Title: Spatial Distributions of the Induced Seismicity in the Upper Silesian Coal Basin

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Spatial Distributions of the Induced Seismicity in the Upper Silesian Coal Basin

Abstract

The Upper Silesian Coal Basin is the region where the great seismic activity is observed. The most of seismic events have the energy not exceeding 10^7 J. Their localisation and character suggest the connections with generation of new discontinuities in rock mass, induced by mining activity. The tremors with higher energy are also registered but their frequency is much lower. In the time interval 1977–1994 there were 3882 tremors with energy equal to 10^6 J or more occurring in the studied area, but only 395 of them have energy not less than 10^7J. The flow of regional tectonic processes on origination of the strongest seismic events is postulated by some authors investigating the induced seismicity of the USCB.

The spatial distribution of tremor epicentres is not uniform in the USCB area. Despite of mining activity carried out in all this area tremor epicentres concentrate in four regions connected with different geological units. Inhomogenity of tremor spatial distribution suggests the fractal character of seismic phenomena. The temporal variability of tremor epicentre co-ordinates shows some kind of "strange attractors". These facts could point that induced seismicity in the USCB is triggered by non-linear dynamical process, having the regional meaning and connected with recent tectonic activity.

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Introduction

The Upper Silesian Coal Basin (USCB) is the region where the high level of seismic activity is observed. The most of seismic events, assumed to be induced by mining activity, have the energy not exceeding 10 MJ. The tremors with higher energy are also registered but their frequency is much lower. In the time interval 1977–1994 there were 3882 tremors with energy 1 MJ or more occurring in the mentioned area, but only 395 of them had energy not less then 10 MJ. The flow of regional tectonic processes on origination of the strongest seismic events is postulated by some of authors investigating the induced seismicity of the USCB (Idziak, Zuberek, 1995).

In presented study the spatial distribution of the seismic events with energy not less than 1 MJ was analysed to find characteristic features of dynamic process generating the strong tremors in the Upper Silesian Coal Basin (USCB).

The Spatial Distribution of Tremor Epicentres in the USCB

The spatial distribution of tremor epicentres is not homogeneous in the USCB. The map of tremor localisation in this region was shown on the Fig. 1. Despite of mining activity carried out in all the USCB area tremor epicentres tend to group in four, well separated clusters corresponding to four, structurally different geological units:

– Bytom syncline ($2000 < X < 10000$; $-10000 < Y < 8000$)
– Kazimierz syncline ($10000 < X < 17000$; $-27000 < Y < -20000$)
– Main anticline ($10000 < X < 25000$; $-20000 < Y < 10000$)
– Main syncline ($33000 < X < 42000$; $-22000 < Y < -13000$)

Inhomogenity of spatial tremor distribution suggests the fractal character of seismic phenomena. It means that spatial distribution of seismicity in the USCB should be scale invariant and the fractal analysis should be applied for ascertaining of its characteristic parameters.

Fractal Analysis of Tremor Epicentres Distribution

The spatial distribution of tremor epicentres was analysed for the rectangular area of size 50 km × 50 km covering the Upper Silesian Coal Basin. The considered tremor catalogue comprised 3882 events of energy exceeding 1 MJ which took place during

