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FRACTALITY OF SPATIAL DISTRIBUTION OF BOTH FAULTS AND SEISMIC EVENTS WITHIN BYTOM SYNCLINE, UPPER SILESIA

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ABSTRACT. The Bytom syncline is one of main structural units forming the Upper Silesian Coal Basin (USCB). It is the region where the great seismic activity is observed. The energy of seismic event is usually less than 10^7 J but from time to time tremors with energy greater than 10^8 J occur. To explain if the biggest seismic events can be connected with recent tectonic activity the fault network geometry and spatial distribution of seismic event epicenters were studied using fractal analysis. The calculated fractal dimension of fault network was close to 1.6 and it was similar to the fractal dimension of epicenters equal to 1.52. This similarity may suggest that the whole fault network of the Bytom syncline is engaged in generating seismic events.

1. Structure of the Bytom Syncline

Upper carboniferous deposits of northern part of the USCB are extensively folded. One of the biggest depressional structures in the area is a synclinorial unit which was formed north of the Main anticline. The Bytom syncline forms the western part of the unit. Geometric features of the Bytom syncline are similar to those of another neighbour synforms and antiforms, pointing to their common origin [Teper 1988]. The features are, as follows: stable azimuth of structure elongation, sigmoidal bend of axis terminations, asymmetry, southern vergence and brachysynclinal shape.

Northern limb of the Bytom syncline, which has a dip of approx. 7° in the axial part, is much steeper in the peripheric part of the syncline reaching 60°, somewhere 80° (Andaluzja coalfield) and has sporadically vertical or even overturned position (Miechowice coalfield). The dip of the southern flank is not higher than 10° to N or NNW. In a transition zone between the Bytom syncline and domes of the Main anticline dip angles reach 25°. The resultant orientation of the axis is $286/4^0$ while the axial surface is vertical. The Bytom syncline represents a type of widely–spaced, upright, asymmetric brachysynform with southern vergence [Teper 1988].

The first–rank basement fracture along NE border of the USCB, called the Cracow deep fault, was influencing the rock–mass deformation in the Bytom syncline at least during Variscan time. Due to the activity of this fault, a system of folds and faults was created. Its type, regularity and geometry were characteristic for the strike–slip stress field with dextral component of horizontal movement [Teper 1988; 1990].

A deep-rooted W–E oriented fracture located south of the Bytom syncline has controlled the formation of new faults, as well as rejuvenation and modification of the old ones since the Tertiary [Teper et al. 1992]. The Tertiary–to–present dynamics of the studied area has been dominated by force couple causing sinistral relative movements of basement segments along the equatorial discontinuity (op. cit.). In a derivative structural pattern, which has appeared in response within the sedimentary cover of the Bytom syncline, submeridional dip–slip faults are the most frequent. That is consistent with a shape of external part of fault network in a model of broad wrench zone introduced for the area [Teper, Sagan 1995].

2. Seismicity of the Bytom Syncline

The Bytom syncline is a region where great seismic activity is observed. Most of the seismic events, assumed to be induced by mining activity, have the energy not exceeding 10^7 J. Their localization and character suggest an association with the generation of new discontinuities in rock mass. The tremors with higher energy are also registered but their frequency is much lower. In the time interval 1977–1991 there were 1651 tremors with energy 10^6 J or more occurring in the studied area, but only 189 of them had energy not less than 10^7 J. The impact of regional tectonic processes on the origin of the strongest seismic events is postulated by some of authors investigating the induced seismicity of the USCB [Idziak, Zuberek 1995].

The spatial distribution of tremor epicenters is homogeneous neither in the USCB as a whole nor in the Bytom syncline. The seismic map of the USCB is shown in Figure 1. Despite of mining activity carried out in all the USCB area tremor epicenters concentrate in four regions connected with different geological units. In the Bytom syncline bigger seismic activity is observed in the western and central parts of this structure and it decreases toward the eastern part (Figure 2). Inhomogeneity of spatial tremor distribution suggests the fractal character of seismic phenomena. It means that spatial distribution of seismicity in the Bytom syncline should be scale invariant.

