3-EPC apparatuses were used for data acquisition (Knejzlík and Kaláb, 2001 and Kaláb and Knejzlík, 2002). The recording of the individual induced seismic events is performed in the triggered regime and subsequently the wave trains are transmissed by modem to the laboratory of the Institute of Geonics AS CR in Ostrava. The measured amplitudes of particle velocities reach mostly values up to 10 mm/s. Velocities exceeding this limit could cause some damage to buildings, the extent of which depends on the intensity of the particular seismic event (Kaláb, 2004).

During the process of evaluating the observed data from several sites, two facts must be taken into account at least: firstly, the recorded and estimated amplitudes can be influenced by the directivity radiation of the seismic source, and, secondly, the essential influence of the geological structure and the level of groundwater is anticipated.

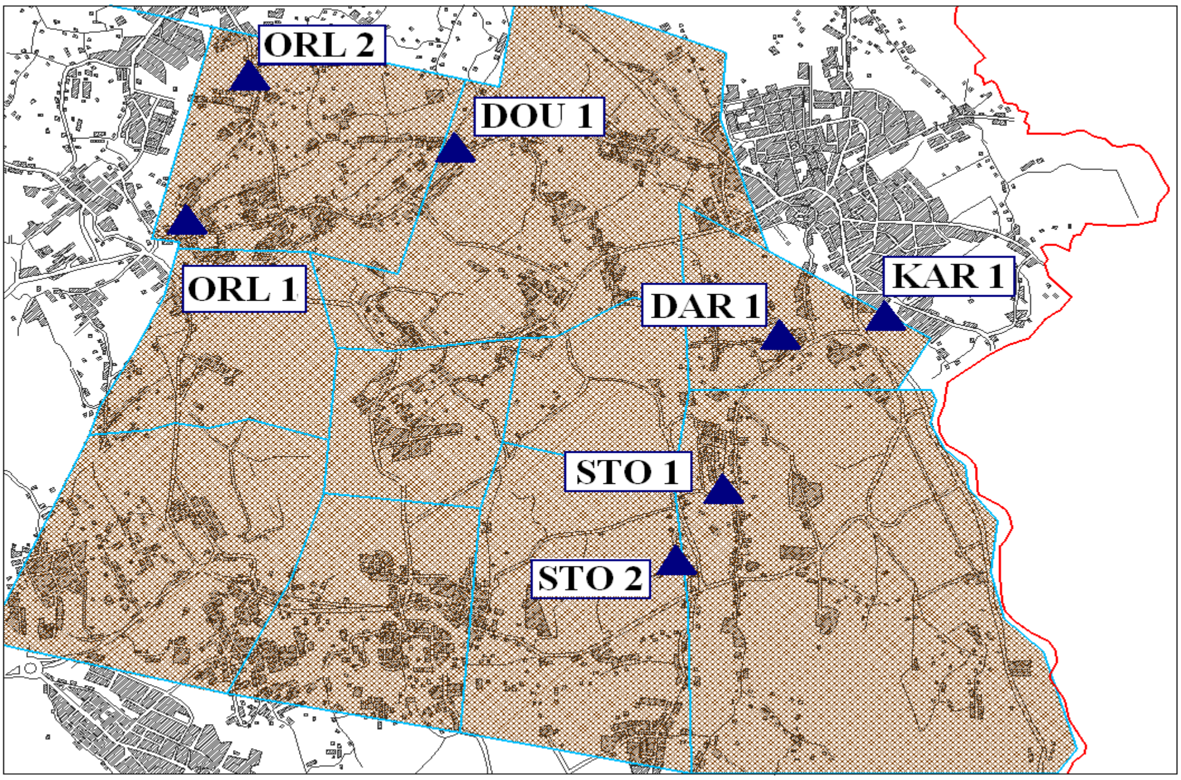

Fig. 12 Situation of surface array operated by the Institute of Geonics AS CR (acc. to Kaláb and Lednická, 2010).

According to the agreement with several Municipal authorities from endangered areas, the results of seismological observations are sent them monthly.

2.6.2. ARRAY OF THE GREEN GAS DPB, A.S.

The purpose of this newly created seismic array is monitoring the surface tremors observed in the undermined area of the Ostrava-Karviná Coalfield. Its operation started in the year 2009. A detailed geological survey preceded the establishment of the array in order to get an idea of the environmental conditions, e.g., the local geological structure and types of rocks, thickness of the weathered zone and the depth of the groundwater level. These parameters are of primary interest, because the uppermost part of this whole area is built mostly of clayed sediments, which have relatively low acoustic resistance. That is why this sedimentary cover may have an unfavourable influence tending towards generally higher amplification, useful seismic signals, as well as disturbing vibrations caused by local traffic, industry, etc. In this particular case such a situation very often makes the records illegible.

The Green Gas DPB network under consideration consists of 15 seismic stations equipped with Polish instrumentation AMAX_GSI designed and made in the Central Mining Institute in Katowice, including the appropriate software. All stations shown in Figure 13 are recording in a triggered regime; data transmission is realized using Internet connection within the net of a mobile operator to the processing centre located in Paskov. Every wave train is recorded in three mutually perpendicular planes, i.e., horizontal NS and EW and Z (Holečko, 2010).

