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Statistical analysis of the relation between locations of high energy epicenter tremors and lineaments in areas of the Upper Silesian Basin

Key words

High mining-included seismicity, lineaments

Abstract

This paper presents results of the statistical analysis of the high energy seismicity relation to lineaments in the areas of the Upper Silesian Basin. Four parameters are chosen, i.e.: lineament azimuth, fault azimuth, tremors vector azimuth (TVAA) (the vector initial point was the epicenter of strong tremors with energy greater than $E \geq 10^8$ J, and the terminal point was the epicenter of strong tremors with energy greater than $E \geq 5.5 \cdot 10^5$ J but less than 10^8 J), tremors vector azimuth (TVAB) (the vector initial point was the epicenter of strong tremors with energy greater than $E \geq 5.5 \cdot 10^5$ J but less than 10^8 J, and the terminal point was the epicenter of strong tremors with energy greater than $E \geq 10^8$ J). Calculations are made on the basis of a set of 31 high energy tremors with energy of $E \geq 10^8$ J within the area of the Upper Silesian Basin. The catalogue of tremors includes the position of the epicenters and their energy. The research reveals a significant relation of the lineament azimuth to the azimuth of tremor vectors after a high energy tremor (TVAA). This relation may prove the theory of the dip-slip tremor mechanism. The fault plane of such a strong tremor may be revealed in the form of a lineament.

Introduction

The distribution of seismic tremors dependents on their energy. In the Upper Silesian Basin (USB) conditions reveals its bimodal character (Kijko 1982; Kijko and Drzęźla 1986; Dubiński and Stec 2000). This may be divided into "mining events" (low energy tremors) and

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"regional events" (high energy tremors). Bimodal distribution results from different physical and mechanical processes at the tremor source. The first type of tremors is the result of mining, and they are located close to workings. The second type of seismicity is the result of the strike-slip focal mechanism. In USB conditions, research reveals the coincidence of mining and tectonic factors. Based on empiric observations, H. Marcak (1985) noticed that high energy tremors are linearly arranged whereas so-called "mining events" form a "cluster" moving along the direction of mining. At the moment, seismic hazard by "mining events" can be performed with sufficient reliability on the basis of geomechanical and geophysical solutions. Whereas preventative measures are more and more effective with respect to "mining events", high energy "regional events" are still a substantial problem with reference to current mining, and they often provoke rock bursts.

Figure 1 presents the amount of high energy tremor distribution in the Upper Silesian Basin from 1980 to 2006. The total amount of tremors with energy higher than 10^5 J reveals a lowering trend up to the year 1988, and then an increasing trend is seen. The percentage of high energy tremors with energy greater than 10^8 J decreases up to 2004 and then increases. It follows then that despite the decreasing amount of high energy tremors with energy greater than 10^8 J, they still pose a high risk for safe coal exploitation in mines.

This paper presents one of the possibilities of using the content of satellite images for the purpose of developing knowledge on regional tremors. The relation of the epicenter location of strong mining tremors to lineaments interpreted from satellite images in several regions of the USB in the context of tectonics was analyzed by Pilecka and Pilecki (2006). In next part, it is shown that lineament directions can be changed after strong seismic tremors (Pilecka and Pilecki 2007).