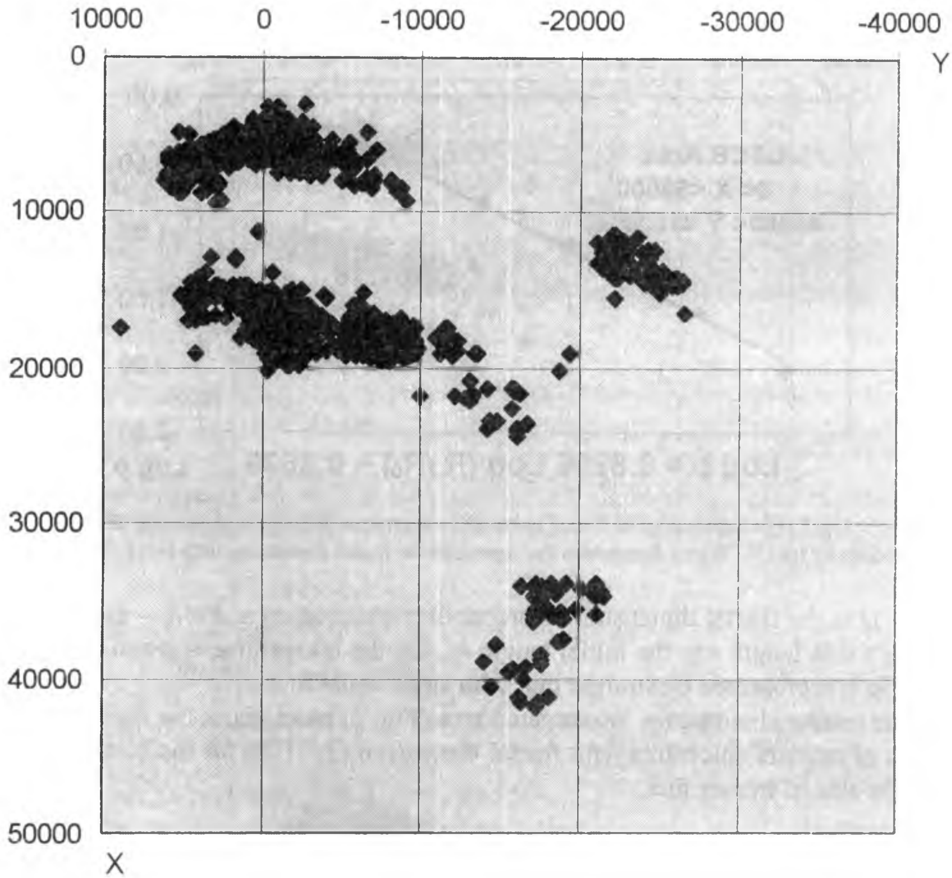


Fig. 1. The localisation of epicentres of strong tremors occurred in the USCB during the 1977–1994 period (3882 tremors of energy not less than 1 MJ mapped in local co-ordinates)

the time interval 1977–1991. The fractal analysis of tremor occurrence probability was employed. The investigated area was sequentially covered by square grids with decreasing side length. In succeeding iterative steps the square side was decreased down to 100 m. The fraction p of squares, in which tremor epicentres occurred, was calculated in every step. It was aimless to analyse the epicentres distribution for grids with side length less than 100 m because the size of smaller squares would be comparable with the size of tremor foci and accuracy of their localisation.

Fractal probability distribution of tremors occurrence should satisfy the relationship (Turcotte, 1992):

$$p(r) = \left(\frac{r}{r_0}\right)^{2-D} \qquad (1)$$

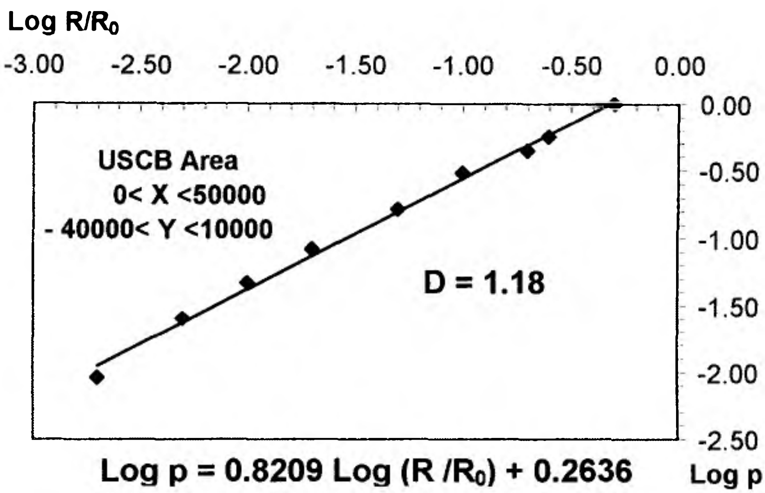


Fig. 2. The dependence of tremor epicentres occurrence probability on the size of grid boxes for the USCB area. Regression line represents the fractal distribution with $D = 1{,}18$

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. On the bilogarithmic graph this relationship is represented by straight line with slope equal to $2\text{–}D$.

The results obtained for investigated area (Fig. 2) pointed out the fractal distribution of tremors epicentres with fractal dimension $D = 1{,}18$ for the boxes bigger than the size of tremor foci.

