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FOCAL MECHANISM AND SOURCE PARAMETERS OF THE ROCKBURSTS IN UPPER SILESIAN COAL BASIN

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1. Introduction

The rocburst hazard in Polish hard coal mining industry has for many years been one of the most serious, in consequences, natural hazards. With all the progress in both the sphere of scientific activity and the mining practice it self a dozen or so of rocbursts occur annually. This fact gives rise to a number of question concerning the methods used for the assessment and fighting against the hazard. The solutions that could bring more progress in this field. Among the different studies being developed is the searching for certain particular elements of those seismic events. Which cause the occurrence of rockbursts. The objective of the analysis is find a correlation between the focal mechanism and source parameters and the mining and geological conditions.

A computer date base that includes the following parameters of the rockbursts has been created: mining conditions, tremor focal mechanism parameters, seismic source parameters. The Rockburst Base thus created allows us to conduct a broad analysis concerning the physical processes of dynamic destruction of the rock structure around mine workings. The results hither to obtained confirm the usefulness of conducting this kind of interdisciplinary research and point out at the necessity of developing new trends in the activity of the mine geophysical services.

2. Characteristics of Investigation Procedures

Hard coal mining in the Upper Silesian Coal Basin induces, in the recent years, annually, about 1000 seismic events with local magnitude $M \geq 1.7$ ($E \geq 10^5$ J). From among that number of events about $10-15$ are the rockburst which cause serious injuries upon miners and considerable damage to workings. For this reason the research works which take into analysis a larger number of parameters describing the phenomenon of a mine tremor are trending towards better of understanding the nature of rockbursts.

In the performed studies the interpretation scope of mining seismology has been extended in order to improve the assessment quality of the rockburst hazard, This method is still basing on the limited number of parameters (seismic energy, source coordinates and the tremor's occurrence time). The number of parameters has been increased by adding the focal mechanism and the source parameters. The double couple forces appears to be the best suitable model for the strong mine tremors which are induced by mining activity. This is because it fits both the most frequently occurring destruction model that is observed in the laboratory studies and the real stress deformation system in the vicinity of mine workings.

Determination of the focal mechanism allows obtaining more information about the physical processes taking place in the mine tremor source zone. The input data are the P–wave first motion polarities on the seismogram. A characteristic distribution of the emission of P and S body waves and the associated distribution of displacement field in the vicinity of the focus are the features of the sources physical model (double couple of forces). The compression and dilatation regions, precisely located and separated by two orthogonal nodal planes occur, thus, in space. These regions are determined by the P–wave first motion polarities at seismic stations randomly located with respect to the tremor hypocenter. The following angular parameters for the solution of focal mechanism are determined:

- parameters which determine the spatial location of nodal planes (azimuth and dip),
- parameters of the stress principal axes P, T (azimuth, rake)
- angle of slip or angle of displacement

Another objective of our effort aiming at the enlargement of the number of parameters in mining seismology is the determination of source parameters.

The Upper Silesian Regional Seismological Network of the Central Mining Institute is in possession of the digital system for monitoring and recording mining tremors. The system allows implementing the procedures for computing sources parameters. Assuming that the stress drop in a source area is instantaneously applied and that the source's size is finite, the shear wave pulses with a flat spectral level are radiated:

$$\Omega_0 = 2\left(\frac{k^3}{I}\right)^{1/4} \qquad \text{[Andrews 1986; Snoke 1987]}$$

where: I – integral of squared ground motion velocity, k – integral of squared displacement.

