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AN APPLICATION OF THE REMOTE SENSING TECHNOLOGY TO THE HIGH-ENERGY SEISMIC ACTIVITY ASSESSMENT, ON THE EXAMPLE OF THE UPPER SILESIAN COAL BASIN (USCB)

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Abstract. Mass wasting (the downslope movement of a sediment and/or rock masses under the gravity influence) concerns also the mining area, which are regions of the increased seismic activity hazard (induced seismic activity). The most dangerous are the high-energy tremors arising as a result of exploitation and tectonic stresses accumulation (mining-tectonic seismic activity). The paper presents possibilities of the use of the remote sensing method for the assessment of high-energy seismic activity in the Upper Silesian Coal Basin (USCB) region. The preliminary analysis proved a great usability of data obtained from satellite images, and acknowledged new possibilities of their interpretation.

Key words: remote sensing, mining-seismic activity, satellite images, lineaments.

Abstrakt. Ruchy masowe (zjawisko przemieszczania się mas skalnych pod wpływem grawitacji) dotyczą m.in. terenów górniczych, będących obszarami o podwyższonym ryzyku ruchliwości sejsmicznej (tzw. sejsmiczności indukowanej). Najbardziej niebezpieczne są wstrząsy wysokoenergetyczne, powstające w wyniku kumulacji naprężeń eksploatacyjnych i tektonicznych (sejsmiczność górniczo-tektoniczna). W artykule pokazano możliwości wykorzystania metody teledetekcyjnej do oceny sejsmiczności wysokoenergetycznej na obszarze Górnośląskiego Zagłębia Węglowego. Wstępna analiza wykazała jej dużą przydatność, a także nowe możliwości interpretacji danych ze zdjęć satelitarnych.

Słowa kluczowe: teledetekcja, wstrząsy sejsmiczne, zdjęcia satelitarne, lineamenty.

INTRODUCTION

Studies on the development of effective methods of seismic tremors and tectonic mobility prediction on the areas of intensive mining exploitation have been performed for many years. Use of the numerical methods for prospecting of the so-called "seismic function" have lead to the determination of the favouring conditions for seismic tremor appearance, but did not present the probability of "seismic days" appearance (after Adamczewski, 2002).

Creation of complicated algorithms and notation models for assessment of the conditions of tremor occurrence in a mine is as important as identification of the location of expected tremor appearance. Regional tectonic schemes with description of dislocation zones activity and specifications of the recent tectonic zones' mobility are helpful in identification of tremor location. Remote sensing method is very helpful in creation of such current maps of the recent mobility. The performance of the remote sensing interpretation with the use of the latest satellite images may provide valuable advise for the regions of the potential contemporary mobility.

Seismic tremors recorded by the mines' seismic stations and the Upper Silesian Regional Seismology Network can provide information on the contemporary mobility within the Upper Silesian Region. The Central Mining Institute operates a central database on the tremors recorded by the Upper Silesian Regional Seismology Network. This database contains primary data concerning strong tremors (E $\geq 10^5$ J): the registered tremors' energy, the date and time of the phenomenon's appearance, the mine's name, and the epicentre's coordinates. It may be helpful in analysing and identification of the potential

