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Zoning of foci of seismic tremors in division G-23, KGHM Polska Miedź SA

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A B S T R A C T

The rock mass disturbed by mining activities in a copper ore mine has a structure consisting of thick layers of predominantly high mechanical parameters. The layers, due to their strength properties and dimensions, have low deformability which influences a vast area in the form of increased stresses. This area is a part of a rock massif where dynamic destruction periodically occurs in particular fragments as the post-mining cavity expands. The size of such an identified fragment of the rock mass depends on the extent of goafs and the distance between them and mining operations as well as inhomogeneities and confinement in the rock massif. The specific structure of the overlying layers, especially their mechanical properties, determine, to a vast extent, the cracks of anthropogenic influence in the rock massif, which result in foci of seismic tremors often recorded far from the areas of conducted mining activities.

A selection of seismic tremors for their spatial location, related to the conducted mining operations and the time of their occurrence, can be useful for forecasting areas which determine seismic hazards in the area of mining operations. The aspect of the analysis of seismic tremors recorded in Division G-23 may indicate the location of the areas of the rock mass which remains in a state of boundary energy balance until another portion of seismic energy is released 'stabilizing' the area containing this rock mass.

The article presents results of the analysis of a set of tremors between 2013 and 2015, induced by mining activities in Division G-23, in order to forecast areas of seismic activity in the rock mass disturbed by mining operations.

1. Introduction

Extensive observations of seismic activity accompanying mining operations show that mining at a depth of over 400 m is associated with dynamic phenomena such as seismic tremors. Their intensity depends on the susceptibility of the rock mass to rockbursts, which means the "ability to accumulate energy in the rock mass or rocks and release it suddenly when its structure is altered or destroyed" (Regulation of the Minister of Internal Affairs and Administration, 2002). This definition refers to the concept of the rock mass structure, including its cohesion and degree of freedom, i.e. the possibility of displacing it. The factors either favour or limit the ability to accumulate and emit elasticity energy in the rock mass, and they per se can determine the occurrence of strong foreseeable and unforeseeable seismic phenomena. The foreseeable ones are phenomena induced by mining operations, which result from the present or forecasted disturbances of the geological structure of the rock mass; thus, its system of physical and mechanical phases; rocks, liquids and gases (Burtan, 2012) and natural hazards (Butra, 2010).

In-depth knowledge of the process of how the disturbance of the system of physical and mechanical phases develops of rocks, liquids and gases, enables mining operations to be conducted in a way that eliminates or limits the possibility of the occurrence of high-energy mining tremors. Unfortunately, as practice shows, despite seemingly good knowledge of the rock mass, and applying a number of technologies limiting hazards, phenomena are observed whose consequences disturb production or render it impossible. First of all, this results from the impossibility of forecasting all the interrelations in the system of physical and mechanical phases of rock mass and the consequences of disturbing their mutual equilibrium, established when a given deposit was formed. Due to the character of the processes, there are areas of unbalanced stresses in the rock mass which are increased even further by anthropogenic

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changes caused by mining operations. Moreover, natural discontinuities in the rock mass lead to its separation, which favours the generation of dynamic phenomena which accompany mining operations. The proper evaluation of the degree of destruction of a rock medium in the direct vicinity of a mine working, or of a change in the degree, as well as evaluation of the share of strong rocks in the area, enables the proper characterization of the rock environment surrounding a mine working and the influence of mining operations on its destruction.

The intensity of continuous and non-continuous strains occurring in the rock mass depends on the distance from cavities that have been and are being mined, as well as on natural geologic disturbances. Any form of mining operations results in areas of unstable stresses. They are usually the source of dynamic phenomena, i.e. the source of wave energy of different levels. It is impossible to pinpoint the exact location of the foci of seismic tremors, due to the geometry of seismometric stations. The basic error made while locating the foci of mining tremors ought to be referred to as the vertical component of a focus, nevertheless there are attempts to select geometry of seismometric stations to create a spatial network to record waves (Lurka & Mutke, 2008). It should be emphasised that the awareness of the accurate foci location of mining tremors increases the credibility of seismic and rockburst hazard assessment.

