

DISTRIBUTION OF SEISMS FOCI DURING THE MINING OF 19TH EASTERN LONGWALL AND EASTERN INCLINED LONGWALL № 3

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РОЗПОДІЛ ОСЕРЕДКІВ СЕЙСМІЧНИХ ЯВИЩ ПРИ ВІДПРАЦЮВАННІ 19 СХІДНОЇ ЛАВИ ТА СХІДНОЇ УХИЛЬНОЇ ЛАВИ №3

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РАСПРЕДЕЛЕНИЕ ОЧАГОВ СЕЙСМИЧЕСКИХ ЯВЛЕНИЙ ПРИ ОТРАБОТКЕ 19 ВОСТОЧНОЙ ЛАВЫ И ВОСТОЧНОЙ УКЛОННОЙ ЛАВЫ №3

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Annotation. The introduction of modern digital seismological monitoring systems at mining facilities has opened up wide opportunities for practical application and implementation of forecasting techniques used in seismology. All this determines the exceptional relevance of the problem in controlling technogenic seismicity, as well as the development of effective measures to prevent the negative effects associated with large dynamic phenomena in mines. The purpose of the paper is to research the influence of mining-geological conditions on the distribution peculiarities of technogenic seismicity foci at the O.F. Zasiadko mine during the development of 19th eastern longwall and Eastern inclined longwall (EIL) № 3. The seismic acoustic system ARAMIS M/E, developed by the Polish company EMAG, was applied at this mine. This system is designed to record seisms, determine their energy and coordinates of the foci epicenters. The system includes massif vibration sensors (geophones) located in the mine workings, signal transmission channels and ground-based recording modules. Seismological monitoring of the rock massif was carried out when performing stoping in 18th eastern longwall, Eastern inclined longwall etc. The sensors were placed in the plane of the m_3 bed. The analysis was performed on the basis of such calculated indicators as the density function of seisms P , the average relative energy $E_{av,rel}$, as well as spatial location of foci in each longwall. These indicators made it possible to compare the number and intensity of seisms that occurred in each longwall under the various mining-geological conditions. To research the nature of technogenic fracturing, one of the methods of fractal geometry was used – the law of frequency of Guttenberg-Richter, which describes the dependence of the number of occurring phenomena on their size. In particular, there are fluctuations in the level of activity A and slope angles γ by months as the longwall mines. The change in the slope of magnitude-frequency relationship showed a greater dependence of the parameters on the mining-geological conditions and the degree of disturbance in the mining section and less on the time. The nature of the change in the magnitude-frequency relationship for the 19th eastern longwall and EIL #3 indicates a significant difference in their seismic activity. Longwalls, mined out in different mining-geological conditions, differ in the relative energy of seisms, in their number, recording time and spatial location of foci.

Keywords: seismological monitoring, seismic activity, relative energy.

Introduction. Intensive exploitation of coal deposits leads to the emergence of various dynamic manifestations of rock pressure in the rock massif. The form, nature and intensity of dynamic phenomena are extremely varied. Their development takes place not only in seismically active regions, but also in regions that are traditionally considered to be geodynamically quiet ones (regions with minor seismicity). So in Donbas after the closure of mines there is an increase in the number of technogenic earthquakes.

With an increase in the depth of the worked horizons, mining began to be

complicated by the cases of large-scale manifestation of rock pressure in the form of mountain-tectonic bumps and technogenic earthquakes caused by the combined action of natural and technogenic factors. The complex nature of large dynamic phenomena in mines has arisen an increased interest in seismological methods, since seisms reflect the process of cracking, and fractured zones are potential areas of increased outburst hazard and zones of methane accumulation. The introduction of modern digital seismological monitoring systems at mining facilities has opened up wide opportunities for practical application and implementation of forecasting techniques used in seismology.

All this determines the exceptional relevance of the problem in controlling technogenic seismicity, as well as the development of effective measures to prevent the negative effects associated with large dynamic phenomena in mines. The purpose of the paper is to research the influence of mining-geological conditions on the distribution peculiarities of technogenic seismicity foci at the O.F. Zasiadko mine during the development of 19th eastern longwall and Eastern inclined longwall (EIL) №3.

Realization of this purpose required the solution of certain tasks, the main of which are: influence analysis of mining-geological conditions on the nature of the technogenic seismicity manifestation and identification of distribution peculiarities of technogenic seismicity foci in various sections of the mine.