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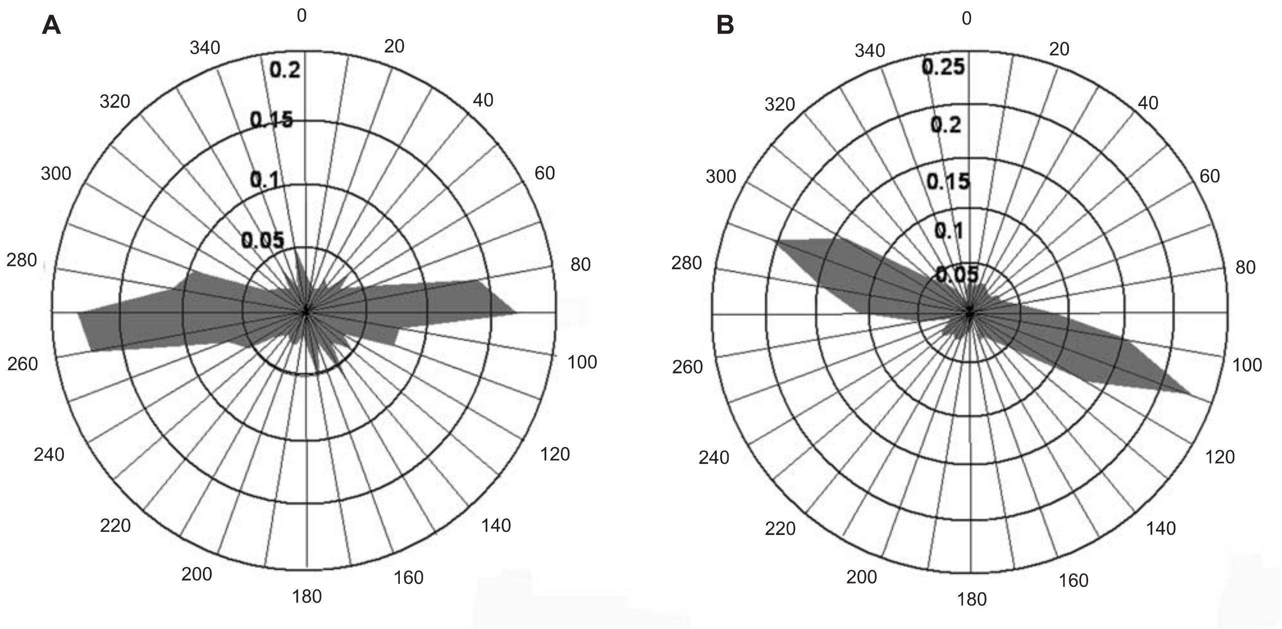

Fig. 1. Distribution of vectors directions, connecting two tremors occurring in the same regions

A — Bytom syncline; **B** — main anticline (Idziak *et. al.*, 1999)

locations of tremors appearance (Mutke, Stec, 1997; Idziak *et al.*, 1999; Stec, 2001; Pilecka, 2005).

The performed studies on the empirical seismic energy distribution in the Upper Silesian Coal Basin (USCB) coalmines indicate that bimodality phenomenon occurs there (Kijko 1982; Drzęźla *et al.*, 1984). After Kijko (Kijko, 1986). The bimodality of the extreme seismic energy distribution has its source in the various physical processes that occur in the tremor's centre. The analysis of mining seismic activity of the whole USCB at a global scale, based on tens years data logging from the Upper Silesian Regional Seismology Network archive, confirms the above theoretical considerations.

Two types of the seismic activity may be clearly identified: mining and mining-tectonic. Low-energy tremors are connected with the rock mass decompression as a result of mining works mainly (mining seismic activity), and high-energy tremors arises as a result of the accumulation of the exploitation stresses and of the rock mass tectonic ones (mining-tectonic seismic activity) (Gibowicz, 1996; Gibowicz, Lasocki, 2001). The centres of the second seismic activity type are located, as a rule, in zones of tectonic disturbance and are characterised by higher seismic energy. These phenomena are also intensively noticeable at the surface (Mutke, Stec, 1997). Conventionally, it is assumed that high-energy tremors have energy above $\geq 10^5$ J.

One of the more important facts that testified the tectonics significant influence on the USCB seismic activity are the results of studies on the strong tremors epicentres distribution in time sequences, that showed directional tendencies of successive tremors formation. The studies have based on the analysis of vectors' distribution connecting the epicentres of two following one after another tremors (Fig. 1).

The described above seismic tremors, called also an induced seismic activity, are one of the tectonic phenomena categories connected territorially with mining areas. The impact of seismic movements disturbs the state of the existing stress occurring in the sub-surface earth crust complexes. The power of these tremors hardly ever appears as a disaster at the land surface. These are phenomena of the small-scale mass movements. However, these tremors are a menace to the mines, where they may cause bounces and breakings down. The USCB region is well developed and has a dense population, and the vibrations caused by underground tremors can be a real hazard for the surface infrastructure.

COMPARATIVE ANALYSIS

Regions, where the occurrence of the induced seismic activity can be expected, are connected with mining activity (exploitation of coal, crude oil or natural gas), which may cause tremors resulting from unbalancing of rock mass, with the man-made lakes: tremendous water mass exerts pressure on the bedrock, what generates quite considerable seismic tremors, and with nuclear explosion.

The main subject of this study is the analysis of the USCB mining area along with identification of tectonic zones, which indicate potential appearance of induced mobility. Comparative analysis concerns: tectonic materials, results of tremors measurements, archival remote sensing data and results of remote sensing interpretation, performed based on the newest satellite images.