Stratigraphy, petrography and structure, mechanical properties of layers and mining technology influence the degree and intensity of the rock mass destruction resulting from mining operations. Analysis of the rock mass structure, assessment of its rockburst susceptibility, forecasts of the migration of high stress areas and areas of critical strain in elastic layers, are indispensable when determining the foci mechanisms of seismic tremors. The analysis of high-energy seismic phenomena, which was carried out in order to determine their focus mechanisms and origin, is indispensable when defining mining and geological factors which influence the location and energy of tremors. It ought to be emphasised that tremors of different focus mechanisms determine the intensity and range of destruction of the rock mass structure differently (Stec, 2009).

In the case analysed the disturbed elastic roof layers, or those layers still experiencing disturbance, in a copper basin formed of sandstones, dolomites and anhydrites; are the source of seismic tremors of the highest energy. Considering the facts, it is necessary to develop new solutions aimed at determining the influence of mining operations on the location of areas where wave energy is emitted, enabling the determination of the extent of the areas of the rock mass where dynamic phenomena occur. It ought to be emphasised that these areas change over time, both moving towards the surface and the plane of the mining face, and thus the proposed solution ought to enable the:

- ➢ Determination of the areas dimensions,
- ➢ Determination of the energy periodicity of the emitted seismic energy,
- ➢ Determination of the main directions of the migration of the foci of seismic tremors induced by mining activities,
- ➢ Forecasting of areas which emit seismic energy for a given direction of the mining face.

In the areas of the rock mass where fragments are deformed and displaced, the evaluation of vertical displacements' destruction processes, which determine the volume of tensile forces in the mined layers, is particularly important. It ought to be emphasised that the process of displacements in successively mined rock massif extends, and the seismicity accompanying mining operations is its expression (Machoń, 2013). In the copper basin, the rock mass has very low deformability while maintaining its continuity; this is a result of its disturbance, its thick-layered structure and the high mechanical properties of the layers (Gogolewska & Bartlewska, 2004). The carbonate-shale series which occurs in division G-23, with anhydrite in the roof, due to their mechanical properties, have hard transverse separateness both within dolomite and anhydrite. This separateness, which is formed during extensive mining operations, is accompanied by strong seismic tremors (Dubiński, Lurka, & Mutke, 2013). The number and location of the foci indicate where wave energy is emitted from and how many seismic tremors accompany a high-energy tremor in short time. Usually the total time, when such tremors are recorded, does not exceed several-minutes or several-seconds of rock mass activity (Dubiński, 1997; Gibowicz & Kijko, 1994).

The analysis of the locations of the foci of tremors, which accompany mining operations, enables the determination of the dimensions of closed areas where wave energy was emitted for given sets of tremors recorded in the analysed period (Drzewiecki, 2015). This article presents the results of work initiated a few years before, aimed at developing a method of forecasting an area of seismic activity induced by mining operations in a division of KGHM SA.

2. Materials and methods

2.1. Geological and mining characteristics of a mining area, area PW division G23

In the "Polkowice II" mining area, located within Fore-Sudetic Monocline, a copper-bearing deposits are mined, e.g. in division G-23. The tectonic features of the area are a result of numerous vertical and nearly-vertical secondary NW-SE cracks filled with gypsum and calcite and isolated flatly inclined cracks and slides of approximately 30° inclination. It ought to be emphasised that the deposit in this area is located at a depth of approximately 1150 m and its thickness ranges between 0.6 and 4.5 m. The deposit is mined using a room and pillar system. The transverse dimensions of the pillars depend on the deposit thickness and the mechanical parameters of the mining face. The deposit in division G-23 belongs to the third degree of rockburst hazard, thus the hazard is constantly assessed to prevent rockbursts by using technological and active measures. Table 1 shows the basic data which characterizes the rock medium of division G-23.