The source parameters are defined as follows

$$f_N = \left(\frac{I}{2\pi^3}\Omega_0\right)^{1/3}$$

$$r_0 = k\beta/2\pi f_N$$

where: $k = 1, 2, 3$, β – S–wave velocity

$$M_0 = 4\pi\rho\beta^3 R\left|\Omega_0\right|/F^c R^c$$

$$\triangle\sigma = 7M_0/16r_0^3$$

$$\sigma_{ap} = \mu E_s/M_0$$

$$E_s = 4\pi\rho\beta R^2 I$$

$$D = M_0/\rho\beta^2\pi r_0^2\,,$$

TABLE 1

ROCKBURST BASE		
Parameter number	Parameter name	Parameter characteristics
1	DATE	Event occurrence date
2	TIME	Event occurrence time
3	KOP	Mine name
4	E	Tremor energy calculated by means of classic method [Joule]
5	WSPX	X coordinate (Sucha Góra coordinate system) [m]
6	WSPY	Y coordinate (Sucha Góra coordinate system) [m]
7	POKŁ	Seam
8	MPOKŁ	Seam thickness
9	EKSPL	Mining system
10	UPOKŁ	Direction of dip of seam
11	KUPADU	Dip of seam (xx means from yy) [°]
12	GŁPOK	Depth of seam
13	PSTSP	Sandstone participation in 100 m of roof lithologic profile and in 50 of seam floor profile (xx{roof}, yy{floor}) [%]
14	ZSTSP	God participation in 100 m of roof lithologic profile and in 50 of seam floor profile (xx{roof}, yy{floor}) [%]
15	KRAWST	Vertical distance to edges located in seam roof
16	KRAWSP	Vertical distance to edges located in seam floor
17	SKUTKI	The location of tremor effects (śc – longwall, ch – heading)
18	USZKODZ	Total length of damaged workings [m]
19	USZOG	Minimum source – effects distances [m]
20	USKOK	Fault occurrences [z – source in the down thrown side; w – source in the upthrown side
21	ZRZUT	Amount of throw of the fault [m]
22	ODLUSK	Minimum fault – effects distances
23	MECH	Type of focal mechanism
24	AZ1	Azimuth of the first nodal plane
25	UP1	Dip of the first nodal plane
26	KP1	Angle of slip of the first nodal plane
27	AZ2	Azimuth of the second nodal plane
28	UP2	Dip of the second nodal plane
29	KP2	Angle of slip of the second nodal plane
30	AP	Azimuth of stress P – axis
31	ZP	Rake of stress P – axis
32	AT	Azimuth of stress T – axis
33	ZT	Rake of stress T – axis
34	KORMECH	Correlation for nodal planes location
35	Ω_0	Spectral level Ω_0
36	F_0	Corner frequency
37	R	Source radius
38	M	Seismic moment
39	DP	Stress drop
40	ES	Seismic energy
41	D	Rupture zone

where F^c – relation coefficient, R^c – amplification coefficient at free surface, S_c – bedrock coefficient.

The rockburst data base (Table 1) has been created based on the available detailed data concerning:

- mining and geological conditions,
- focal effects in workings,
- focal mechanism and source parameters.

The rocburst base thus created, after more data have been stored in it will allows performing broad analyses for the determination of physical processes of dynamic destruction of rocks surrounding the workings and for the better assessment of rockburst hazard.

3. Analysis of the Conditions for the Rockbursts Occurrence

A data set related to the mining and geological conditions under which the rocbursts have occurred and the computation results of tremor focal mechanism and source physical parameters are presented in Tables 2a–c.

TABLE 2A. Rockburst Base of the uper Silesian Coal Basin
Mining and Geological Conditions