Methods. To research the influence of mining-geological conditions on the distribution peculiarities of technogenic seismicity foci, we used the results of seismological observations conducted at the O.F. Zasiadko mine. The seismic acoustic system ARAMIS M/E, developed by the Polish company EMAG, was applied at this mine. This system is designed to record seisms, determine their energy and coordinates of the foci epicenters. The system includes massif vibration sensors (geophones) located in the mine workings, signal transmission channels and ground-based recording modules. Seismological monitoring of the rock massif was carried out when performing stoping in 18th eastern longwall, Eastern inclined longwall etc. The sensors were placed in the plane of the m_3 bed. This arrangement allowed us to cover the mine field with a total area of about 10 km^2 . At the sensor installation site, the m_3 bed lies at a depth of 1000 – 1400 m, amount of inclination is $7^\circ - 10^\circ$ [1].

To analyze the distribution of technogenic seismicity foci, such indicators as the density function of seisms P were calculated:

$$P = N/S;$$

where: N – the number of registered seisms within the longwall; S – longwall square.

And the average value of the relative energy $E_{av.rel}$:

$$E_{av.rel} = \Sigma E_{rel}/N;$$

where: ΣE_{rel} is the sum of energies of seisms foci within the longwall.

These indicators made it possible to compare the number and intensity of seisms that occurred in each longwall under the various mining-geological conditions.

To research the nature of technogenic fracturing, one of the methods of fractal geometry was used – the law of frequency of Guttenberg-Richter, which describes the dependence of the number of occurring phenomena on their size [2].

The law of frequency describes the destruction process of environment statistically, and the energy distribution E of the number of seismic pulses N recorded in the massif is written in the following formula:

$$\lg N = A - \gamma \cdot \lg E;$$

The parameters of the magnitude-frequency relationship — inclination to the abscissa axis γ and level A — are among the most important quantitative characteristics of the seismic regime. Inclination of the graph reflects the ratio between the number of strong and quiet events, the level of the graph is their total intensity in the rock massif.

Results and discussion. The solution of the tasks was carried out using analysis of seismic data obtained at the O.F. Zasiadko mine when the seismological monitoring of 19th eastern longwall and EIL №3.

On average, 300-400 events with relative seismic energies from 10^1 to 10^5 conventional units were recorded at the mine during the month. For the period 2009-2014 years, 17052 events were recorded.

The 19th eastern longwall was mined along the strike of rocks, to the left along it there was the mined-out area of the 18th eastern longwall.

EIL №3 was going to the rise, to the left of it there was an unmined massif complicated by tectonic disturbances, to the right a mined-out area of EIL (Fig. 1).

Seismological monitoring of the 19th eastern longwall was carried out from the beginning to the end in the mining of a longwall, while at EIL №3, seismological observations were made for only one third of the total length of the longwall (up to the A-B line, Figure 1).

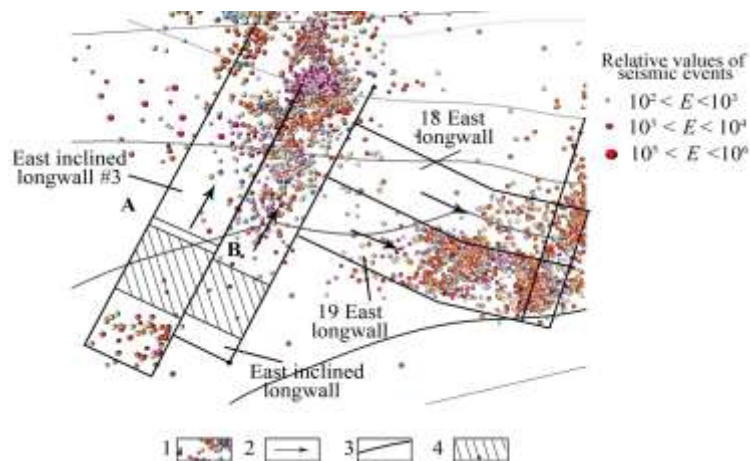


Figure 1 - Seisms of varying intensity, recorded during mining of the m_3 bed for the 2009-2014 period. 1 – projections onto the plane of seisms epicenters; 2 – the direction in the mining of a longwall; 3 – isolines of the m_3 bed; 4 – seismic quiescence zone

For these longwalls, an analysis of recorded seisms was performed, as well as comparison with similar results from the 18th eastern longwall and EIL was made [3].