2.2. Seismicity accompanying mining operations

Between 8 November 2013 and 11 October 2015, 1015 seismic tremors of energy exceeding 10^3 J were recorded, see Fig. 1. Tremors with seismic energy over 10^5 J (more than 100 tremors in the analysed period) are an indicator of seismic hazard, as for such tremors, energy is accumulated in large volumes of the rock mass. It ought to be noted that the source of tremors of lower seismic energy are usually the same elastic layers which are the source of high-energy tremors. Therefore, the seismic phenomena are also located in the areas of locally weakened rock massif, and each of them is accompanied by local fragment deformations and displacements of the rock mass. This implies the presence of a vast unstable area maintaining 'temporary' stability in the roof of the mining face. A long enough sequence of such tremors, within a period when it is possible to identify their approximate location, shows that there are a number of local anthropogenic discontinuities of different ranges in the rock mass. The process prepares a limited, through the location of tremors, fragment of the rock mass for periodical sudden strain associated with the displacement of a significant fragment of the rock mass/elastic layer. It must be

Table 1
The average values of the mechanical parameters of the mining face as well as roof and floor layers in division G-23 O/ZG (Gogolewska & Bartlewska, 2004).

Lithology	Thickness, m	Compression strength R_c, MPa	Tensile strength R_r, MPa	Elastic modulus E_s, GPa	Poisson's ratio
Dolomite, cracked, hard	20.3	125	6.9	52.6	0.240
Dolomite, very hard	6.0	151.6	9.5	63.5	0.246
Fine-crystalline streaky dolomite	0.7	106.3	5.9	32.9	0.22
Dolomitic clayey shale, hard	2.50	63.0	5.8	23.2	0.189
Quartz sandstone, very hard	2.6	103.7	3.9	33.3	0.206
Quartz sandstone, hard	4.6	52.3	2.9	18.3	0.180
Quartz sandstone, low strength, brittle	3.8	23.0	1.4	3.7	0.131
Quartz sandstone, low strength, brittle	2.0	18.5	0.7	6.2	0.120

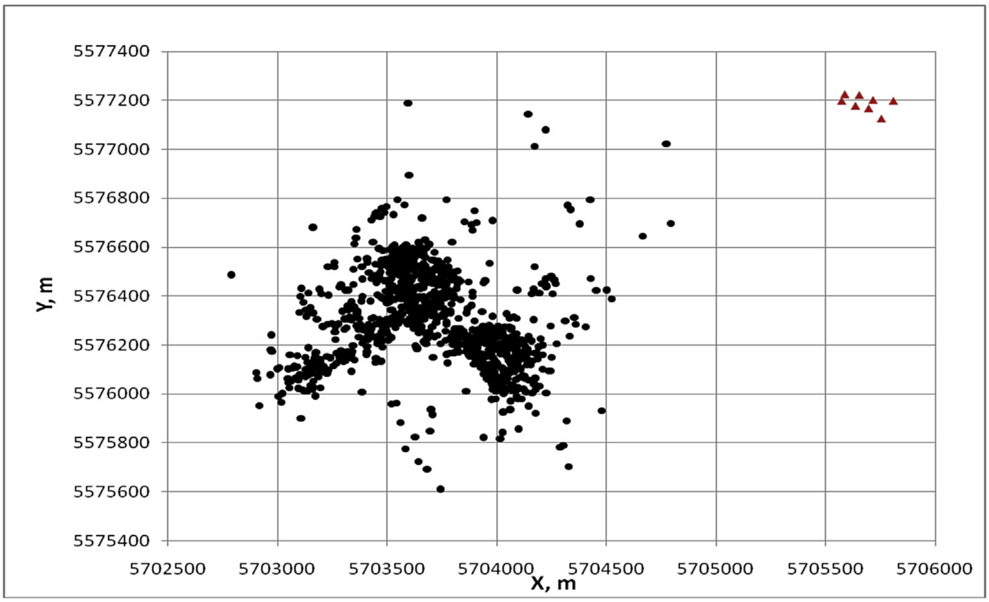

Fig. 1. Location of the foci of tremors recorded in area PW, 8 November 2013–11 October 2015.

emphasised that this is a dynamic process which periodically generates high-energy seismic phenomena.

Analysis of the location of high-energy tremor foci, recorded throughout the analysed period, identified twelve tremors whose timing and focus coordinates suggest that they should not be linked with current mining operations – Table 2. They indicate occasional dynamic destruction of the rock mass in an area which is not associated with the current mining operations in division G-23. Energy accumulation over a longer period of time, in the remote exploitation areas, occurs independently on its accumulation and dissipation in the areas of direct influence of mining operations.