DATA	TIME	KOP	E	E*	E	WSPX	WSPY	POKL	MPOKL	EKSPL	UPOKL	KUPADU	GLPOK
93-02-11	17,58	SLASK	7	E	5	18660	-5310	507	1,5	zawal	S	5,07	790
93-03-17	16,56	SLASK	1	E	5	18690	-5370	507	1,5	zawal	S	5,07	790
93-07-15	4,45	PORABKA KL	4	E	4	11500	-22760	510	14,4	podsa	SW	9,00	410
93-08-19	17,57	SLASK	5	E	5	18450	-2240	414	3,8	zawal	SW	4,00	710
93-09-11	11,10	WUJEK	8	E	7	18950	-6850	501	7,5	zawal	SE	4,00	680
93-09-17	1,34	MIECHOWICE	5	E	5	4940	1940	510	4,0	drazo	SE	16,00	690
93-12-09	11,30	WIREK,HALE	3	E	9	17600	-1880	506	2,2	podsa	SW	6,08	800
93-12-14	0,30	KLEOFAS	2	E	6	17340	-9600	501	8,7	podsa	S	5,09	480
93-12-21	6,45	MIECHOWICE	3	E	6	5300	1350	509	5,2	zawal	SE	7,11	815
94-01-12	11,34	HALEMBA	2	E	6	16890	-166	510	6,6	drazo	SW	6,08	840
94-02-22	9,18	HALEMBA	1	E	5	16919	12	510	6,6	drazo	SW	6,08	840
94-02-23	19,00	WUJEK	9	E	5	19320	-8930	510	6,0	podsa	SW	4,06	715
94-03-21	17,03	NOWY WIREK	9	E	5	17390	-1890	507	3,0	podsa	SW	6,08	800
94-04-15	16,46	WUJEK	1	E	6	18910	-9400	510	6,0	zawal	SW	4,06	670
94-04-26	16,24	WUJEK	3	E	6	19240	-8890	510	6,0	podsa	SW	4,06	715
94-06-23	8,12	ZABRZE	1	E	7	15250	3970	507	3,6	zawal	S	6,15	830
94-09-22	10,22	MIECHOWICE	3	E	6	5390	1420	509	5,2	zawal	SE	7,11	815
94-10-27	19,09	WIECZOREK	6	E	6	21470	-15462	510	10,3	podsa	SW	4,00	560
94-12-08	9,25	SLASK	6	E	5	18660	-5380	507	1,5	zawal	S	5,07	790

zawal – rockfall, podsa – backfilling, drazo – excavation

TABLE 2A. Rockburst Base of the uper Silesian Coal Basin
Mining and Geological Conditions

DATA	TIME	KOP	KUPADU	GLPOK	PSTSP	ZSTSP	KRA WST	SKUTKI	USZKOD Z	USZOG	USK OK	ZRZUTU	ODL USK
93-02-11	17,58	SLASK	5,07	790	48,08	6,00		sc,ch	41	80			
93-03-17	16,56	SLASK	5,07	790	48,08	6,00		sc	30	22			
93-07-15	4,45	PORABKA KL	9,00	410	88,36			sc	48	75	z	7,0	12
93-08-19	17,57	SLASK	4,00	710	63,49	3,00	20	ch	27	30	z	60,0	36
93-09-11	11,10	WUJEK	4,00	680	62,65		65	sc,ch	180	38	z	3,0	40
93-09-17	1,34	MIECHOWICE	16,00	690	48,15		13	ch	56	24	w	2,0	130
93-12-09	11,30	WIREK,HALE	6,08	800	63,39			sc,ch	1421	20	z,w	1,6	0
93-12-14	0,30	KLEOFAS	5,09	480	70,15		60	ch	37	60	w	110,0	26
93-12-21	6,45	MIECHOWICE	7,11	815	43,21		20	ch	268	304			
94-01-12	11.34	HALEMBA	6,08	840	52,34	2,00	10	ch	160	190			
94-02-22	9,18	HALEMBA	6,08	840	52,34	2,00	10	ch	30	58			
94-02-23	19,00	WUJEK	4,06	715	51,02	9,00	110	sc	72	25			
94-03-21	17,03	NOWY WIREK	6,08	800	64,39			ch	80	95	z	5,0	15
94-04-15	16,46	WUJEK	4,06	670	51,02	9,00	45	sc,ch	140	20			
94-04-26	16,24	WUJEK	4,06	715	51,02	9,00	110	sc,ch	177	16			
94-06-23	8,12	ZABRZE	6,15	830	46,20	2,00	20	ch	64	165	w	5,5	110
94-09-22	10,22	MIECHOWICE	7,11	815	54,47	2,00	15	ch	169	190			
94-10-27	19,09	WIECZOREK	4,00	560	71,16		27	sc	70	220			
94-12-08	9,25	SLASK	5,07	790	48,08	6,00		ch	0	20			