Tectonics of the USCB

Variscan orogenesis had an essential influence on the USCB tectonic structure. During this period, main faults and folds systems had been created. Detailed studies of the USCB tectonics revealed that most of the tectonic structures were formed during the Asturian phase of the Variscan orogenesis (Goszcz, 1999; Doktorowicz-Hrebnicki, 1963; Znosko, 1965; Kotas, 1985).

The deep breaks zones within the crystalline basement had an important influence on the Variscan structures creation. It was found that besides vertical movements along the deep dislocations, horizontal movements of blocks displacement had occurred. Northeastern boundary zone of the Upper Silesian block with Małopolska Block showed a great multi-phase activity of the displacement character, from Palaeozoic to Permian (Buła *et al.*, 2005). As a result of this activity, the Upper Silesian Massif made a sinistral rotation. It was probably connected with collision of continent–continent type between Brunovistulikum as a lower plate, and Czech Massif as the upper one (Buła *et al.*, 2005; Kotas, 1985) (Fig. 2).

Productive Carboniferous structures were best identified in the Variscan complex. This identification resulted mainly from the possibilities of research and observations in mining excavations. Three structural zones were selected in the productive series formations: folded tectonics zone, block tectonics zone, and an adherent to it from the north and north-east: fold–block tectonics zone that exceeded the basin region (Idziak *et al.*, 1999).

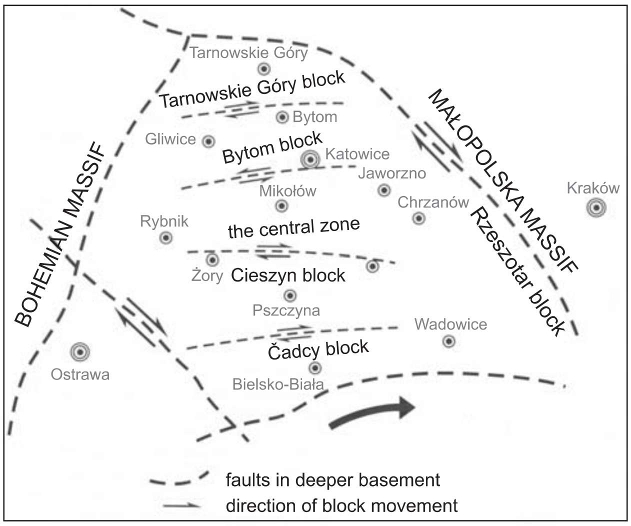

Fig. 2. The USCB and faults in the deep Precambrian bedrock Kotas, 1985)

Folded tectonics zone occurs in the western part of the Basin as a narrow belt about 25 km wide. This zone is directed towards SSW–NNE, in accordance with the adjacent Moravian–Silesian zone direction. In this tectonic zone, most structures were formed with dominant horizontal components fraction of compressive stress field, connected with the ingress from the west of the Moravian–Silesian front of the Variscan origin. Michałowice–Rybnik and Orłów–Boguszów overthrusts, formed as a result of horizontal compressive stresses, have a meridional run.

Block tectonics zone occurs to the east of the folded zone. Carboniferous formations lie flat, the beds dips do not exceed 15° in general, exceptionally they amount to 20–25° in large fault zones. The fault tectonics is very strongly developed there. The occurring faults are mainly of standard, seldom reversed, form. Tectonics of this zone shows very exact connections with the base structure, reflecting its block form. Structural elements have in this zone parallel extension. The main trough occurs in the main part of the block tectonics zone. This is an extensive synclinal structure with the beds dips that do not exceed 10°. Its axis runs in the arc shape from the west to the east, and further to the south-east, through the basin centre. It borders the main anticline on the north, also with parallel extension. To the north of the main anticline, another large structure of the parallel extension — the Bytom brachysyncline — is located.

Geometry of the faults' network is compatible with the dominant block zone direction. The biggest dislocations are the sub-parallel faults' zones that thrust Carboniferous layers in southern direction. Within those zones small faults occur, most often of meridian direction. A series of other, smaller faults, of directions close to the meridian one appear within the central parts.

The fold-block zone is located in the northern and northeastern parts of the USCB, and on its northeastern border. The occurrence of fold units of NW–SE extension is characteristic for this region. Tectonic zones have general NW–SE direction. The studies proved that there is a similarity between the series of fold structures, which course follows closely intersection lines of the base faults. One of such complexes is a sub-parallel belt of the main anticline brachyanticlines.