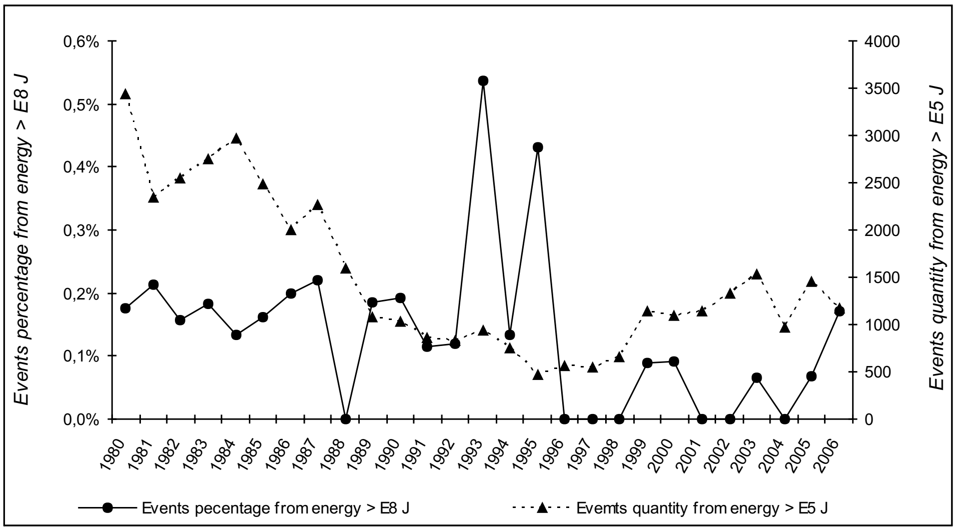

Fig. 1. Amount of high energy tremor distribution in the USB from 1980 to 2006

Rys. 1. Rozkład wysokoenergetycznych wstrząsów w GZW od 1980 do 2006 r.

1. Lineament as a representation of the fracturing zone in rock mass

One of the elements interpreted from satellite images are characteristic lines called lineaments. Lineaments are derived from different types of satellite images in both visual infrared and radar range and may be analyzed with reference to geological and tectonic data. Literature has many examples describing lineaments as a representation of seismically active fault zones. The compatibility of lineaments with tectonic structures has been proven by Allen (1975) and Campbell (1976). Liu and Haselwimmer (2006) describe the appearance of a new lineament as a representation of the appearance of a cracking zone following a strong tectonic tremor which took place on 14.11.2001, 60 km from the Kunlun fault (China). A similar example (Sharifika et al., 2006) is given with reference to lineaments observed in satellite images before and after a tectonic tremor in Iran on 28.05.2004. After the tremor, a new lineament was observed and was connected with the direction of the cracking zone in the rock mass. Singh and Singh (2005) described changes of lineament directions observed before and after a strong tremor on 26.01.2001 in the region of Bhuj in India. The lineament direction was in very good correlation to the direction estimated from the tremor focal mechanism. It also showed compatibility with the regional stress direction in this region.

Research of position epicenter tremors in relation to lineaments was carried out by Graniczny (1991) in the region of Belchatow and by Pilecka et al. (2006) in the USB region.

Research of seismicity in USB mines has shown that in most of cases of high energy tremors, a normal dip-slip mechanism with a noticeable horizontal focal movement may be observed. Azimuths and their dips correlate with the fault strikes and dips. These relations allow us to conclude the possible influence of tectonics on seismicity (Zuberek et al. 1996; Mutke and Stec 1997; Dubinski and Stec 2000). High energy tremors induced by a deformation process in the rock mass have, in general, a slip character in the weakening zone between rock blocks. If the direction of this deformation is parallel with the strikes of big faults, one can expect the occurrence of high energy tremors.

In conditions of high mining-induced seismicity, lineaments can represent the dynamic movements between rock blocks or the “activation” of faults. Figure 2 shows a model of lineament creation on a surface induced by mining.

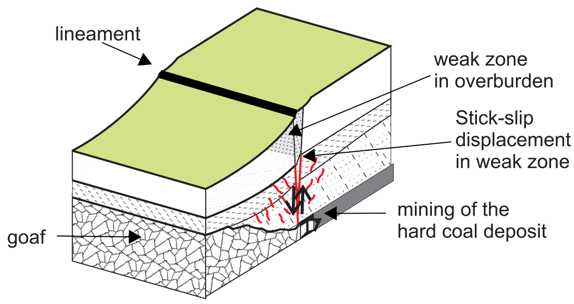

Fig. 2. Lineament which appears as a result of mining (Pilecka et al. 2006)