TABLE 2B. Rockburst Base of the uper Silesian Coal Basin
Tremor Focal Mechanism Parameters

DATA	TIME	KOP	MECH	AZ1	UP1	KP1	AZ2	UP2	KP2	AP	ZP	AT	ZT	KORMECH
93-02-11	17,58	SLASK	RS	231	69	22	329	69	158	280	0	190	30	front(1)
93-03-17	16,56	SLASK	RC	257	52	51	23	52	129	320	0	239	60	front(2)
93-07-15	4,45	PORABKA KL	NC	123	57	−140	237	57	−40	90	50	0	0	filar(1)
93-08-19	17,57	SLASK	NC	308	62	−136	63	52	−36	270	50	8	6	u(2)
93-09-11	11,10	WUJEK	ND	213	75	−95	14	16	−72	130	60	298	29	u(1)
93-09-17	1,34	MIECHOWICE	RS	137	79	137	37	48	14	260	20	6	37	u,kr,kch(2)
93-12-09	11,30	WIREK,HALE	NC	219	79	−48	117	44	−165	90	40	430	29	u(1);kch(2)
93-12-14	0,30	KLEOFAS	NC	127	63	−149	233	63	−31	90	40	0	0	u,kr(2)
93-12-21	6,45	MIECHOWICE	RS	5	71	37	109	55	157	60	10	322	39	kr(1)
94-01-12	11,34	HALEMBA	RC	90	66	134	337	49	33	210	10	312	49	kr,kch(2)
94-02-22	9,18	HALEMBA	NS	231	69	−159	329	69	−22	190	30	100	0	kr,kch(2)
94-02-23	19,00	WUJEK	RS	29	77	29	126	62	165	80	10	344	29	kr(2)
94-03-21	17,03	NOWY WIREK	RC	123	79	43	223	48	166	180	20	74	37	u(2)kch(2)
94-04-15	16,46	WUJEK	ND	145	54	−113	289	42	−61	110	70	219	7	kr(2)
94-04-26	16,24	WUJEK	RC	118	71	120	358	35	35	230	20	351	54	kr(1)

94–06–23	8,12	ZABRZE	NS	204	76	–59	91	34	–153	80	50	317	24	u(1);kch,kr(2)
94–09–22	10,22	MIECHOWICE	RC	322	74	33	62	59	161	15	10	278	34	front(1);kch(2)
94–10–27	19,09	WIECZOREK	NC	160	66	–40	51	54	–149	20	45	283	7	brak
94–12–08	9,25	SLASK	RC	150	66	134	37	49	33	270	10	12	49	front(2)

TABLE 2C. Rockburst Base of the uper Silesian Coal Basin

Tremor Source Spectral Parameters

DATA	OMEGA0	E*	OMEGA0	OMEGA0	R	E*	R	M	E*	M	DP	E*	DP	ES	E*	ES	APA	E*	APA	D	E*	D
93–02–11	6,2	E	–7	6,7	6,8	E	1	1,0	E	12	2,1	E	6	1,7	E	7	1,6	E	5	7,9	E	–3
93–03–17	3,3	E	–7	5,8	7,6	E	1	8,4	E	11	8,7	E	5	3,4	E	6	5,3	E	4	3,1	E	–3
93–09–17	1,3	E	–6	4,1	1,0	E	2	7,5	E	12	2,9	E	6	8,7	E	7	1,7	E	5	1,4	E	–2
93–12–09	7,1	E	–5	2,5	1,2	E	2	8,1	E	13	2,2	E	7	2,4	E	10	1,6	E	6	4,0	E	–1
93–12–14	5,9	E	–7	4,5	8,8	E	1	1,4	E	12	1,1	E	6	8,3	E	6	5,9	E	4	4,3	E	–3
93–12–21	4,8	E	–7	2,7	1,6	E	2	3,9	E	12	4,4	E	5	1,4	E	7	3,7	E	4	4,3	E	–3
94–01–12	4,9	E	–6	6,5	6,8	E	1	1,4	E	13	1,9	E	7							8,7	E	–2
94–02–22	8,8	E	–7	8,0	5,5	E	1	2,5	E	12	9,4	E	5							2,4	E	–2
94–02–23	2,9	E	–6	6,0	7,3	E	1	5,5	E	12	6,2	E	6							3,0	E	–2
94–03–21	2,9	E	–6	6,5	6,8	E	1	6,7	E	12	9,3	E	6							4,2	E	–2
94–04–15	3,6	E	–7	4,7	1,1	E	2	2,8	E	12	6,5	E	5	7,5	E	6	5,4	E	4	5,4	E	–3
94–04–26	6,6	E	–6	5,0	8,8	E	1	1,2	E	13	1,1	E	6							4,5	E	–2
94–06–23	2,4	E	–5	3,0	1,5	E	2	9,5	E	13	1,3	E	7							1,2	E	–1
94–09–22	2,8	E	–6	3,1	1,5	E	2	8,5	E	12	1,6	E	6	1,7	E	8	1,5	E	4	1,7	E	–2
94–10–27																						
94–12–08	1,2	E	–7	5,1	8,8	E	1	1,6	E	12	2,9	E	6	1,4	E	7	9,0	E	4	6,0	E	–3