Table 2
Tremors unrelated to current mining operations in division G-23.

Date	Hour	Min	Sec	Energy	X	Y	Z
30/11/2013[a]	2	39	45	5.9E+05	[a]	[a]	−748
31/12/2013[a]	10	15	19	8.2E+05	[a]	[a]	−747
6/01/2014[a]	3	14	33	9.9E+05	[a]	[a]	−762
20/01/2014[a]	20	23	29	8.2E+5	[a]	[a]	−778
25/02/2014	9	16	13	4.5E+5	5705636	5577178	−734
2/03/2014	0	16	24	2.5E+5	5705754	5577125	−748
18/03/2014	7	47	55	2.1E+6	5705809	5577198	−749
23/04/2014	7	24	56	8.9E+5	5705653	5577222	−735
18/06/2014	19	56	36	2.2E+05	5705696	5577167	−758
23/09/2014	18	10	29	3.1E+5	5705587	5577225	−731
14/10/2014	2	30	47	2.6E+6	5705573	5577198	−744
9/11/2014	6	21	12	1.3E+5	5705716	5577202	−764

[a] No X and Y coordinates due to measuring equipment overload.

Taking these facts into consideration, further analysis focused on a set of tremors excluding the unrelated ones shown in Table 2. In Fig. 1, locations of the foci of the aforementioned tremors are marked with red marks.

In the Legnica-Głogów Copper Basin (LGOM), deposits are mined by applying the room and pillar system with mined roof bending. Whilst using this mining system, disturbing overlying layers means that the primary stresses in the rocks over the cavity being mined are also disturbed (over goafs). In LGOM's mining division, mining operations disturb thick rigid layers of dolomite and anhydrite of low deformability, which influences a vast area in the roof while maintaining continuity. For such areas, analysis of displacement and strain processes ought to consider areas which vastly exceed the area of the mining operations (Drzewiecki, 2013).

In the areas of mining operations, both at the mining face and in the area of mined pillars, rock mass undergoes multidirectional strains. Predominant strains follow the direction of the vertical component of gravitational forces, yet, due to the thickness, elasticity and shape of goafs it is also possible to determine the predominant direction of horizontal roof strains. The results of the two strains, both ahead of and behind the mining front and over goafs (i.e. in the areas where there is a change in the strain direction), determines the area where periodical dynamic destruction of the roof layer/s may occur. Primary (sedimentation) separateness of overlying dolomite and anhydrite and their transverse separateness in fault areas determine the location of mining-induced laminations of the rock mass in areas where critical tensile stresses are exceeded. The easier it is to separate the rock mass, the higher the deformability of the laminated layers.

As previously mentioned, due to the mechanical properties of the roof layers, the area of the rock mass where the influence of mining operations is observed can be much larger than the area of actual mining activities. It may then be concluded that seismic phenomena induced by mining operations can be located quite far away from the place where the mining operations are conducted.

The initiating of a deterministic mechanism of generating dynamic phenomena by mining operations, indicates the possibility of forecasting the places of tremors that accompany mining operations. The extent of the areas of seismic activity between 8 November 2013 and 11 October 2014, with 1012 tremors of seismic energy over 10^3 J, makes it impossible to determine forecasting dependences through analysing the location of the tremors foci or energy. An attempt to create such forecasts made for seismic phenomena of between 8 November 2013 and 9 November 2014 (Drzewiecki, 2015), and for the seismic phenomena recorded in the following year, showed unacceptable inaccuracy in the determining time boundaries of recorded seismic tremors. Taking all the above into consideration, for the extended set of seismic tremors, a mechanism for predicting them, based on a model of seeking a tremor equivalent to a set of considered tremors, was applied. It enabled the application of the analysis to real life conditions of disturbed rock mass where each tremor is associated with the relaxation of stresses in the surroundings of a focus and, at the same time, with the concentration of stresses in its surroundings, i.e. in an area maintaining its continuity.

For such analysis of a set of seismic tremors the value of tremor energy equivalent whose location would show their separateness and periodicity is sought. The aforementioned aims were realized by building a model of a body of mass equal to the seismic energy of tremors balanced by mass whose centre of gravity (seismic energy of a tremor) counterbalances it.