Rys. 2. Lineament powstały w wyniku eksploatacji górniczej (Pilecka i in. 2006)

2. Statistical analysis of lineaments in relation to induced seismicity

To determine the relation between positions of high energy epicenter tremors and lineaments, a statistical analysis was performed. The relation between the analyzed features is expressed as an absolute value of the correlation ratio. The first investigative step was analysis of the distribution of variables used for calculations. The analysis was carried out on the basis of a catalogue set of 31 tremors with energy greater then 10^8 J which appeared in the USB between 1980–2006. Research was based on information related to lineament position available in the work of Pilecka et al. (2006), and such information about the fault position was taken from the geologic-structural map of productive carbon (Bula and Kotas 1944). For the purpose of this analysis, four parameters, shown also in Figure 3, were taken into account.

Typical statistical analyses – investigation of random variable distribution, correlation analysis and testing of statistical hypotheses – were applied. Statistica and Excel software was used for the purposes of these analyses.

The analysis started with a graphic presentation of each parameter's size distribution (Fig. 4–7). Each histogram was then completed with the most fitting normal distribution

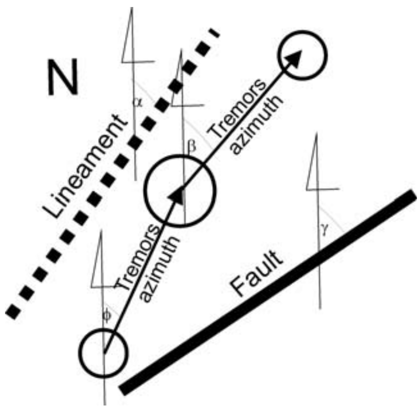

Fig. 3. Parameters applied to statistical analysis of lineament dependence on high energy seismicity
α – azimuth of the nearest lineament; β – tremor vector azimuth (TVAA), the vector initial point was the epicenter of strong tremors with energy greater than $E \geq 10^8$ J, and the terminal point was the epicenter strong tremors with energy greater than $E \geq 5.5 \cdot 10^5$ J but less than 10^8 J; γ – azimuth of the nearest fault; ϕ – tremor vector azimuth (TVAB), the vector initial point was the epicenter of strong tremors with energy greater than $E \geq 5.5 \cdot 10^5$ J but less then 10^8 J, and the terminal point was the epicenter of strong tremors with energy greater than $E \geq 10^8$ J

Rys. 3. Parametry wykorzystywane w statystycznej analizie związku między wysokoenergetyczną sejsmicznością a lineamentami
α – azymut najbliższego lineamentu; β – azymut wektora wstrząsu (TVAA), wektor którego początkiem było epicentrum silnego wstrząsu o energii $\geq 10^8$ J, a końcem było epicentrum silnego wstrząsu o energii $\geq 10^5$ J ale mniejszej niż 10^8 J; γ – azymut najbliższego uskoku;
ϕ – azymut wektora wstrząsu (TVAB), wektor którego początkiem było epicentrum silnego wstrząsu o energii $\geq 10^5$ J, ale mniejszej niż 10^8 J, a końcem było epicentrum silnego wstrząsu o energii $\geq 10^8$ J