Further to the north, similarly oriented series occur, created by Malinowice brachyanticlines and flexural-overthrust structures, located north of the Bytom syncline. The series of brachyanticlines and brachysynclines can be recognised further to the east. It is located diagonally in relation to two former ones and overlaps almost conformably the big NW–SE faults lines. Hypothetical discontinuity of the crystalline block at the base of folded series was identified as a border zone that separates segments of the Upper Silesian Massif: the Bytom and central blocks.

According to Teper (1998), in the basement of the Main Anticline runs the central part of the wide parallel tectonically active zone, with recognisable sinistral rotation displacement movements. The dynamics of this zone shows that in the neighbourhood of the deep dislocation, where dynamic processes were the most intensive, the low-angular derivative structures were active almost solely. Activity of other complexes, located above the fault structures, increased towards the borders of this zone.

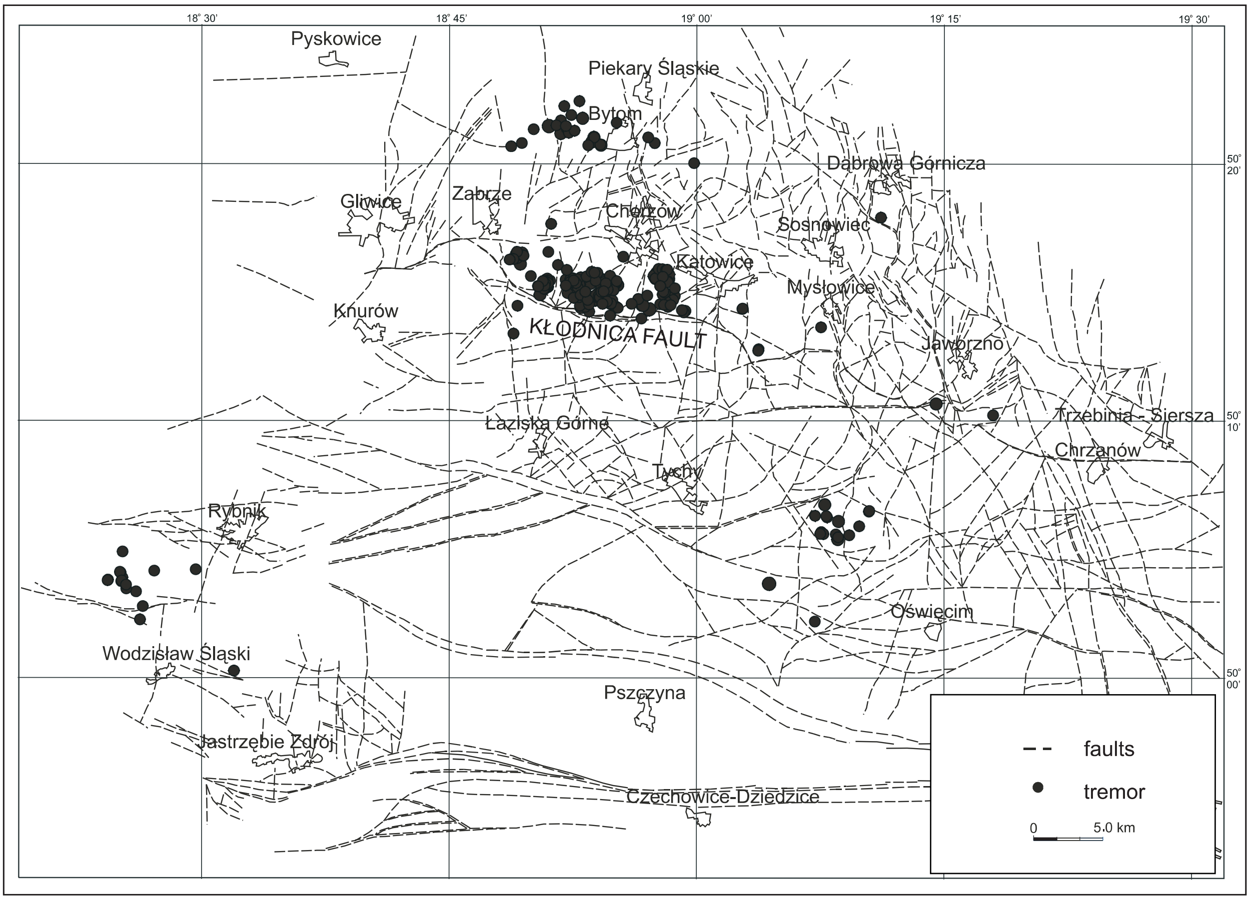

Fig. 3. The USCB tectonics and epicentres of high-energy tremors (>10^7 J) during the 1985–2004 period

Analyses performed for Bytom Through (Idziak, Teper, 1996; Teper, 1998) show that a network of active, differently oriented faults exists in this area, and that the fault zone may generate tremors.