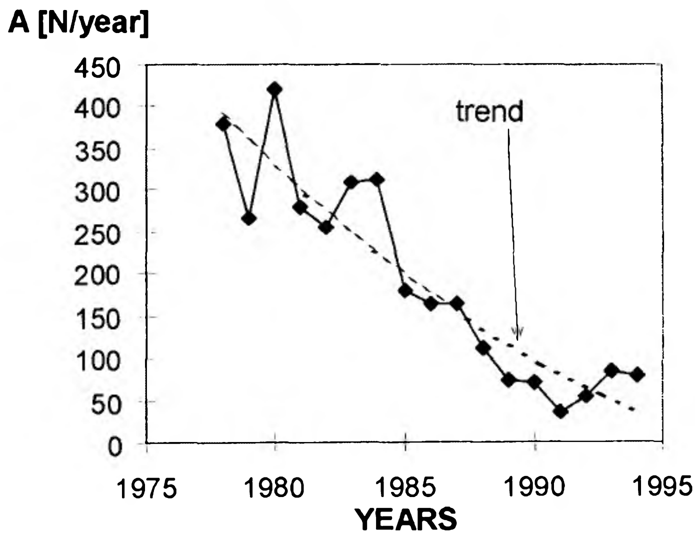


Fig. 3. Changes of seismic activity in the USCB during the period of 1977–1994

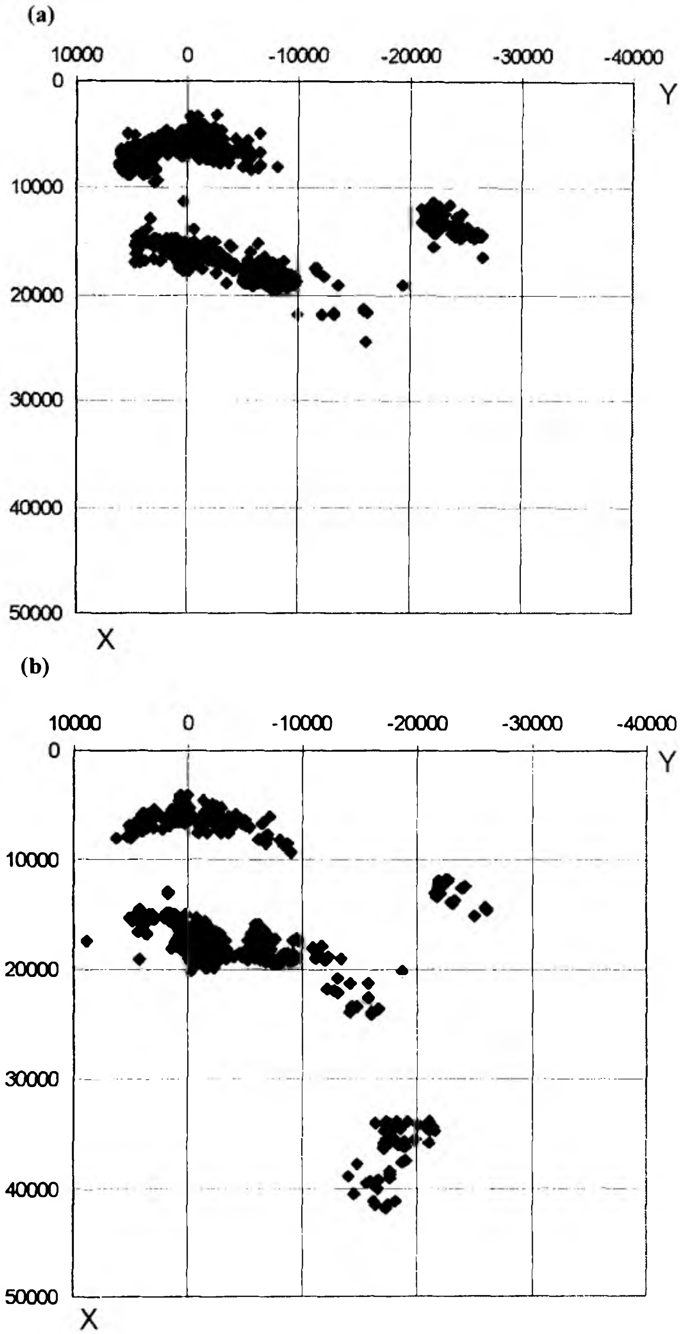


Fig. 4. The localisation of epicentres of strong tremors occurred in the USCB during the 1977–1984 period (**a**) and during the 1985–1994 period (**b**) – termors mapped in local coordinates

The spatial distribution of epicentres is self-similar in statistical sense. It means that epicentres tend to group themselves in some clusters and make the random fractal set of Sierpinski's carpet type. The presented results indicate that considered induced seismicity in the USCB can be described as a fractal process.