3. Results and discussion

3.1. Equivalent body built of mass that corresponds with the seismic energy of tremors

The seismic energy which results from destroying a fragment of the rock mass, is a function of the mechanical strength of the destroyed medium and the extent of destruction to the original structure of the rock mass which corresponds to the dimensions of the focus. Initiating such a mechanism of dynamic phenomena, induced by mining operations, leads to the local relaxation of the rock mass in the surroundings of the foci of seismic tremors, causing an accompanying increase in stresses/energy in other areas. Thus, we may assume that the rock mass, where mining operations are being conducted, is in a state of unstable energy equilibrium, provided by a strictly spatially defined mass equivalent to the mass of the total seismic energy of tremors recorded during a given period of mining operations. Hence it is possible to find its mass point energy model where the mass equals the energy accumulated at various points (Dubiński & Drzewiecki, 2013).

The model of its destruction will also be a mass point model, where its mass, which corresponds to the whole analysed area of the rock mass, is built of masses from the points of seismic energy emitted from the foci of seismic tremors. Considering this assumption, it is possible to build a point body of mass equal to the seismic energy of tremors recorded in any given period of time and determine the resultant mass and its spatial location for masses defined in such a way. In any case, as a result an imbalanced body will be received, for which it is possible to determine the location of the point and its mass/seismic energy providing equilibrium of a body defined in such a way. In other words, what we seek is the mass centre of a point body, where the resultant mass is applied to provide equilibrium to the body.

For a body which can be presented in the form of a closed set of point masses (the foci of seismic tremors with defined spatial coordinates), the centre of mass is located in the point where the resultant mass affecting the body is applied. With catalogues of recorded seismic tremors containing recorded spatial coordinates of the foci of tremors, their seismic energy, time and location, it is possible to directly calculate the coordinates of the centre of mass of such a body. Coordinates with a focus determine vector $\vec{r}_k$ representing its location in the coordinate system, while seismic energy k of tremors corresponds to k elements of masses $m_k \cdot k = 1, 2, 3...$ For any period of time or area, it is possible to determine the coordinates of the centre of such a mass and its volume, which in the proposed model equals the total seismic energy of the tremors in the analysed set.

$$\vec{r}_0 = \frac{\sum_k m_k \cdot r_k}{\sum_k m_k} \tag{1}$$

For each set of seismic tremors, i.e. any period of time of seismic activity accompanying mining operations, it is possible to find their energy equivalent which makes their total seismic energy equal to zero.

Mining operations conducted in the copper ore deposit disturb the original distribution of mass within a limited volume/section of the rock mass. Its stability, despite mass loss, is provided by static friction forces whose value depends on the primary cohesion forces of the layers, their physical and mechanical properties, and the quality of the contact surfaces. The proposed mass point model of the rock mass, in the form of a two dimensional figure, consists of point masses of defined coordinates of the centres x and y, whose weights represent their seismic energies. In vector form it is possible to determine, for each finite set of weights of seismic tremors, their coordinates and find the resultant vector of the weights of seismic energy, later on referred to as the equivalent of seismic energy R_{es}, of all the seismic tremors in the analysed set. For the set of tremors in are G-23, the temporary equivalent of seismic energy, i.e. a total of energy of consecutive tremors, will also change its location as another recorded tremor is added to the set of tremors. Fig. 2 presents the location of the equivalents of seismic energy for an increasing, chronological number of tremors. It resulted in the distinct zoning of the equivalents of seismic energy R_{es}. Moreover, the change in their location over time is oriented in a plane.

As previously mentioned, from an energy point of view, it is equal to the total amount of energy of the seismic tremors of the analysed set and provides equilibrium with the weights of the recorded seismic tremors. It has to be emphasised that the equivalent corresponds only to temporary mining operations, i.e. it is determined for a closed set of seismic tremors. Each further seismic tremor resulting from the dynamic destruction of a fragment of rock medium, by entering their set the coordinates change (x_s, y_s, z_s, ΣE_s) by the equivalent of seismic energy R_{es}.