(E* – is $a \cdot 10^b$)

All the studied rockburst incidents were associated with the occurrence of mine tremors of the local magnitude from 1.53 to 4.04 (energy from $5 \cdot 10^4$ to $3 \cdot 10^9$). These tremors have been located in thick sandstone beds the share of which in the whole of 100 m roof profile was from 48 to 71 %. The tremors sources have been located 16 to 304 m away from the occurred effects. The rockbursts took place at depths, covering a wide range from 410 to 840 m. In most cases, in the area of rockburst occurrence, seam edges and other old mining remainders are found at vertical distances from 10 to 110 m.

Also, in several cases, in the rockburst areas, at distances from 0 to 130 m, faults have been encountered. The total length of damaged longwall workings and entries was 3120 m. During the rockbursts the number of casualties among miners amounted to 47, of which 11 were fatal.

For all the analysed rockbursts a correlation of focal mechanism angular parameters with mining and geological conditions existing in the afflicted areas has been derived (Table 2b). A clear interdependence between the focal mechanism and the mining and geological conditions may be observed.

In general, the tremor sources can be divided into two groups. The first group is characterised by dip– slip normal type mechanism, the second group by dip – slip reverse type mechanism.

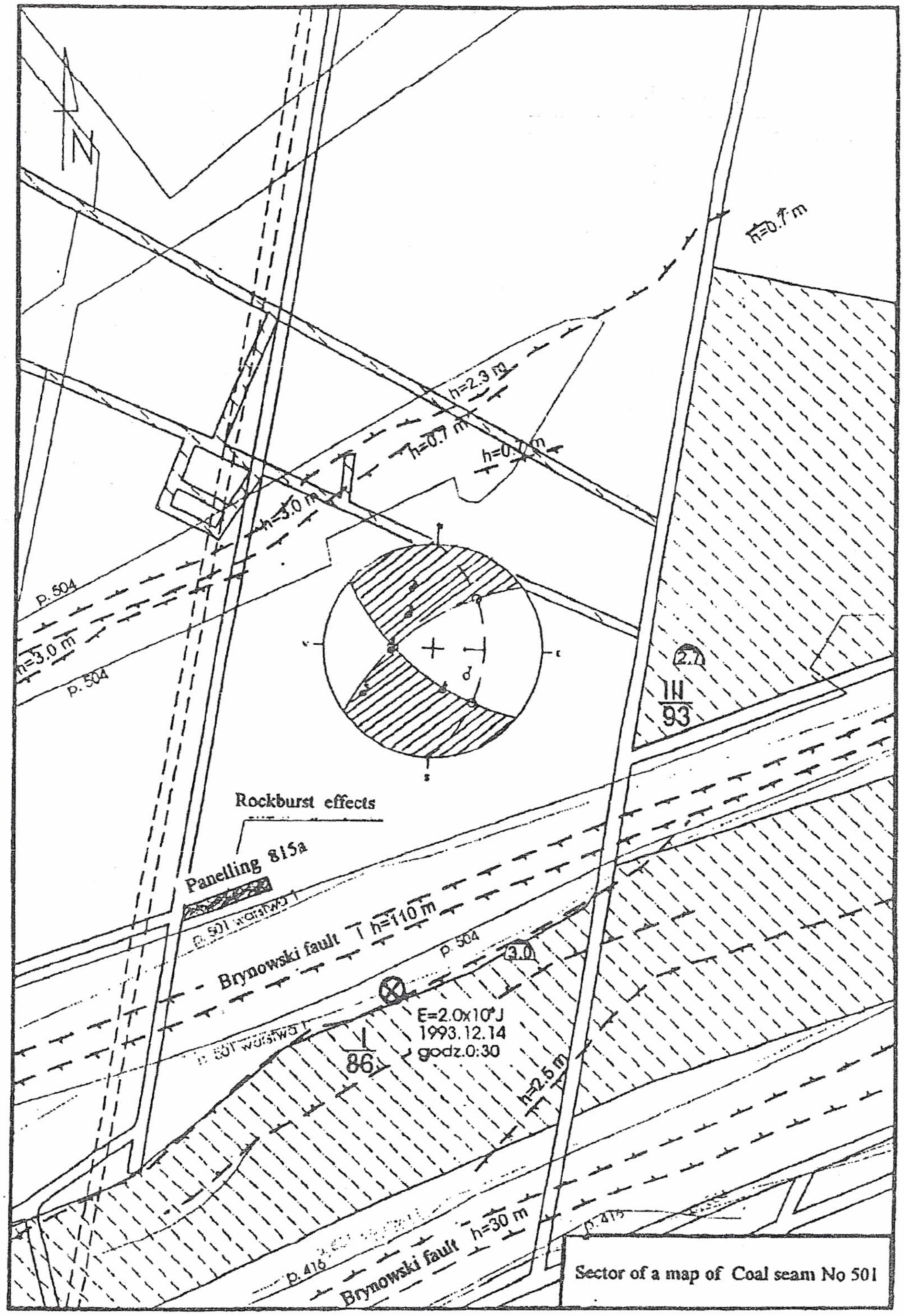

FIG. 1. Kleofas coal mine. The tremor focal mechanism against the background of mining situation.