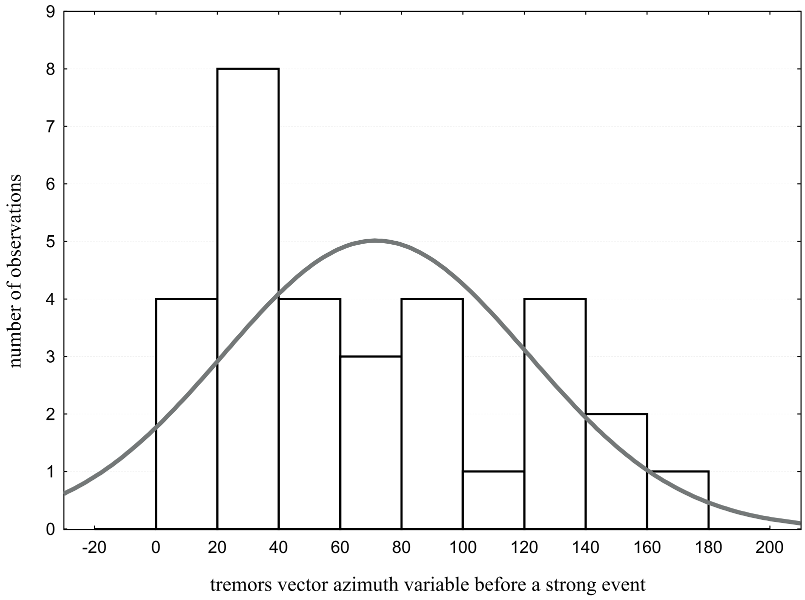

Fig. 4. Histogram of the tremor vector azimuth variable tremor (TVAB)
(for the Upper Silesian Basin – USB)

Rys. 4. Histogram zmiennej – azymut wektora wstrząsu (TVAB)
(dla Górnośląskiego Zagłębia Węglowego – GZW)

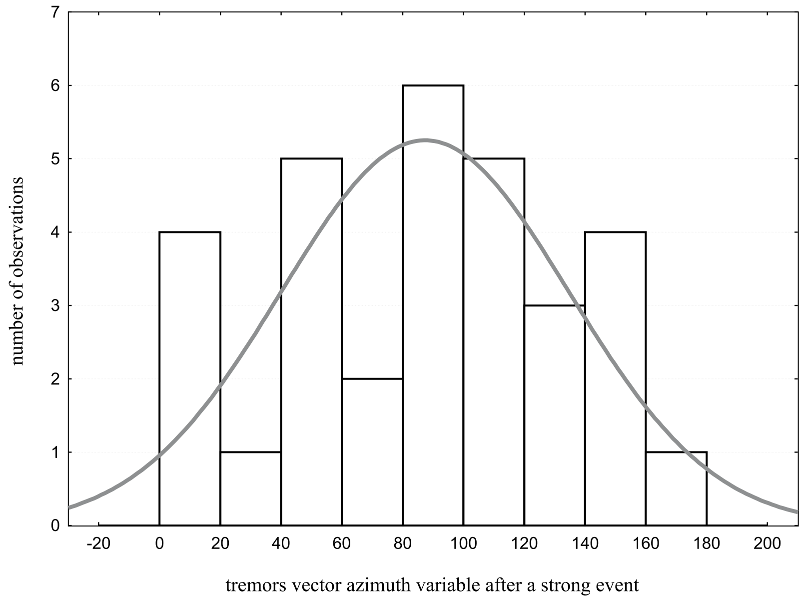

Fig. 5. Histogram of the tremor vector azimuth variable tremor (TVAA)
(for the Upper Silesian Basin – USB)

Rys. 5. Histogram zmiennej – azymut wektora wstrząsu (TVAA)
(dla Górnośląskiego Zagłębia Węglowego – GZW)