3. Fractal Geometry of Fault Systems in the Bytom Syncline

The geometry of fault systems in the Bytom syncline is complex and fractal methods have to be employed to describe it. To determine the fractal dimension of these systems the algorithm known as a "box counting method" was applied. Accordingly to the algorithm a fault network was firstly covered by N_0 squares with a side length r_0. In the next steps the fault lines were covered with boxes whose side length decreased in sequent iterations. The lowest number of boxes needed for covering all of the fault lines was counted in every iteration. If the fault systems had a self–similar structure this number should satisfy the following

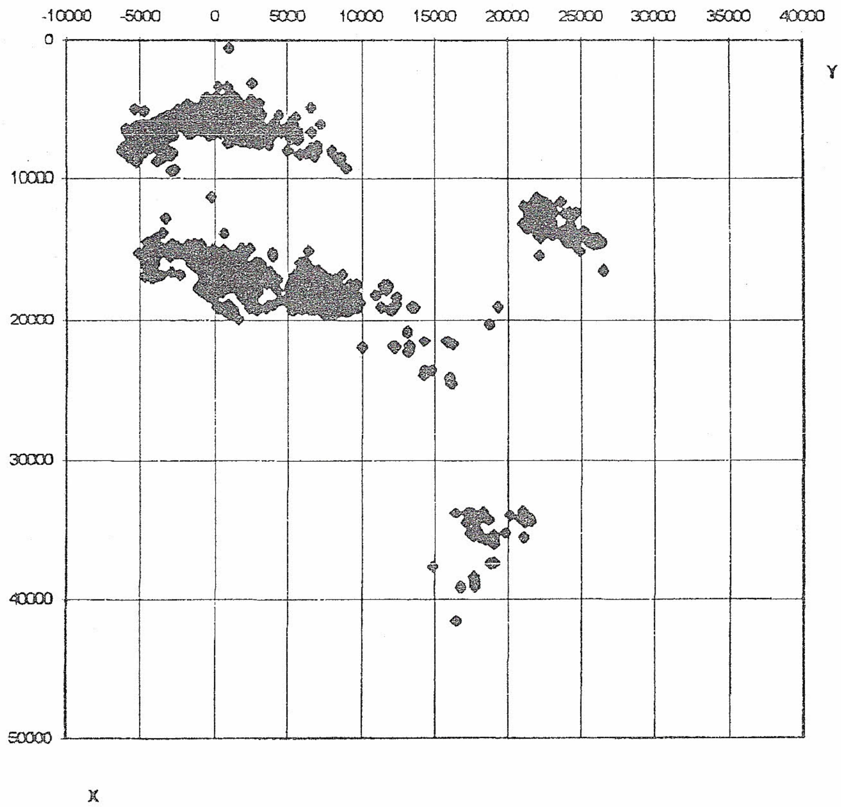

FIG. 1. Distribution of seismic events in the USCB during 1977 – 1991 period mapped in local geographical coordinates.

equation [Mandelbrot 1983]:

$$N(r_i) = N_0 \cdot \left(\frac{r_i}{r_0}\right)^{-D}, \tag{1}$$

where $N(r_i)$ is the number of boxes of side length r_i covering the faults lines and D is the fractal dimension of fault system.

The $\log N - \log(r/r_0)$ graph plotted for the experimental data should be linear. For the fault systems mapped in the Bytom syncline area (Figure 3) this graph was linear in the box size range of 125 m to 8 km (Figure 4). The calculated fractal dimension of fault network was 1.60. Accordingly to [Hirata 1989] this value is an upper limit to the fractal dimension of the fracture geometry and points to the generation of discontinuities in conditions of minimum energy needed for crack growth. The lower limit of fractal relationship for $r = 125$ m was due to the map scale (1:25 000) whereas the upper limit was connected with the size of separate fault systems. For the boxes of side length bigger than 8 km spatial distribution of the different fault systems was taken into account and the fractal dimension changed.