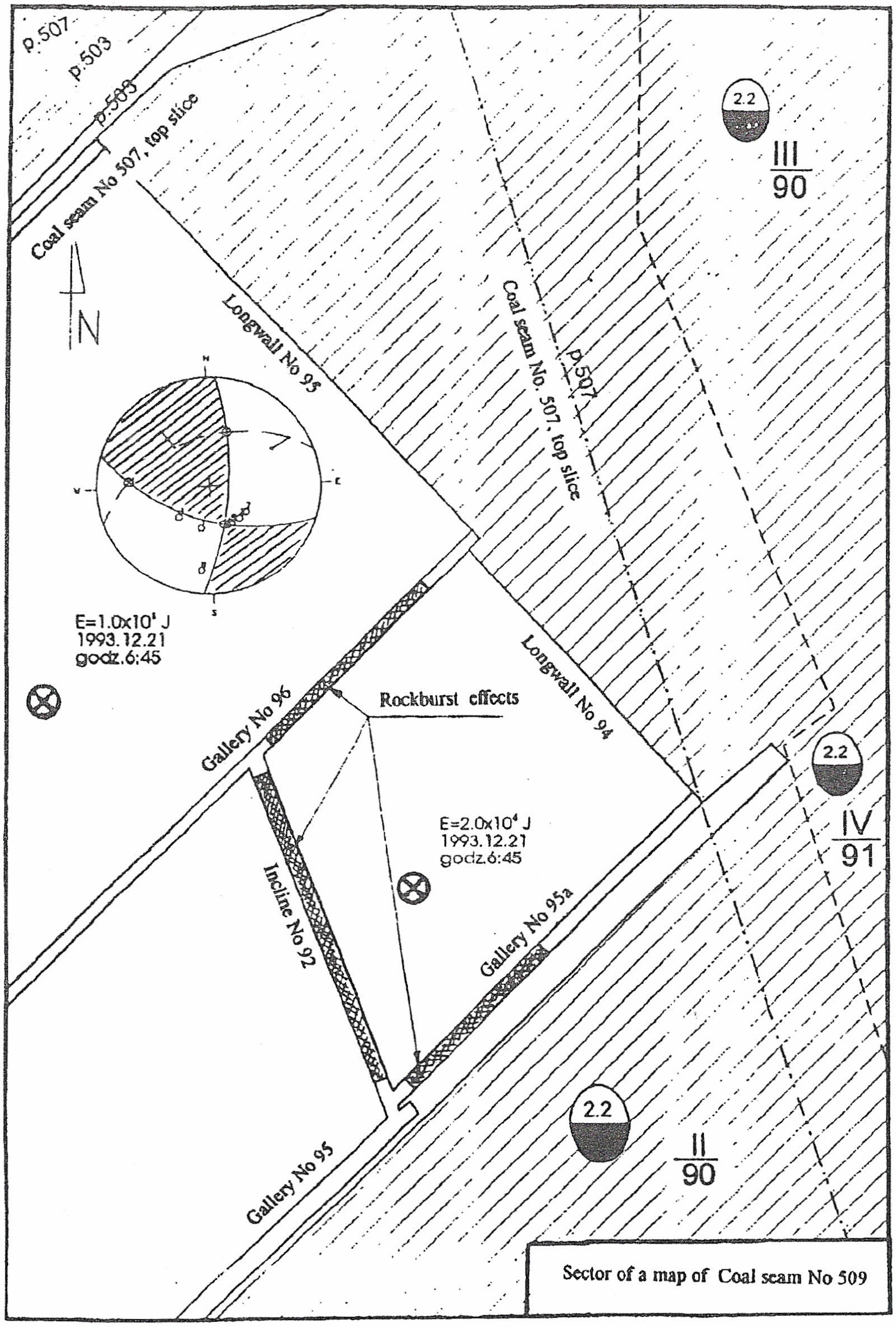

FIG. 2. Miechowice coal mine. The tremor focal mechanism against the background of mining situation.

In both cases a horizontal ground motion in the source may be noted. It is interesting that the dip – slip normal type focal mechanism tremors have occurred in the fault zones. Azimuths of their nodal planes correlate well with the fault strikes (see Fig. 1).

However for the dip – slip reverse type focal mechanism tremors the azimuths of their nodal planes are correlated with the longwall face or the position of entries and the overlying seam edges (see Fig. 2).

Also considering the source location and the focal plane position (following its determination), in most cases, it could be observed that the ground in the source had moved in the direction of the occurred damages.

The next step in the analysis was the determination of tremor source parameters. The results are summarised in Table 2c. The corner frequencies of the analysed tremors ranged from 2.5 to 6.7 Hz, being lower for high energy events than for low energy events. The seismic moment ranged from $6 \cdot 10^{11}$ to $8 \cdot 10^{13}$ Nm and the stress drops from 0.6 to 2.9 MPa. A high energy tremor with the stress drop of 22 MPa that occurred in the Halemba coal mine was an exception. The source radius (Madariaga's model) varied from 60 to 200 m and the displacements from 0.3 to 4 cm. The seismic energy as computed from spectral analysis was higher for all the tremors than the seismic energy calculated by the classic method.

The main purpose of the performed study was to produce a relation between the tremor focal mechanism, source parameters and the mining and geological conditions. Despite the incomplete data base, in the case of source physical parameters (lack of digital records). The obtained data set shows certain regularities .

In general, it has been observed that in the fault zone area the tremors were characterised by dip – slip normal type mechanism. These tremors were energetically stronger and produced comparatively lower stress drops and smaller effects. However, in the case of dip – slip reverse type mechanism, the energetically weaker tremors produced higher stress drops and the larger damage.