Based on the proposed mass point model of the rock mass, through determining the coordinates of the equivalent seismic energy R_{es}, the places where, for the given set of seismic tremors, coordinates of further seismic tremors were predicted were determined. In the proposed solution, the essential problem is defining the period of time the coordinates of the equivalent of seismic energy R_{es} ought to be calculated for, which means determining the area of seismic activity remaining in temporary equilibrium. The analysed set of tremors must contain tremors from coordinates which clearly indicate that their locations can be linked

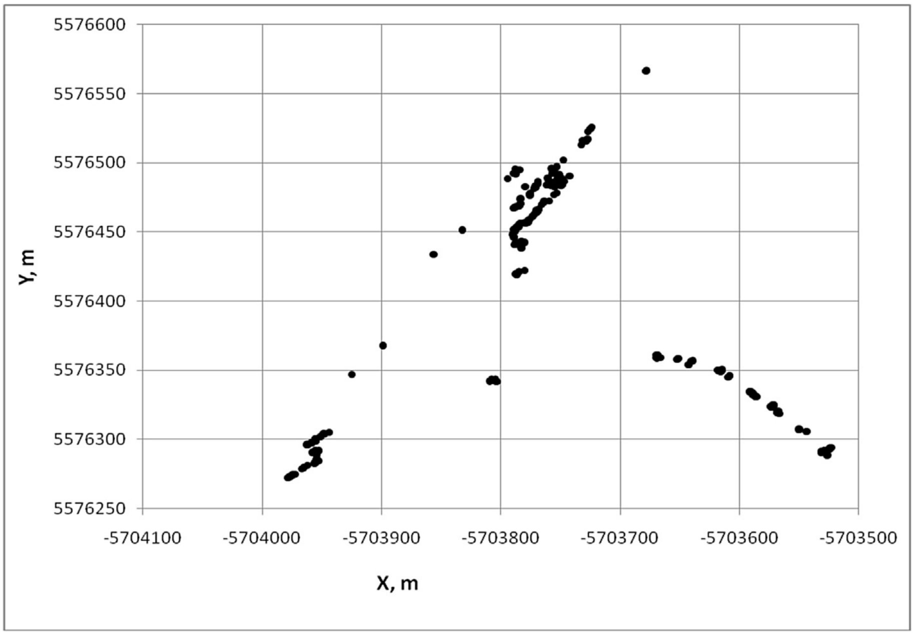

Fig. 2. Location of the equivalents of the energy of tremors recorded in area PW, 8 November 2013–11 October 2015.

with local mining operations. To much distant in time seismic tremors, in relation to the analysed period of mining operations, will mean that the coordinates of the equivalent seismic energy R_{es}, are totally unrelated to the current mining operations. It has to be emphasised that its location will always be determined by tremors of the highest energy, whose foci will indicate the extent of the area of instability in the rock mass.

3.2. Defining sets of seismic tremors recorded between 8 November 2013 and 11 October 2015 in division G-23

Considering the scope of mining operations in the analysed area, the basis for calculating the coordinates of the equivalent of seismic energy R_{es} was the defining of sets of seismic tremors with similar focus coordinates. Analysis of the tremors shows that four sets of tremors which occurred during periods of mining operations in division G-23 are such sets, see Table 3. What distinguishes them is the location of their foci, indicating that the destruction areas in the rock mass, which result from the location of mining operations, are separate.

By applying dependence 1, the coordinates of *the equivalents of seismic energy* R_{es}, for the sets of tremors which are presented in the map of division G-23, were calculated. The map shows the directions of the displacements of the equivalents of seismic energy $\boldsymbol{R_{es}}$, for the four periods of mining operations.

Analysing the time sequence and location of further equivalents of seismic energy R_{es}, within the four sets, it is visible that their directions are not random. The directions of migration of the equivalents of seismic energy R_{es}, presented in Fig. 3, illustrate, in a

Table 3
Seismic tremors recorded in area PW from 8 November 2013 to 11 October 2015 divided according to the time of their appearing and location.