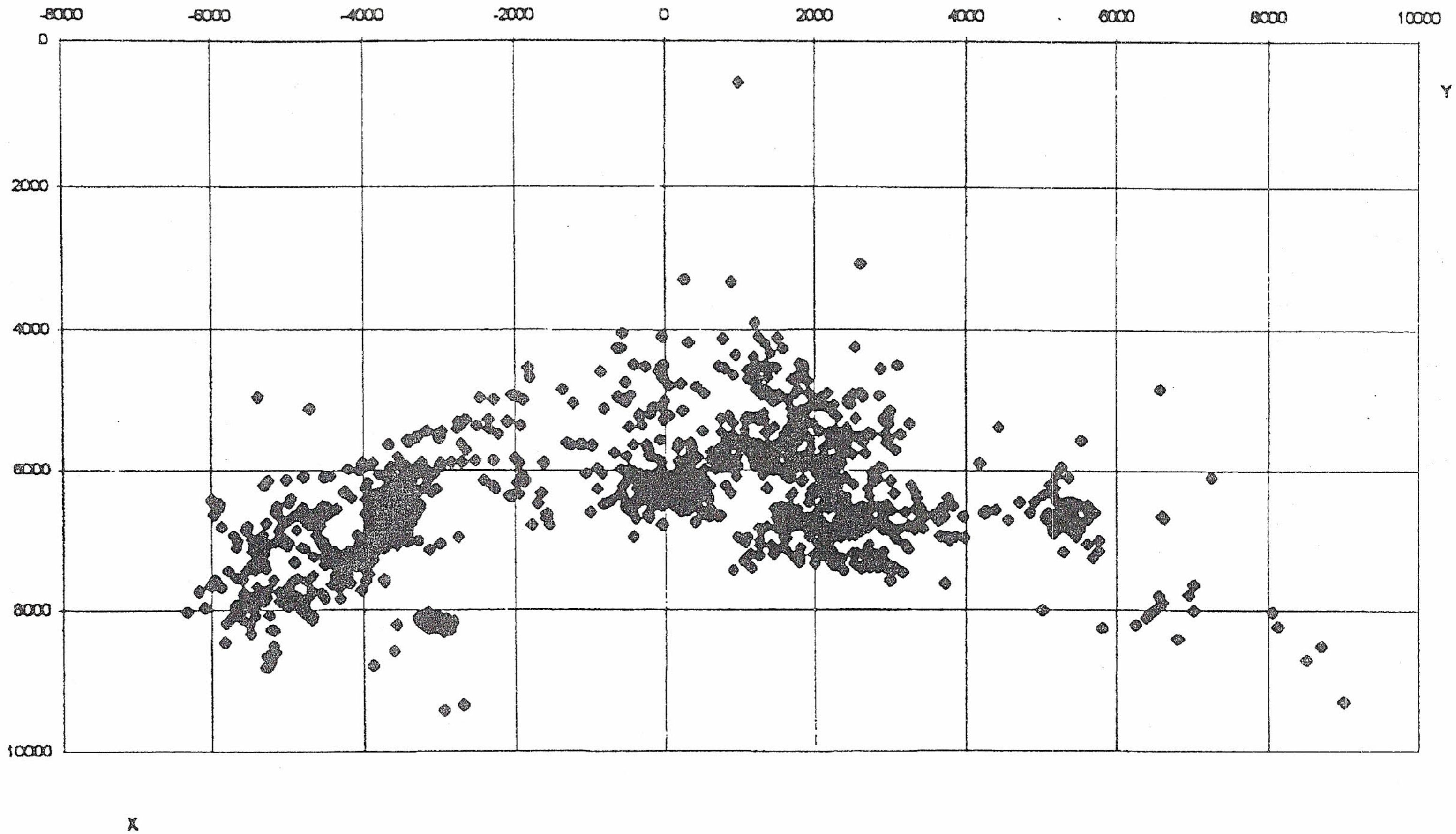

FIG. 2. Distribution of seismic events in the Bytom syncline during 1977–1991 period mapped in local geographical coordinates.