The Time Changes of Induced Seismicity in the USCB

During the analysed time period the migration of seismicity and general decreasing of seismic activity could be observed. The seismic activity decreased from about 400 events per year in 1977 to less then 100 events per year in 1994 (Fig 3).

Since 1977 to 1984 there were 2869 strong tremors, which concentrated in Bytom syncline, Main anticline and Kazimierz syncline (Fig. 4a).

Between 1984 and 1994 the number of tremors was about 3 times less. During the last ten years there were 1013 tremors only. The Main syncline became the new active region concurrently the seismic activity in Bytom syncline, and especially in Kazimierz syncline significantly decreased (Fig. 4b).

Investigations of temporal changes of tremor epicentres localisation gave very interesting results. The graphs of tremor epicentres X and Y co-ordinates versus tremor occurrence time were plotted (Fig. 5). The points on these graphs showed the zones attracting the tremors. The X co-ordinate oscillated between two attractive zones during the first 3500 days of observation period. The third zone appeared for latter time period. In the same time another attractive zones were getting narrow. The Y co-ordinate had initially three attractive zones closed one to another as well as the fourth well separated zones and oscillated among them. In the second part of investigated period Y co-ordinate changed rather in chaotic way making some kind of "strange attractor" typical for non-linear dynamic system in chaotic state. The examples of X and Y co-ordinates oscillations during the 200-days time interval taken from the latter part of observation period are shown on the Fig. 6.

The strongest tremors of energy equal or higher than 100 MJ were localised mostly in two regions: Bytom syncline and Main anticline (Fig. 7). Their X co--ordinates oscillated between two atractors but their Y coordinates show typical chaotic behaviour (Fig. 8).