The analysis was performed on the basis of such calculated indicators as the density function of seisms P , the average relative energy $E_{av.rel}$, as well as spatial location of foci in each longwall. The results of indicators are presented in Table 1.

Table 1 - Indicators of seisms in longwalls

Longwall name	Events quantity, N (unit)	Density function of seisms, P (unit/m ²)	Average relative energy, E_{av} (conv. units)
18th eastern longwall	1441	0.024	$0.9 \cdot 10^3$
19th eastern longwall	3388	0.023	$4.4 \cdot 10^3$
EIL	3608	0.024	$1.0 \cdot 10^4$
EIL #3	372	0.009	$8.1 \cdot 10^4$

It follows from the Table that for different values of N and the square of worked-out longwalls, the density of seisms has almost the same value, i.e., density function of seisms for all longwalls is alike. The low value of P for EIL №3 is probably due to the fact that monitoring was carried out for only one third of the longwall.

During the mining of the m_3 bed at the 19th eastern longwall, seisms moved after the face advance and were evenly distributed within the technological sizes of the longwall.

The emergency of seisms foci were recorded mainly forward of the face and in the regular roof caving zone. This longwall is characterized by low energies of the recorded events ($10^2 - 10^3$ conventional units). A similar pattern was observed when mining the 18th eastern longwall.

A common feature in the development of the 18th and the 19th eastern longwalls is a large number of seisms with low energy of foci within the longwall being mined. There were no significant differences in the manifestations of seismic activity of the 18th and the 19th eastern longwalls.

Analysis of the distribution of technogenic seismicity foci during the mining of EIL and EIL №3 showed the following: both longwalls are characterized by seisms with high relative energy of foci ($10^4 - 10^5$ conventional units) and a small number with low ($10^2 - 10^3$ conventional units).

The peculiarity of the EIL №3 mining is that the fixed seisms foci are distributed over a considerable area, far beyond the mined-out area of the longwall (Fig. 1). This pattern of seisms distribution began to take shape during the EIL mining. The foci were located far beyond the longwall. It is possible that such a high activity of cracking ($10^4 - 10^5$ conventional units) is due to the fact that the section is in a shear zone, which is currently active. The areas with the most intense cracking can be considered as zones favorable for gas accumulation, which can be associated with abnormal gas manifestations in mines [4, 5]. It is possible that the gas-dynamic event

that occurred at EIL #3 on March 24, 2015, is certainly connected with such a zone. In the longwall there was a catastrophic gas breakthrough in to the working. The gas breakthrough made an emergency, and the end result was a methane explosion.

It is characteristic that at the EIL and EIL №3 after four months from the start of mining operations, there are periods of seismic decline in the number of recorded seisms up to their total disappearance. Seismological monitoring of the EIL showed that in October, November and December, only 17 seisms were recorded. At EIL №3 in May, there were no single seisms, that is, a complete seismic quiescence was observed, and in June ten seisms were recorded.

The periods of decline in seismic activity coincide not only in time, but also in space. In Figure 1, the activity depletion areas for each longwall are highlighted by hatching. There is a coincidence in the location of these sections. This indicates that decline in seismic activity is due to the mining-geological conditions.

According to the available data of the registration of seisms at the mine, graphs were constructed for the 19th eastern longwall and EIL№3 for every month of their operation.

The magnitude-frequency relationship for the 19th eastern longwall and EIL №3 were compared with similar for the 18th eastern longwall and the EIL.

Analysis of the magnitude-frequency relationship of the 19th eastern longwall showed that they have a classic view – a straight line with a negative slope.

Figure 2 shows the magnitude-frequency relationship of the 19th eastern longwall for the period May – October. A similar behavior of the graphs was observed during the mining of the 18th eastern longwall.

The slope angles for the 18th and the 19th eastern longwalls are constantly increasing, which is evidence of an increase in the number of events with low energies. The EIL is characterized by the presence of both positive and negative slope angles of graphs, which reflects the influence of mining-geological conditions on the bed mining.

At the EIL in October, November and December, a decline in seismic activity is observed (Fig. 3). At EIL #3, the first four months, the magnitude-frequency relationship also looks like a straight line with a negative slope. In April, the angle value of the magnitude-frequency relationship decreases, and in May there is a complete seismic quiescence (Fig. 4).