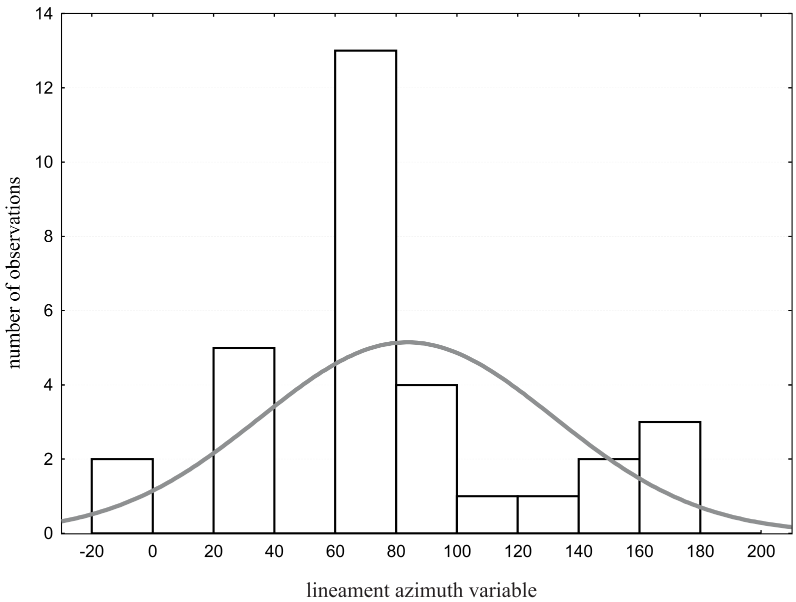

Fig. 6. Histogram of the lineament azimuth variable (for the Upper Silesian Basin – USB)

Rys. 6. Histogram zmiennej – azymut lineamentu
(dla Górnośląskiego Zagłębia Węglowego – GZW)

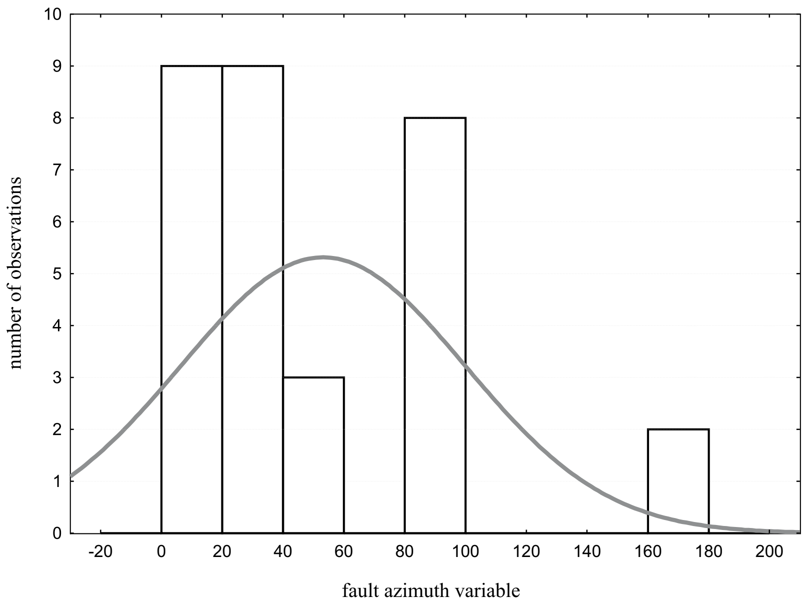

Fig. 7. Histogram of the fault azimuth variable (for the Upper Silesian Basin – USB)

Rys. 7. Histogram zmiennej – azymut uskoku
(dla Górnośląskiego Zagłębia Węglowego – GZW)

curve. Unfortunately, visual estimation showed that the estimated parameters are not of normal distribution. For the purpose of more accurate results, a Shapiro-Wilk W-test was applied to investigate the normality of distribution.

The analysis carried out for the region of the USB (Fig. 4–7) showed that only the tremor vector azimuth variable (TVAA) after a strong tremor, according to the Shapiro-Wilk W-test, has normal distribution. This means that the distribution of this variable is 95% compatible with normal distribution. Distribution of other variables cannot be recognized in terms of the Shapiro-Wilk W-test as normal. This conforms to the rock mass properties. Faults, as well as lineaments, show directionality within the given area. There are privileged azimuths of these variables; therefore, the variable distribution does not reveal compatibility with normal distribution. A variable which does not reveal compatibility with normal distribution is the tremor vector azimuth before a strong tremor.

The analysis of the distribution of the selected variables allowed us to conclude that the correlation of these variables can not be analyzed with the help of the frequently used Pearson correlation factor. In this case, the Spearman correlation ratio was finally calculated. (Tab. 1).