Period	Tremor no.
I – 8 Nov 2013–10 May 2014	1–326
II – 11 May 2014–4 Nov 2014	327–417
III – 5 Nov 2014–13 Dec 2014	418–467
IV – 14 Dec 2014–11 Oct 2015	468–1015

simplified form, the influence of the location of mining operations on the location of tremors and the zoning of foci of seismic tremors in KGHM SA's division G-23. Similar orientation of the lines of the mining front in the identified periods of time indicate the locations of mining faces. Whereas the extent of disturbance in the roof layers will determine the intensity of the strain in the layers and the energy of dynamic phenomena which accompany their cracking. It has to be emphasised that determination of the direction of the migration of the equivalents of seismic energy R_{es}, within the distinguished sets of tremors, can be useful when planning the sequence of mining the pillars. That would create the possibility of controlling the areas of concentration of mining stresses as a means of seismic and rockburst hazard prevention.

Each seismic tremor changes the location of the equivalent of seismic energy R_{es}, calculated on the basis of the set of tremors which preceded it. Changes in the location in the division map indicate where energy resulting from the roof strain is accumulated, i.e. changes of the location of the areas of the rock mass in the roof of the mining face where it is advisable to consider processes that destabilize it. The extent of the areas where elastic strain is followed by destruction processes, is affected by the volume of the strains in the roof layers. Local relaxation of the rock mass, which occurs in the vicinity of the foci of seismic tremors, also causes a local increase in stresses in other areas, which is reflected by the location of the equivalent of seismic energy R_{es}. Mining operations disturb the rock mass and its stability, maintained by primary cohesion forces and internal friction forces. The rock mass which was originally monolithic, in the course of mining operations, locally becomes a cracked structure. Areas where it is destroyed were originally in a state of equilibrium, despite a difference in strain. When the mechanical strength of its fragments is exceeded, it is always accompanied by a seismic effect. The location of foci can help to forecast areas of energy concentration.

For the defined periods of mining operations influencing the rock mass, it can be presented in the form of areas of energy accumulation migrating in directions which are not random. Thus, it is possible to analyse a change in location of such areas as a result of changes in the seismically active areas. By considering seismicity