The moments, when the value of the angles of magnitude-frequency relationship tends to zero or take negative values, coincide in time with the passage of longwalls of geological disturbances sections, bends of a bed, zones of local structures and other anomalies of the massif structure.

The nature of the change in the magnitude-frequency relationship for each longwall indicates a significant difference in their seismic activity.

In particular, there are fluctuations in the level of activity A and slope angles γ by months as the longwall mines. The change in the slope of magnitude-frequency relationship showed a greater dependence of the parameters on the mining-geological conditions and the degree of disturbance in the mining section and less on the time.

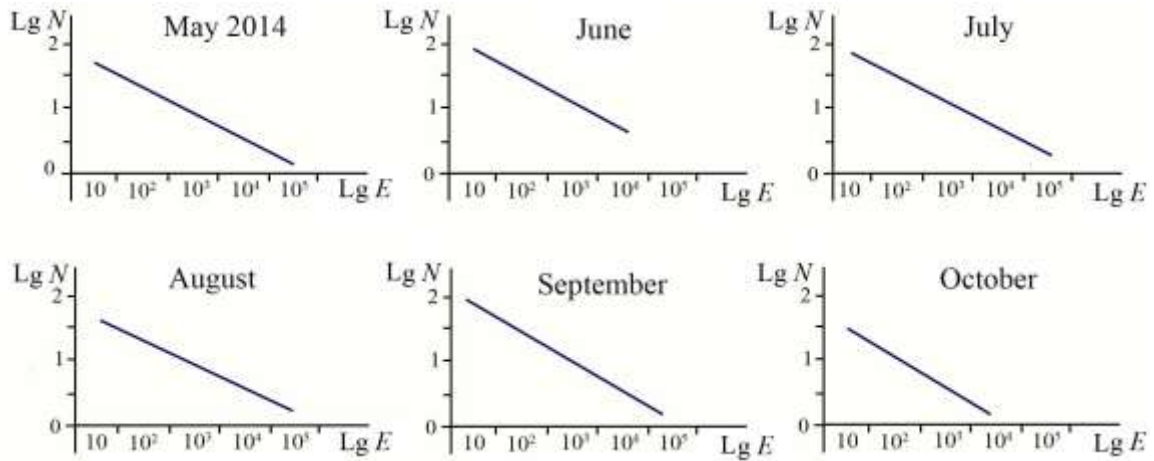


Figure 2 - Fragment of magnitude-frequency relationship of the 19th eastern longwall, May – October period, 2014

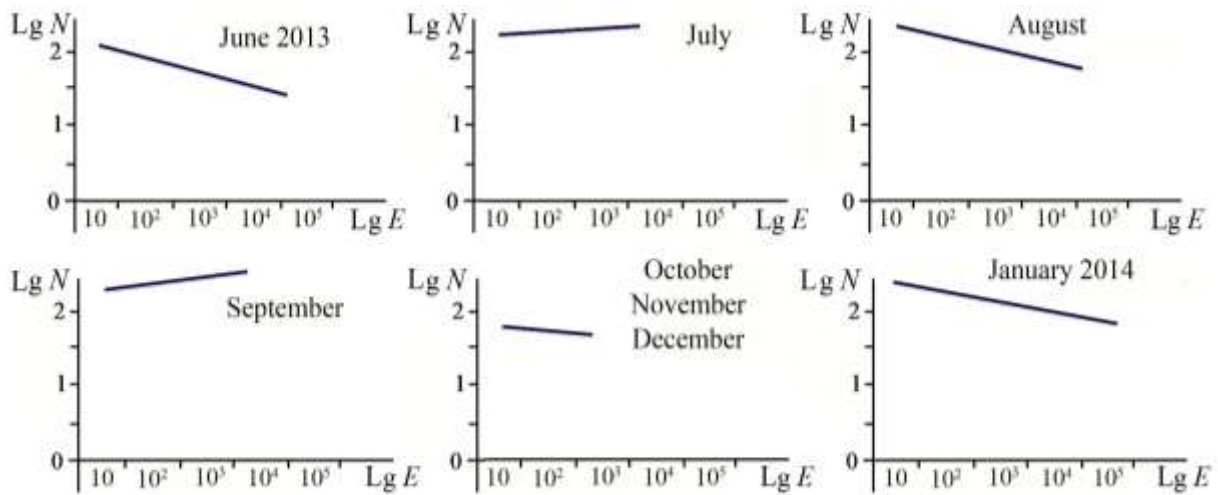


Figure 3 - Fragment of magnitude-frequency relationship at the EIL, June 2013 – January 2014.