After completion of the correlation analysis, it turned out that the **R = 0.605491** factor gained a significant level for the relation of the lineament azimuth to the tremor azimuth vector **after a** high energy tremor (TVAA). In other words, the variation of the vector direction after a high energy tremor is related to the lineament direction. It is possible to check what percentage of one variable variation is related to the variation of the other variable. If R = 0.605491, the direction of the tremor vector after a strong tremor is 37% related to the variation of the closest lineament. This means that the tremor vector is also

TABLE 1

Correlation ratio of variables

TABELA 1

Współczynnik korelacji zmiennych

Spearman R correlation Pronounced correlation significance level p < 0,05				
Variable	tremor vector azimuth before a strong tremor (TVAB)	tremor vector azimuth after a strong tremor (TVAA)	azimuth of the closest lineament	azimuth of the closest fault
Tremor vector azimuth before a strong tremor (TVAB)	1.000	0.115	–0.086	0.213
Tremor vector azimuth after a strong tremor (TVAA)	0.115	1.000	0.605	0.172
Azimuth of the closest lineament	–0.086	0.605	1.000	0.242
Azimuth of the closest fault	0.213	0.172	0.242	1.000

influenced by elements other than lineament direction. **With 95% probability, a tremor following a strong tremor is strongly (R = 0.6) related to the lineament.**

Summary

The analysis proves that there is a statistical relation of lineaments interpreted from satellite images to positions of high energy epicenter tremors induced. The character of this relation is based on the compatibility of the lineament location and direction to the tremor vector azimuth (TVAA) and (TVAB). Research revealed a significant relation of lineament azimuth to the tremor vector azimuth **after** a high energy tremor (TVAA). This relation may prove the theory of the tremor dip-slip mechanism. The fault plane of a high energy tremor may appear in the form of a lineament.

Interpretation of satellite images from the lineament point may be of importance to seismic hazard research.

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STATYSTYCZNA ANALIZA ZWIĄZKU MIĘDZY POŁOŻENIEM EPICENTRÓW WYSOKOENERGETYCZNYCH WSTRZĄSÓW A LINEAMENTAMI NA OBSZARZE GÓRNOŚLĄSKIEGO ZAGŁĘBIA WĘGLOWEGO

Słowa kluczowe

Wysokoenergetyczna sejsmiczność indukowana, lineamenty

Streszczenie

W artykule pokazano wyniki statystycznej analizy związku między wysokoenergetyczną sejsmicznością indukowaną a lineamentami na terenie Górnośląskiego Zagłębia Węglowego. Wybrano cztery parametry do obliczeń. Były to: azymut lineamentu, azymut uskoku, azymut wektora wstrząsu (TVAA), którego początkiem było epicentrum silnego wstrząsu o energii większej niż $E \geq 10^8$ J, a końcem epicentrum silnego wstrząsu o energii większej niż $E \geq 5{,}5 \cdot 10^5$, ale mniejszej niż 10^8 J, azymut wektora wstrząsu (TVAB), którego poczatkiem było epicentrum silnego wstrząsu o energii większej większej niż $E \geq 5{,}5 \cdot 10^5$, ale mniejszej niż 10^8 J, końcem zaś było epicentrum silnego wstrząsu o energii większej niż $E \geq 10^8$ J. Obliczenia przeprowadzono dla 31 wysokoenergetycznych wstrząsów o energii co najmniej $E \geq 10^8$ J z obszaru Górnośląskiego Zagłębia Węglowego. Katalog wstrząsów zawierał współrzędne epicentrum i energię wstrząsów. Badania pokazały istotną zależność azymutu lineamentu z azymutem wektora wstrząsów (TVAA) po wysokoenergetycznym wstrząsie. Zależność ta może potwierdzać mechanizm poślizgowy wysokoenergetycznego wstrząsu. Płaszczyzna rozrywu takiego silnego wstrząsu może się ujawnić w postaci lineamentu.