4. CONCLUSION

1. In the article a solution that allows expanding seismological output data set is presented. The solution leads to the determination of both the parameters that describe tremor focal mechanism and the physical parameters of seismic sources and then to the correlation of these data with mining and geological conditions.

2. The rocbursts base created for the parameters mentioned at point 1 will gradually be complemented by the grounds for conducting broad analyses to elucidate the physical processes involved in dynamic destruction of rocks surrounding the mine workings. This will allow us to develop more accurate methods for the assessment of rockburst hazard and to use preventive solutions adapted to the character of rockburst hazard in a given area.

3. It has been noted that in the area of fault occurrences the tremors are characterised by the dip – slip normal type focal mechanism. These events are energetically stronger and cause comparatively lower stress drops and smaller effects. However in the case of the dip – slip reverse type focal mechanism the energetically weaker events produce higher stress– drops and the effects of comparatively larger extent.

4. The information obtained from the geomechanical and seismological analyses should be applied, as recommendations, to the design of mining operations that could prevent the occurrence of multi–plane deformations of thick, monolithic and competent roof layers able to general tremors causing disastrous effects in the workings.

References

Aki K., Richards P.G. (1980), *Quantitative Seismology - Theory and Methods*, vol. 1, 2, W.H.Freeman and Co., San Francisco.

Bath M. (1973), *Introduction to Seismology*, John Wiley & Sons, New York – Toronto.

Biliński A. (1992), *Ocena zagrożenia tąpnięciem wyrobiska eksploatacyjnego*, Wyd. GIG, Katowice.

Dubiński J., Stec K. (1995), *Określanie zagrożenia sejsmicznego w oparciu o parametry mechanizmu ognisk wstrząsów górniczych*, Publs. Inst. Geophys. Pol. Acad. Sc. **M–19** (281), 59–71.

Dubiński J., Nowak J., Stec K. (1991), *Zwiększenie informatywności sejsmologii górniczej przez określanie parametrów mechanizmu ognisk wstrząsów*, Mat. III Krajowej Konf. Naukowo – Techn. nt: "Zastosowanie metod geofizycznych w górnictwie kopalin stałych", T.1. Wyd. AGH, pp. 217–238.

Dubiński J., Mutke G., Stec K. (1994), *Focal mechanism of mining tremors in the light of seismological studies carried out in the Upper Silesian Coal Field*, Proc. Int. Conf. "Rocbursts and outburst in the underground mines", ed. ECE/UN, St. Petersburg.

Gibowicz S.J. (1989), *Seismicity in Mines*, Pure and Applied Geophysics **129**, no. 3/4.

Kidybiński A., Dubiński J.(ed.) (1992), *Effect of geomechanics on Mine Design*, A.A.Balken, Rotterdam, Brookfield.

Konopko W. (1984), *Stan i przyczyny zagrożenia tąpaniami w kopalniach węgla kamiennego PRL*, Mat. Konf. nt. Doświadczenia w zakresie prognozowania i zwalczania zagrożenia tąpaniami, Wyd. GIG, Katowice.

Stec K., Dubiński J., Nowak J. (1992), *Correlation between the parameters of mining tremors focal mechanism and the seismic hazard state based on an example of the Wujek Coal Mine*, Acta Montana **A2** (88), 145–160.

Stec K., Mutke G. (1994), *Ocena sejsmiczności GZW na bazie wstrząsów górniczych zarejestrowanych przez Regionalną Sieć Sejsmologiczną GIG*, Dok. Dział. Statut. GIG, Katowice.

Young P. (1993), *Rocbursts and Seismicity in Mines*, Queens University, Kingston, Ontario.

Zuberek W., Mutke G., Żogała B. (1986), *Sejsmiczność Górnośląskiego Zagłębia Węglowego indukowana eksploatacją górniczą*, Mat. Konf. nt: "Problemy ochrony środowiska i zasobów naturalnych w województwie katowickim, PTPNoZ, Odd. Górnośląski, Sosnowiec.