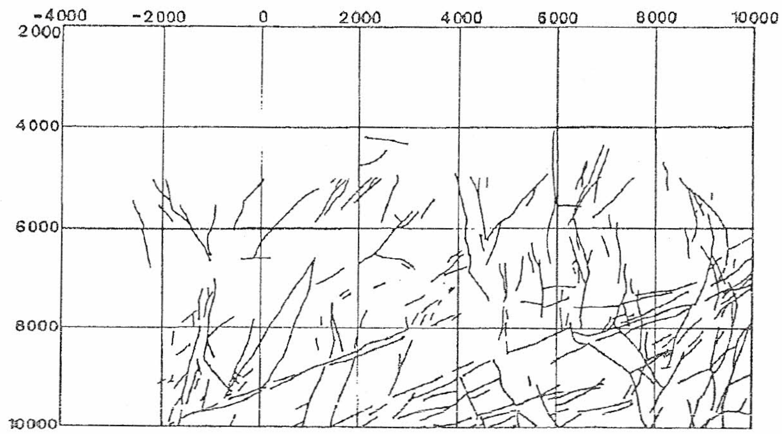

FIG. 3. Digital map of fault network in the Bytom syncline (local geographical coordinates).

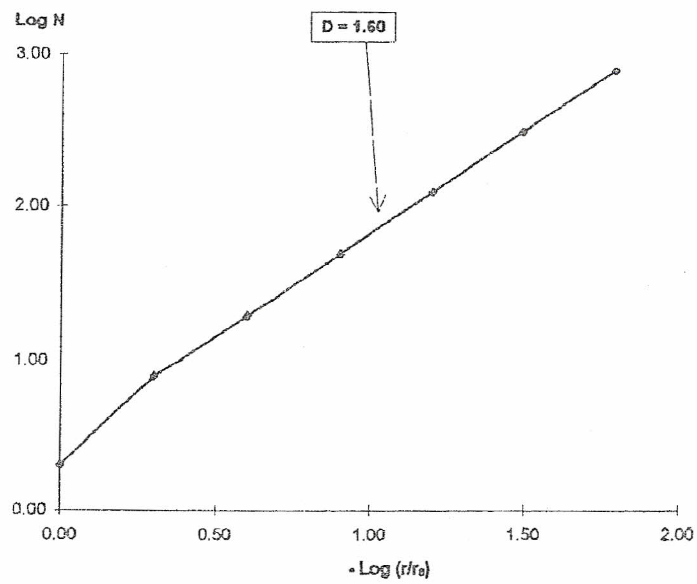

FIG. 4. Log – log graph plotting minimum number of squares required to cover fault lines versus normalized box size.

4. SPATIAL DISTRIBUTION OF TREMOR EPICENTERS IN THE BYTOM SYNCLINE

The spatial distribution of tremor epicenters was analysed for the rectangular area of 16 km × 8 km size covering the Bytom syncline. The considered tremor catalogue comprised 1651 events of energy exceeding 10^6 J during the time interval of 1977 – 1991. Fractal analysis was employed. The investigated area was sequently covered by square grids with decreasing side length, starting with squares 8 km × 8 km. In every next step the square side was two times less down to 125 m. The fraction "p" of squares in which tremor epicenters occurred was calculated in every iterative step. Fractal spatial distribution of tremors should satisfy the relationship [Turcotte 1992]:

$$p(r) = \left(\frac{r}{r_0}\right)^{2-D}, \tag{2}$$

where D is the fractal dimension of probability distribution and r/r_0 – the ratio of square's side length "r" to the initial length r_0.

The results obtained for the investigated structural unit (Figure 5) pointed out the fractal distribution of tremors with fractal dimension $D = 1.52$ for the grid side bigger than 0.5 km.