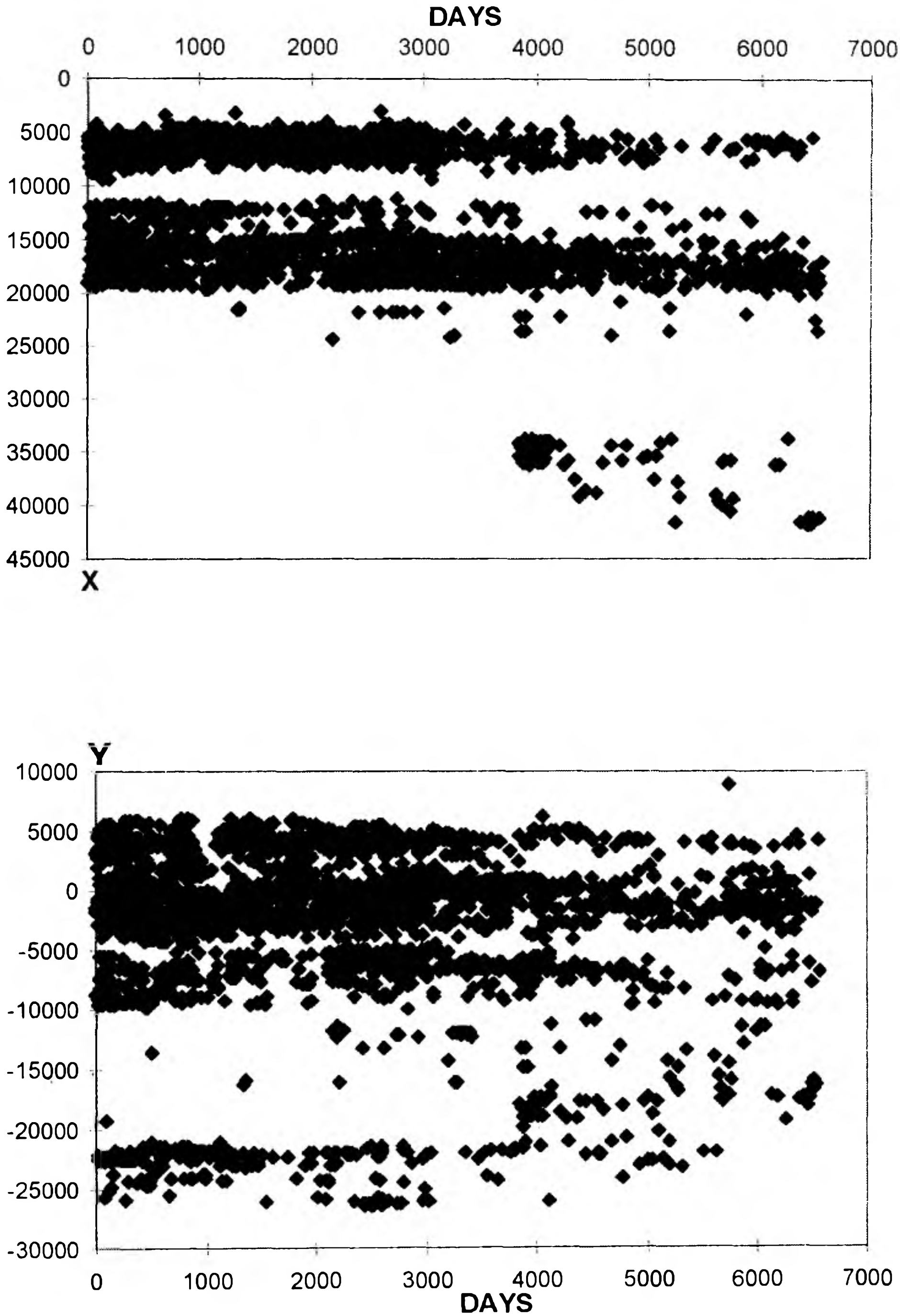


Fig. 5. Temporal distribution of tremor's X and Y co-ordinates