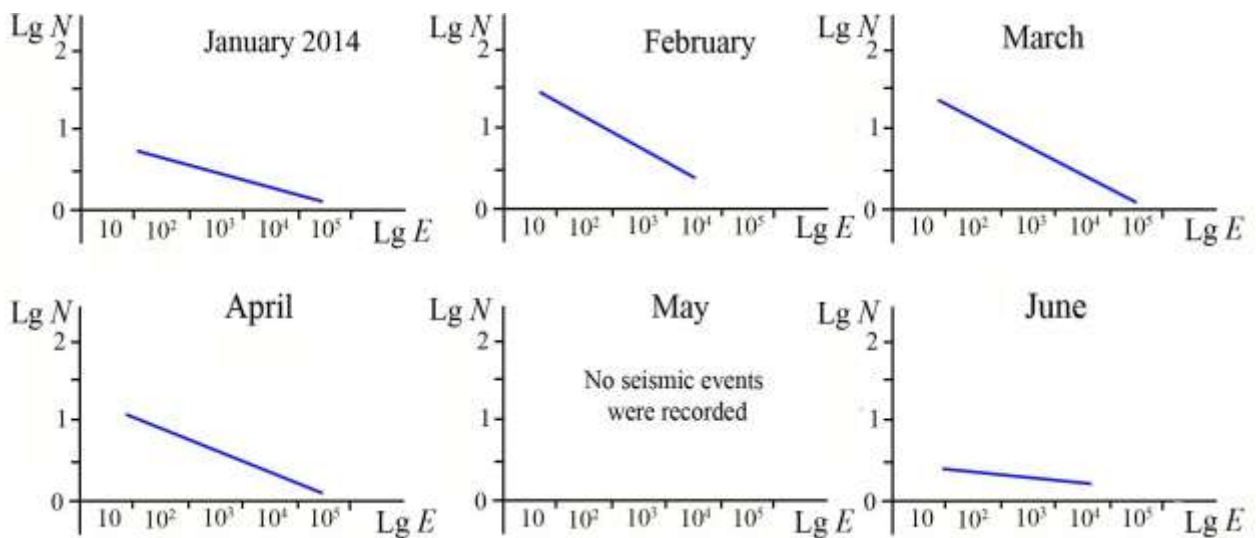


Figure 4 - Fragment of magnitude-frequency relationship at EIL №3, January – June period, 2014

Conclusions.

1. It is established that the distribution of the seismic foci during the mining of the 19th eastern longwall and EIL №3 has its own characteristics, which are caused, first of all, by the influence of mining-geological conditions.

2. Longwalls located in the same mining-geological conditions - (the 18th and the 19th eastern longwalls, the EIL and EIL №3) - have a similar view of the seismic foci distribution. A common feature at the mining of the 18th and the 19th eastern longwalls is a large number of seismic events with low relative energy of foci within the mined longwall. For the EIL and EIL №3 – a large number of seismic events with high relative energy of foci, periods of seismic quiescence, the emergence of foci far beyond the boundaries of the mined longwall.

The nature of the change in the magnitude-frequency relationship for the 19th eastern longwall and EIL №3 indicates a significant difference in their seismic activity.

Longwalls, mined out in different mining-geological conditions, differ in the relative energy of seismic events, in their number, recording time and spatial location of foci.