Figure 3, based on the geological-structural map (Buła, Kotas, 1994), presents tectonics of productive Carboniferous formations. The map contains strong tremors epicentres of over 10^7 J of energy, according to data from the Central Mining Institute Data Base. As could be seen, the strong tremors epicentres do not show a direct correlation with faults, except for the Kłodnica fault zone, where epicentres occur parallel to the fault, on its northern side.

The influence of the Alpine tectonic movements on the basin structure is not well identified because Mesozoic sediments that cover the basin are small. However, general analysis shows that a net of Triassic faults repeats in principle the main directions of the Carboniferous fault network. System of sub-parallel faults, forming semi-horsts, distinguishes itself by the characteristic arrangement and the size of thrusts among the fault network registered in Carboniferous formations, and continued in Triassic and Miocene. These data allow to acknowledge that even a creation during the Alpine orogenesis of some new fault zones and renewal of older fault zones did not change the principal tectonic configuration of the USCB created during the Variscan orogenesis.

Remote sensing

The results of remote sensing analyses provide information of: lithological variability, hydro-geological conditions (such as humidity region) in sub-surface geological complexes, occurrence of tectonic zones (zones of joint) and morpho-structural elements. Drafts and maps of the network shape of linear structural elements are most often an effect of the remote sensing interpretation. The determined linear structural elements are based on the interpretation of satellite, radar or aerial images, kept on various carriers (paper, negative and positive plates, and recently, in digital form). Lineament is a linear surface feature (or their composition), of a whole unit or its certain segments, rectilinearly oriented and reflecting a geological phenomena in the basement. This definition exists in Polish literature, taken from the Anglo-Saxon one. Hobbs (1904, 1912) and O'Leary *et al.* (1976) forwarded this definition into the satellite time.

Identification of geological structures and mechanism of their sensing from features visible on the satellite images of the Earth surface depends on the character of superficial cover of sediments and flora. In regions where thick unconsolidated cover occurs, the identification is possible in an indirect way, only, and requires difficult process of the indirect deep structures interpretation. Despite such complexity of the interpretation pro-