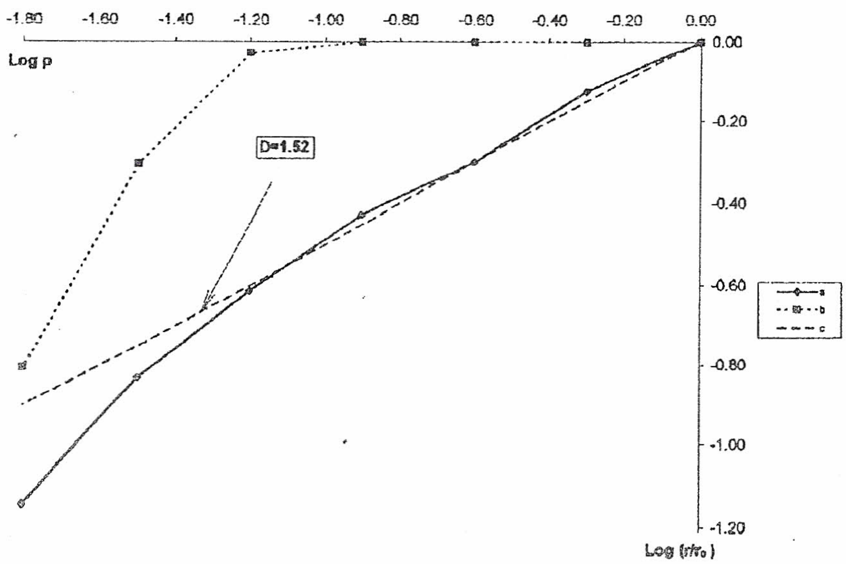

FIG. 5. Log–log graph plotting geometrical probability of tremors occurrence versus normalized box size.
a – empirical distribution of epicenters
b – simulated random distribution of epicenters
c – estimated fractal distribution of epicenters

The geometrical probability of seismic event occurrence for randomly distributed 1651 events with respect to grid size is also shown in Figure 5. As one can notice, the experimental results differ significantly from the random distribution for the whole–scale range. For grids with sides much bigger than the size of tremor foci the spatial distribution of epicenters is self–similar. It means they tend to grouping themselves in some areas. The lower limitation of fractal distribution suggests that inside the clusters the tremor distribution is either random or changes its fractal dimension. For a large scale of observation the tremor's focus cannot be treated as a point but as fracture zone of finite dimension comparable with the length of a grid side. It affects epicenter localization accuracy and may break down the fractal distribution of epicenters.

5. DISCUSSION

The spatial distribution of tremor epicenters is characterized by a geometrical probability of tremor occurrence in the chosen area. The distribution is fractal if its dependence on area size is governed by a power law. The fractal dimension can be explained by the concept of renormalization. Firstly the studied region is covered by N_0 squares and then every square is divided into k^2 smaller cells. Let the probability of tremor occurrence be the same in every cell and equal to "f". Continuing this process n–times we will obtain k^{2n} boxes. The average number of boxes with tremors will be equal to $(fk^2)^n$. It is simple to show that the fractal dimension of the distribution depends on "f":

$$D = \frac{\operatorname{Log}(f.k^2)}{\operatorname{Log} k}. \tag{3}$$

For a uniform distribution of tremors ($f = 1$) the fractal dimension is equal to 2. The fractal dimension $D = 1.52$ is obtained for $f \approx 0.7$.

The presented results indicate that considered induced seismicity in the Bytom syncline can be described as a fractal process in the limited range of scale. The fractal dimension is equal to 1.52 what means that areas with tremors are more frequent than those without seismic activity.

The "box counting" algorithm – used for a fault network – gives the fractal dimension called the Kolmogorov's capacity dimension which is a measure of filling the space by elements of investigated structure. The D–value obtained for the Bytom syncline fault network characterizes a quite dense structure, similar to a river network, with branches of first order, second order etc.

The similarity of both – tremor distribution and fault geometry – fractal dimensions suggests that the whole fault network may be engaged in generating of tremors in the Bytom syncline. It can support the hypothesis about an important role of tectonic structure in the inducement of the strongest tremors.

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