The advantage of data assessment in the central processing laboratory of Green Gas DPB, a.s. consists in the immediate confrontation with data observed at seismic stations of both local and regional seismological networks. The results of observation at the surface seismic stations are regularly handing over to Municipal authorities settled on undermined areas. These reports are completed with records of wave trains of particular events which represent output data for archive (Holečko et al., 2005; Koníček and Holečko, 2006; Holečko and Koníček, 2007).

CONCLUSIONS

We intended to summarize all significant information drawn from the long-term operation of seismo-acoustic and seismic networks:

- SA networks operate close to probable sources of seismic waves and, therefore, they provide the first information related to stress-strain changes in the rock mass and in its neighbourhood. These changes can be caused either in the process of coal extraction and/or due to destress blasting in the coal seam.

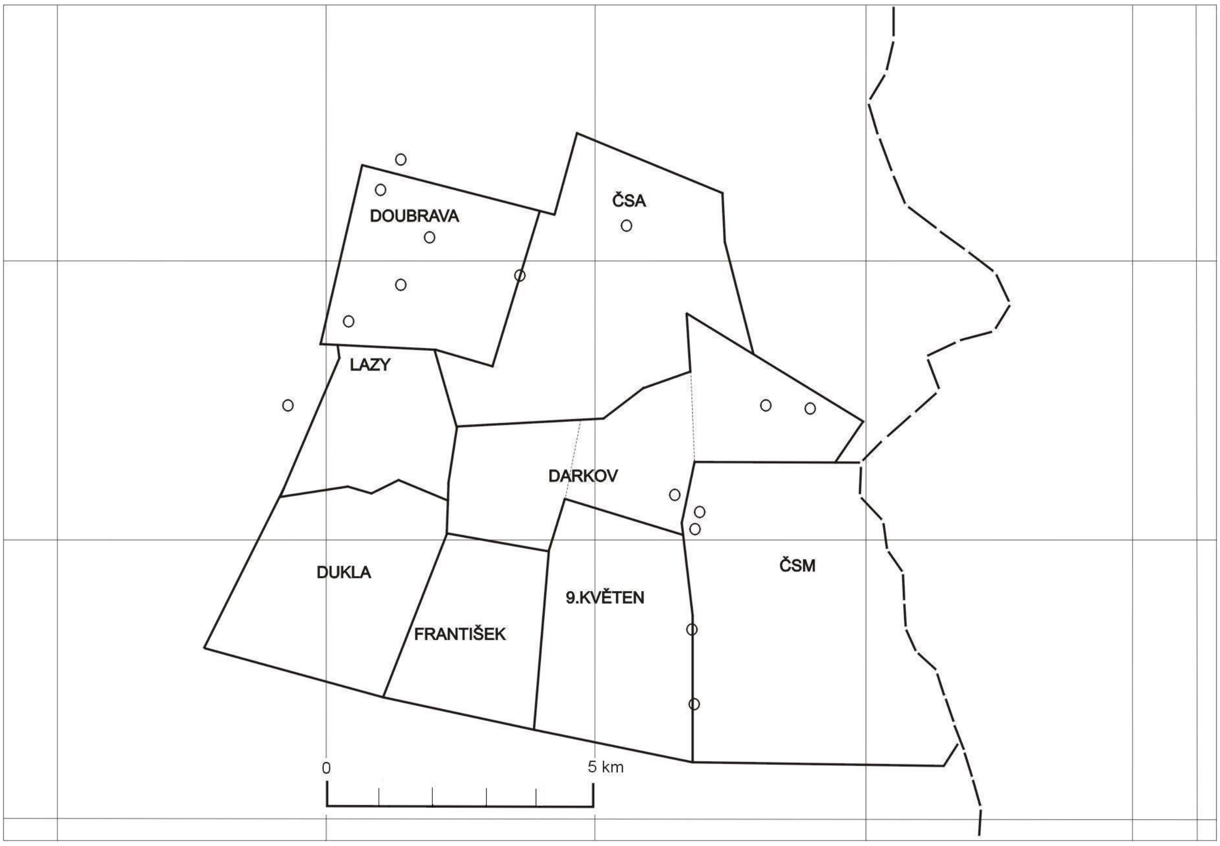

Fig. 13 Situation of surface array operated by the Green Gas DPB.

- Continuous long-term monitoring of induced seismic events makes it possible to describe the changes in the distribution of seismic events in space, as well as in time. Based on location plots, it is possible to monitor, e.g., dense concentration of foci within a limited area, which is a symptom of higher rock mass loading, while the investigation of seismic activity in time enables one to monitor the process of energy accumulation and/or its release in time.
- Our experience with operating seismic surface arrays in investigating mining shocks on the surface confirmed that this is an approach which could help solve the problems with compensations successfully. In all cases mentioned above, we started with continuous observations of individual seismic events using seismoacoustic or seismic networks operating in the Ostrava-Karviná Coal Basin, and the need of such observations was thus reliably documented.

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