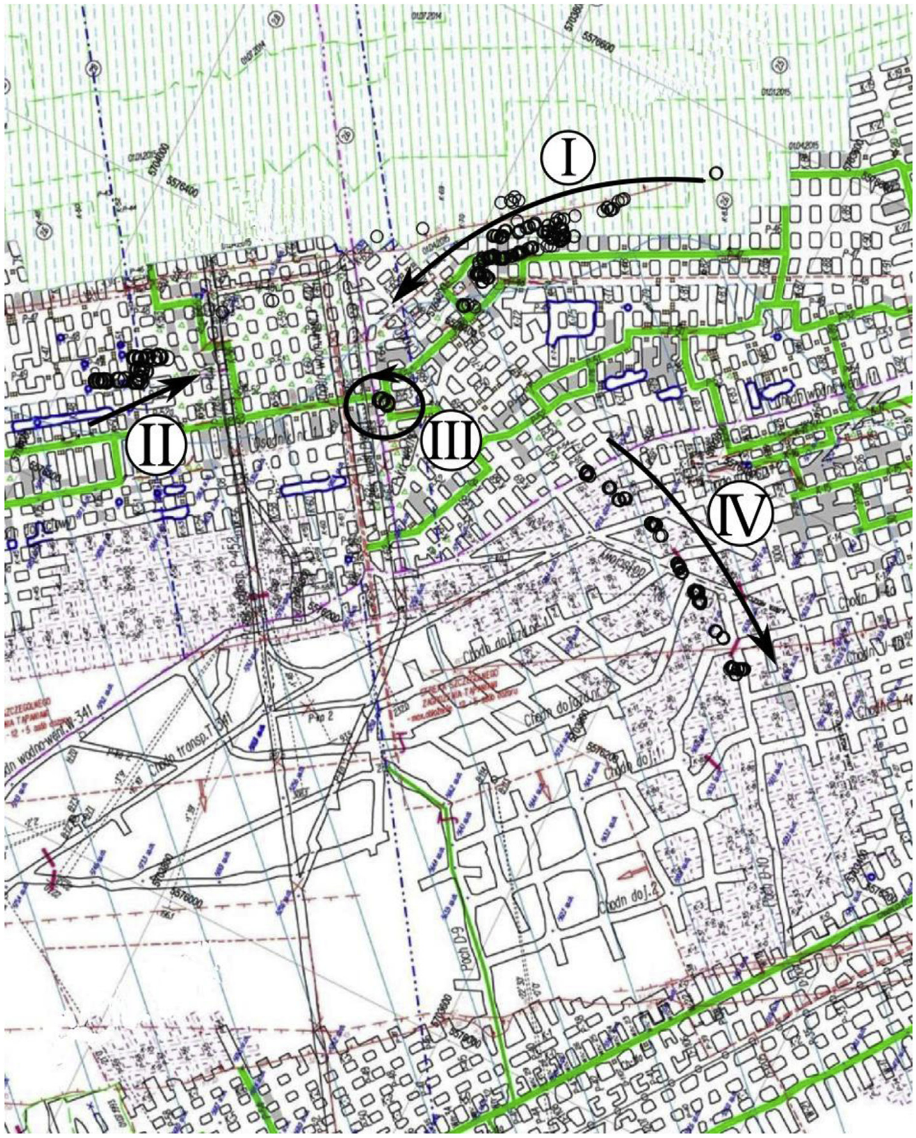

Fig. 3. Map of division G-23, 5 May 2015 – directions of displacement of the equivalent of seismic energy $\boldsymbol{R_{es}}$, for given periods of mining operations.

induced by mining operations, it is possible to distinguish sets of tremors referring to a closed area of mining operations, e.g. a mining area division or for a given period of recorded tremors, which reflects the temporary extent of mining operations. Following the presented method, analysis led to defining finite sets of seismic tremors induced by mining operations in a deposit for which it is possible to forecast the zones of foci of seismic tremors, i.e. areas of seismic activity which accompany mining operations. Such analysis, carried out for 24 months during which time mining operations were conducted in one area, indicate a deterministic nature of the 1015 recorded seismic tremors. Hence they may be helpful in forecasting areas of seismic hazard.

4. Conclusions

In the rock mass where mining operations are conducted, there are areas of heightened energy, in comparison with gravitational energy, resulting from the extent and intensity of mining-induced disturbance of the overburden. Areas where the volume and intensity of the accumulated energy change together with the mining situation are usually a source of wave energy resulting from the dynamic destruction of a fragment of the overburden. In a long term perspective, mining operations lead to the local instability of fragments of the rock mass, while their location changes together with the change in location of the influence of the operations.

Rock mass with predominant layers of very strong dolomite and anhydrite, has low deformability and high energy capacity. In such conditions, energy is released as mining operations advance, i.e. as the areas where the gradient of stresses is close to their ultimate mechanical strength migrate. The determination of the location of such areas, requires the defining of a deterministic mechanism for locating the foci of tremors, based on recording their locations independently of their energy. The proposed solution for determining the direction of their strains assumes that in the rock mass where mining operations are conducted, at any moment, the balance of seismic energy equals zero. This assumption leads to the seeking of coordinates of the vector form of the equivalent of seismic energy R_{es}, i.e. the coordinates of the initial point of the equivalent resultant vector of vectors of weights of the seismic energy of tremors recorded for a closed set of tremors. The following changes in its location in the area map, indicate where the energy resulting from roof strain accumulates, i.e. how the location of the area of rock mass in the roof of the mining face, where dynamic phenomena is expected, change.

Bearing in mind the seismic hazard and rockburst hazard associated with it, defining the location of such unstable areas which migrate together with mining operations, will directly affect the safety of mining operations. The presented attempt to define such areas through the determination of the equivalents of seismic energy R_{es} based on a 24-month mining operations in one area, shows that it may be possible to predict their mobility. This results from the fact that for the given extent of mining operations, within time and space boundaries, it is possible to identify the fragment of the rock mass that remains in temporary equilibrium.

Based on the proposed methodology of determining such areas, it is possible to forecast the location of places where energy is accumulated, which are the source of seismic phenomena. It may also be useful when designing the sequence of mining of the pillars, as it would be possible to control the areas where mining stresses concentrate and use it as a form of seismic hazard and rockburst hazard prevention.

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