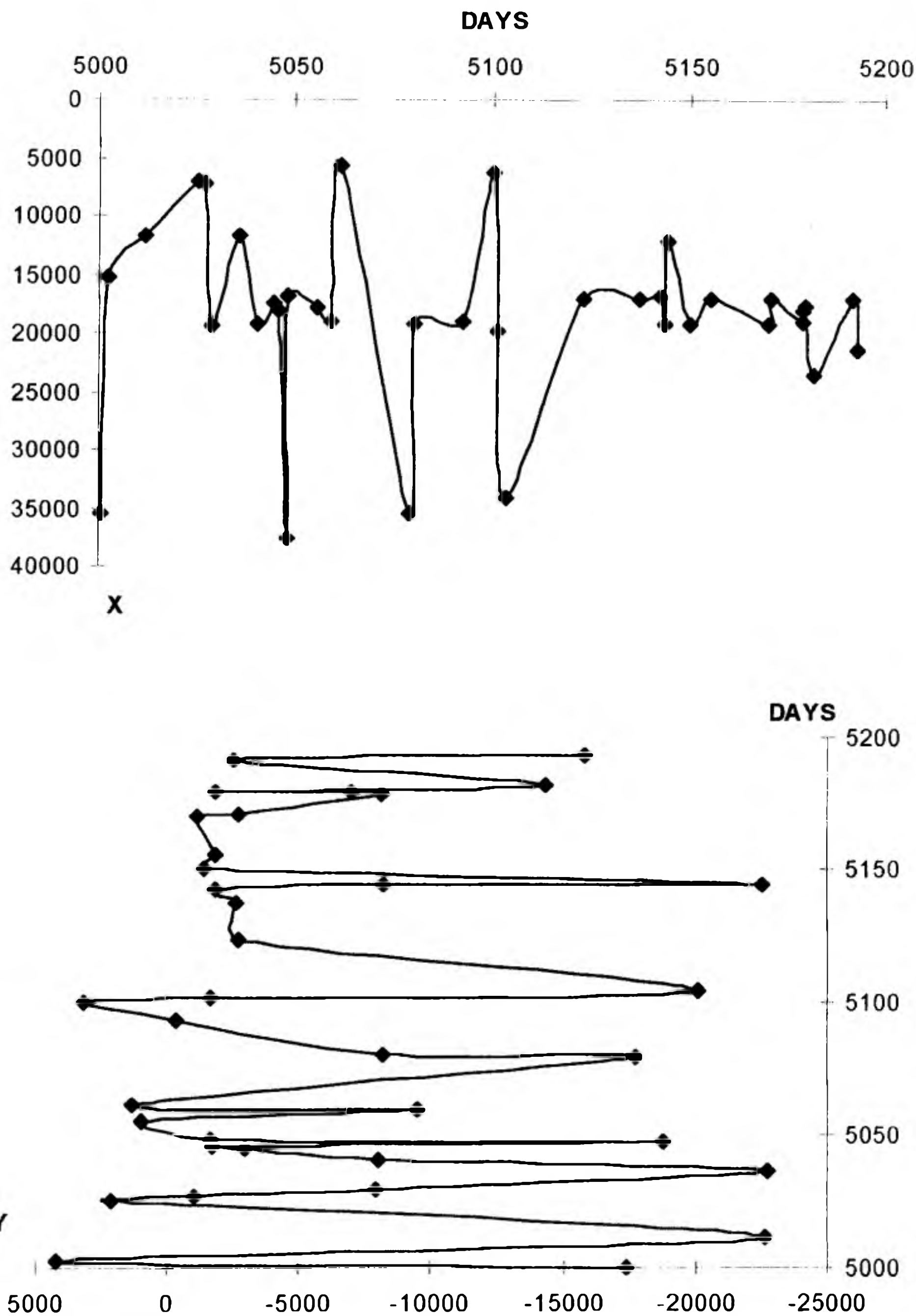


Fig. 6. Oscillations of X and Y co-ordinates for tremors occurred between 9-09-1990 and 20-03-1991