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Анотація. Впровадження сучасних систем цифрового сейсмологічного моніторингу на об'єктах гірничих робіт відкрило широкі можливості для практичного застосування і впровадження методів прогнозування, що використовуються в сейсмології. Все це визначає виняткову актуальність проблеми управління техногенної сейсмічністю, а також розробку ефективних заходів щодо запобігання негативних наслідків, пов'язаних з великими динамічними явищами в шахтах. Метою статті є дослідження впливу гірничо-геологічних умов на особливості поширення осередків техногенної сейсмічності на шахті ім. О.Ф. Засядька при розробці 19 східної лави і Східної ухильної лави №3. У роботі наведені результати виконаних на шахті ім. О.Ф. Засядька сейсмологічних спостережень по реєстрації і локації сейсмічних явищ, що виникають при відпрацюванні пласта m_3 . На шахті введена в дію сейсмоакустична система ARAMIS M/E, розроблена польською компанією EMAG. Дана система призначена для реєстрації сейсмічних явищ, визначення їх енергії та координат епіцентрів явищ. Система включає в себе датчики вібрації масиву (геофони), розміщені в гірничих виробках, канали передачі сигналів та наземні реєструючі модулі. Рішення поставлених завдань здійснювалося за допомогою аналізу сейсмічних даних отриманих на шахті ім. О.Ф. Засядька при сейсмологічному моніторингу 19 східної лави і Східної ухильної лави №3 (СУЛ №3) Для зазначених лав було виконано аналіз зареєстрованих сейсмічних явищ, а також було проведено порівняння з аналогічними результатами 18 східної лави і СУЛ. Аналіз виконувався на основі таких розрахованих показників як щільність розподілу сейсмічних явищ (P), середня величина відносної енергії ($E_{\text{ср. відн.}}$), а також просторове розташування осередків по кожній лаві. Для дослідження природи техногенної тріщинуватості був застосований один з методів фрактальної геометрії - закон повторюваності Гуттенберга-Ріхтера, в якому описується залежність числа явищ, що відбуваються від їх величини. Характер зміни графіків повторюваності по кожній лаві свідчить про значне відміну їх сейсмічної активності. Зміна нахилу графіків повторюваності показало велику залежність параметрів від гірничо-геологічних умов і ступеня порушення ділянки відпрацювання, і меншу - від часу. Характер зміни графіків повторюваності по 19 східній лаві і ВУЛ №3 свідчить про значну відміну їх сейсмічної активності. Лави, що відпрацьовувались в різних гірничо-геологічних умовах, відрізняються по відносній енергії сейсмічних явищ, за їх кількістю, часом реєстрації і просторовому розташуванню осередків.

Ключові слова: сейсмологічний моніторинг, сейсмічна активність, відносна енергія.

Анотація. Внедрение современных систем цифрового сейсмологического мониторинга на объектах горных работ открыло широкие возможности для практического применения и внедрения методов прогнозирования, используемых в сейсмологии. Все это определяет исключительную актуальность проблемы управления техногенной сейсмичностью, а также разработку эффективных мер по предотвращению негативных последствий, связанных с крупными динамическими явлениями в шахтах. Целью статьи является исследование влияния горно-геологических условий на особенности распространения очагов техногенной сейсмичности на шахте им. А.Ф. Засядько при разработке 19 восточной лавы, и Восточной уклонной лавы №3. В работе приведены результаты выполненных на шахте им. А.Ф. Засядько сейсмологических наблюдений по регистрации и локации сейсмических явлений, возникающих при отработке пласта m_3 . На данной шахте введена в действие сейсмоакустическая система ARAMIS M/E, разработанная польской компанией EMAG. Данная система предназначена для регистрации сейсмических явлений, определения их энергии и координат эпицентров очагов. Система включает в себя датчики вибрации массива (геофоны), размещенные в горных выработках, каналы передачи сигналов и наземные регистрирующие модули. Решение поставленных задач осуществлялось с помощью анализа сейсмических данных полученных на шахте им. А.Ф. Засядько при сейсмологическом мониторинге 19 восточной лавы и Восточной уклонной лавы №3 (ВУЛ №3). Для указанных лав был выполнен анализ зарегистрированных сейсмических явлений, а также было проведено сравнение с аналогичными результатами 18 восточной лавы и ВУЛ. Анализ выполнялся на основе таких рассчитанных показателей как плотность распределения сейсмических явлений (P), средняя величина относительной энергии ($E_{\text{ср. отн.}}$), а также

пространственное расположение очагов по каждой лаве. Для исследования природы техногенной трещиноватости был применен один из методов фрактальной геометрии – закон повторяемости Гуттенберга-Рихтера, в котором описывается зависимость числа происходящих явлений от их величины. Характер изменения графиков повторяемости по каждой лаве свидетельствует о значительном отличии их сейсмической активности. Изменение наклона графиков повторяемости показало большую зависимость параметров от горно-геологических условий и степени нарушенности участка отработки, и меньшую – от времени. Характер изменения графиков повторяемости по 19 восточной лаве и ВУЛ №3 свидетельствует о значительном отличии их сейсмической активности. Лавы, отрабатываемые в разных горно-геологических условиях, отличаются по относительной энергии сейсмических явлений, по их количеству, времени регистрации и пространственному расположению очагов.

Ключевые слова: сейсмологический мониторинг, сейсмическая активность, относительная энергия.

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