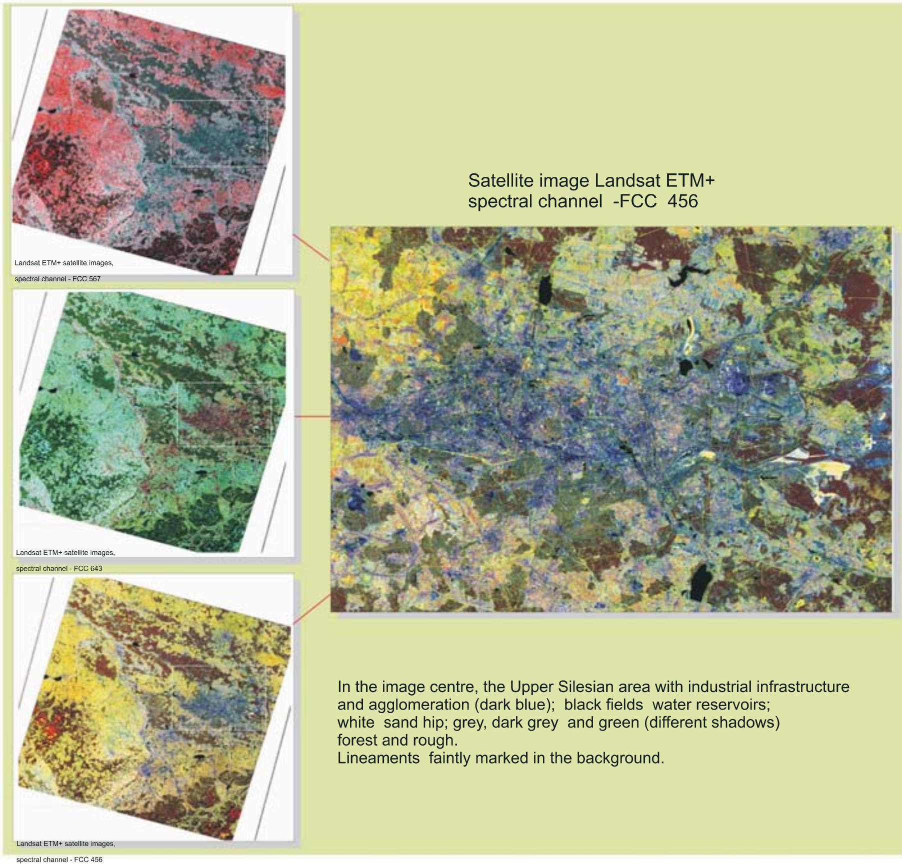

Fig. 4. Satellite image of the USCB and examples of various spectral channels

cesses, numerous publications on geological interpretation of satellite images show an undoubted connection of lineaments even with the deep discontinuities lines (Ostaficzuk, 1981; Doktór, Graniczny, 1982; Jaroszewski, Piątkowska, 1988).

Synthetic remote sensing material for the USCB area was created in the lineaments' draft form, based on archival remote sensing, regional and detail reports. Regional reports (Graniczny, 1989; Doktór, Wilczyński, 1981; Graniczny, 1991; Bażyński *et al.*, 1984; Piątkowska *et al.*, 2001; Graniczny, Mizerski, 2003; Buła *et al.*, 2003) presents of the regional geological structures system and more important fault zones visible on the Earth surface in one-dimension form. Supplementary draft of the linear regional elements was performed based on the latest images of Landsat ETM+, and is compatible with outlines of the existing regional tectonic directions. Remote sensing interpretation performed for the Buła *et al.* (2003) report was a supplement to the outlines of regional tectonic zones trends, and was of a local significance, only.

Only the high-energy tremors of over 10^7 J, from the 1984–2004 period, were analysed. As can be seen, the lineaments course is very differentiated in this area. They extent most often in WSW–ENE and NW–SE directions. There can be observed a correlation of lineament no.1, extending in the Bytom region in WSW–ENE direction, with high-energy tremors. The epicentres of most tremors cover mining areas of the following mines: Jadwiga, Bobrek–Mechowice, Bytom II and Centrum, Bytom I.

Also in the region south of Chorzów and in the western part of Katowice, most of the high-energy tremors are grouped on the lineament no. 2 of WSW–ENE direction, running through the mining areas of Bielszowice, Halemba, Polska–Wirek, and Katowice–Kleofas mines. In this region, the high-energy tremors occur also in the area between the lineament no. 2 and the lineament parallel to it from the south. In the region no. 3, the tremors epicentres correlate with two lineaments of NW–SE direction. It is a border area between Ziemowit and Piast mines. On Sobieski–Jaworzno III mining area, the correlation of one high-energy tremor can be seen. Its epicentre is on the lineament of SW–NE direction. In the region of Rybnik Mining Company (Rybnicka Spółka Węglowa), no clear correlation of tremors' epicentres with lineaments was observed, except for a tremor on the Rydułtowy mining area, located on the lineament of WSW–ENE direction.

The results of comparative analyses

High-energy seismic activity (energy of over 10^7 J, during the 1984–2004 period) was presented against the background of the main lineaments directions and the most important tectonic structures of the USCB. Faults and fold structures were taken into consideration. As can be observed in Bytom and Katowice regions, the tremors occur along tectonic structures as well as in directions sub-parallel to the lineaments. In other region, such evident dependence is not observed.

CONCLUSIONS

An analysis of lineaments' azimuth distribution within the research area shows a dominance of two directions: NW–SE and ENE–WSW. Evidently dominant NW–SE direction is generally convergent with the morphological (morpho-tectonic) elements direction, which are noted on the Palaeozoic roof surface, and with the direction of certain

Fig. 5. High-energy seismic activity and the main directions of lineaments and tectonic structures of the USCB

regional faults crossing the Carboniferous coal-bearing USCB formations. The same direction have got the Kraków–Lubliniec tectonic zone and parallel faults noted in Palaeozoic formation structures of the Małopolska Block. The NW–SE lineaments direction can be compared with geological-structural borders of Permian trough (Fig. 5) as well as Triassic, Jurassic and Cretaceous formations (Pożaryski *et al.*, 1979).

The second distinguished ENE–WSW lineaments' direction cannot easily fit to structural elements. May be, it is connected with faults' network of general sub-parallel course, which is noted mainly in the USCB Carboniferous formations structure. This direction requires additional detailed information and acknowledgements.

There was performed an interpretation of the latest images of Landsat ETM+, and it confirms the assumptions that the observed weak sub-parallel direction is present in the structure of the USCB region. Its presence confirms the existence of the small lineaments system creating zones of regional course or corresponding to the identified small faults.

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