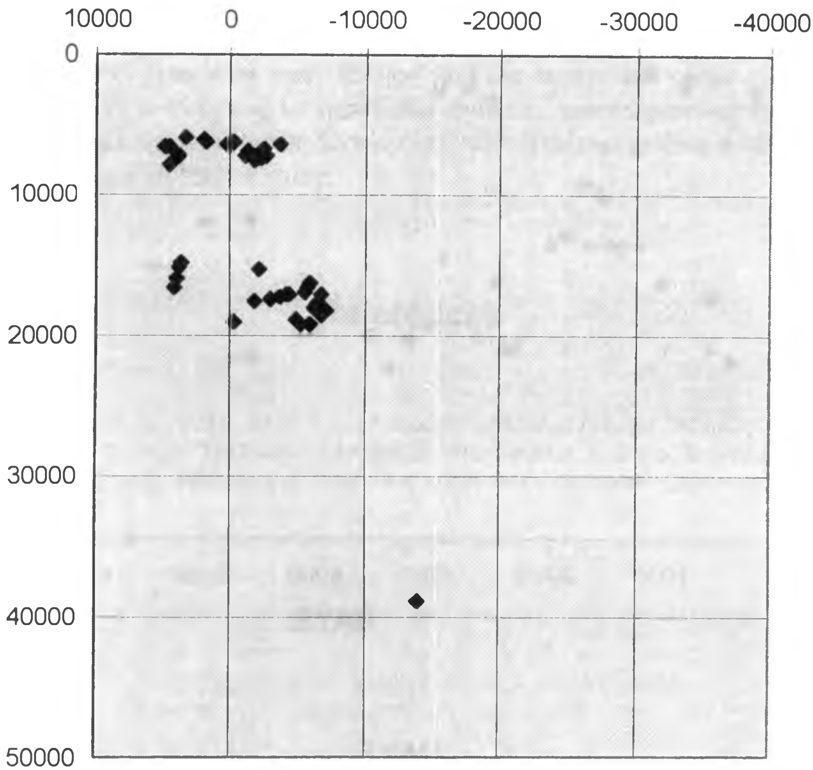


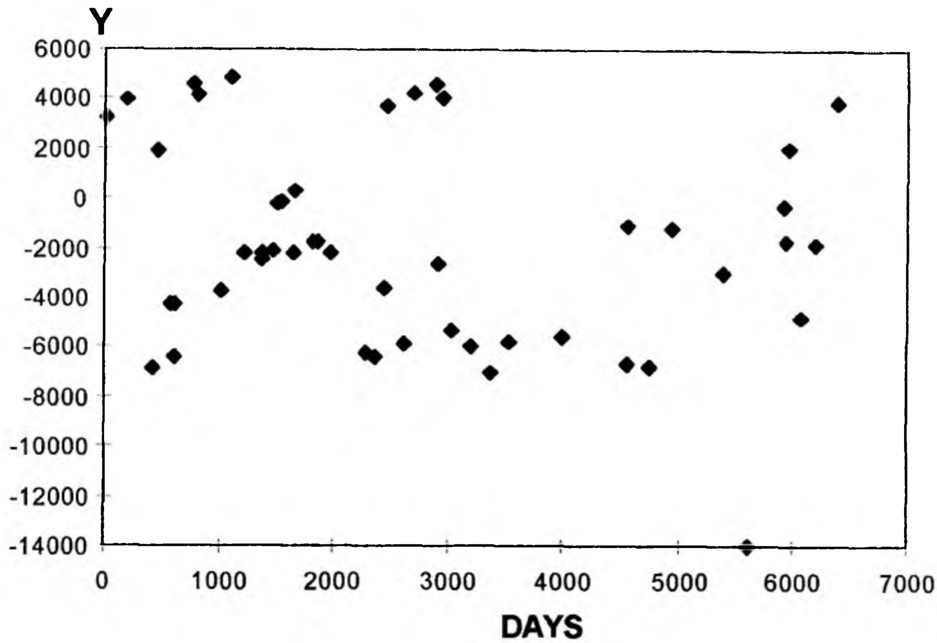
Fig. 7. The localisation of epicentres of the strongest tremors ($E \geq 100$ MJ) occurred in the USCB during the 1977–1994 period

Conclusions

Inhomogenity of spatial tremor distribution suggests the fractal character of seismic phenomena in the USCB. The fractal dimension of surface probability of tremor occurrence accounted for the whole USCB area was equal to 1,18. It means that tremors tend to concentrate in some clusters which are near one-dimensional objects from topological point of view.

The variability of tremor epicentre co-ordinates points to existing of some attractors. X co-ordinates of tremor epicentres concentrate around several attracting points whereas Y co-ordinates show rather chaotic behaviour. These regularities are especially characteristic for the strongest tremors.

The descent of seismic activity in Bytom syncline and Kazimierz syncline and concurrent ascent of seismic activity in Main syncline point to migration of



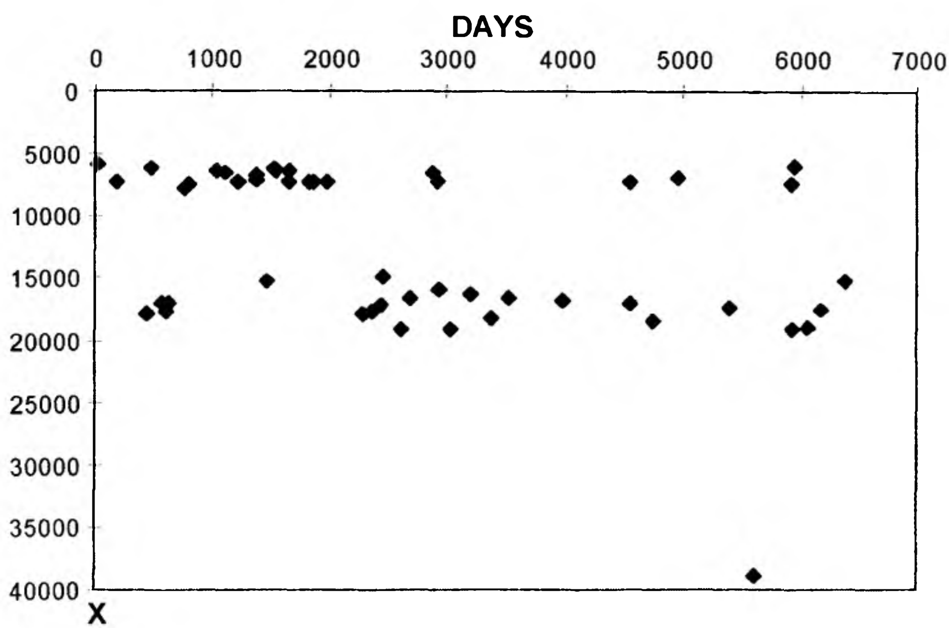


Fig. 8. X and Y co-ordinates temporal distributions of the strongest tremors ($E \geq 100$ MJ)

seismicity in the USCB. This phenomenon can't be explained on the ground of changes in mining activity and spreading of exploited area.

The results of presented study suggest that the origination of the strong tremors in the USCB is triggered by non-linear dynamic process, having the regional range and connected with recent tectonic activity. The recognition of this process should be the goal of further study.

References

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