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GEOMECHANICAL AND GEODETIC METHODS OF PREDICTION OF CHANGES IN THE STATE OF THE GEOLOGICAL ENVIRONMENT IN THE MINING REGION

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Abstract. The mining industry is one of the most destructive for the environment. The properties of rocks, the state of the natural complex, the relief, a surface and underground water regime change significantly around the deposit being developed, over a large area and at depth, which leads to the development of negative natural and technogenic processes, such as landslides, shifts, flooding, etc.

Therefore, it is necessary and urgent to develop forecasts of changes in the state of the geological environment for the early development and application of measures that will reduce the negative impact or even prevent the development of landslides and flooding.

In the article, the main negative natural and technogenic processes developed in mining regions are discussed. It is noted that their development depends on the factors of all processes of mining production, their regime and capacity, as well as the state of the environment itself, which preceded the action of these processes.

It is shown that the parameters of the interaction of different types of environments, as well as their mutual location, also affect changes in the state of the geological environment. It is noted that the areas of the primary disturbed environment for conditions of open development of the deposit, as well as the areas of technogenic environments are calculated during the design period of the development of the deposit. And the area of the secondary disturbed environment is individual for each object, it can be roughly calculated using the presented expressions.

Since the behavior of changes in the geological environment at each of the deposits being developed is different and depends on many factors, it is proposed to perform forecasting using geomechanical modeling of the state of a complex system. Due to the fact that such forecasting requires a large amount of data, it is proposed to obtain them by geodetic methods, namely by performing lidar surveying, which will allow obtaining data not only on the position in space of all points of the research area, but also to assess the state of the territory itself, which is impossible with other geodetic methods.

Keywords: forecasting, state change, environmental area, geodetic methods, quarry, dump, 3d model of the territory, lidar survey, modeling.

1. Introduction

During the extraction of minerals, negative natural and man-made processes develop, which lead to a change in the state of the geological environment in the mining region.

Changes in the state of the geological environment are caused both directly by mining operations and as a result of the interaction of different types of environments. The development of negative natural and man-made processes within the territories disturbed by mining activity is directly influenced by the processes of mining production (such as the extraction of rocks and minerals from the massif, the storage of empty rocks in dumps, the storage of beneficiation tailings in tailings), the factors of these processes (the order of working out the deposit , applied technology, productivity, mining technical and geometric parameters) and their mode of action (in time - constant, temporary); in terms of power - static, dynamic (intensive, extensive) (Fig. 1).

Definition of types of environments and their classification are given in work [1].

Therefore, it is necessary and urgent to develop forecasts of changes in the state of the geological environment for the early development and application of measures that will reduce the negative impact or even prevent the development of landslides and flooding.

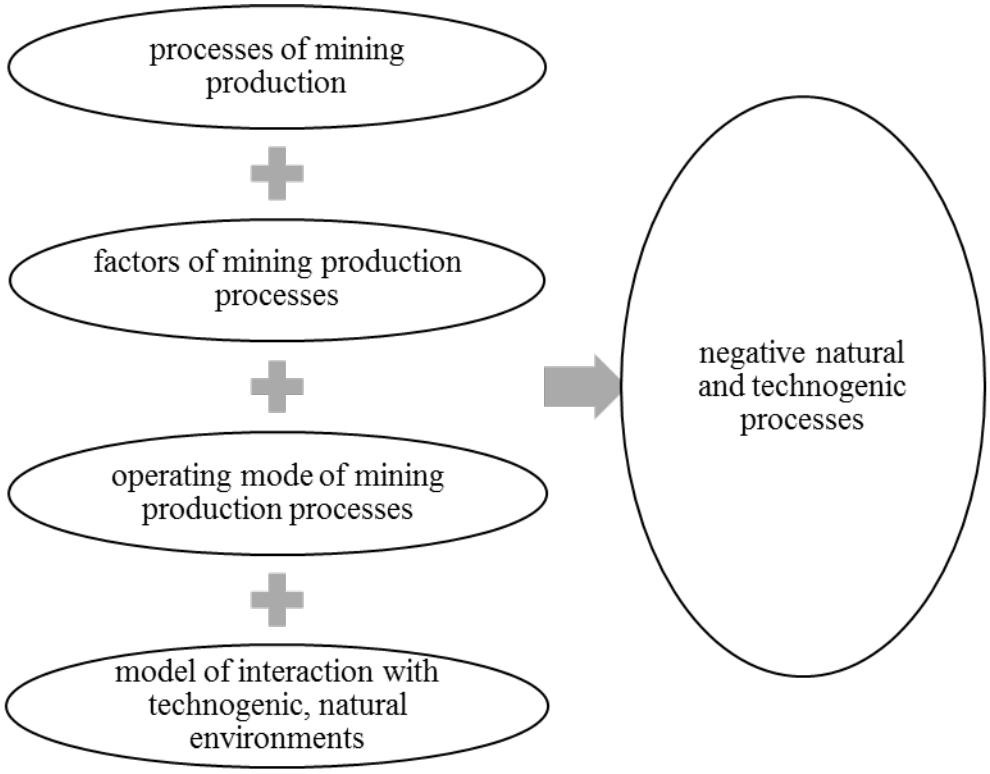


Figure 1 – Scheme for determining the factors that determine the formation and development of dangerous natural and man-made processes in territories affected by mining activities

2. Methods

In the article, based on the results of previous studies using the logical-analytical method, developed an idea about the different types of environment that occur in the places of mineral development. The methods of abstraction and elementary-theoretical synthesis determined the changes that occur in the geological environment during mining operations, and proposed expressions for estimating the areas of territories with changed properties. Through the analysis of applied field research methods, it is proposed to apply geomechanical modeling methods based on precise geodetic surveys using lidars.

3. Results and discussion

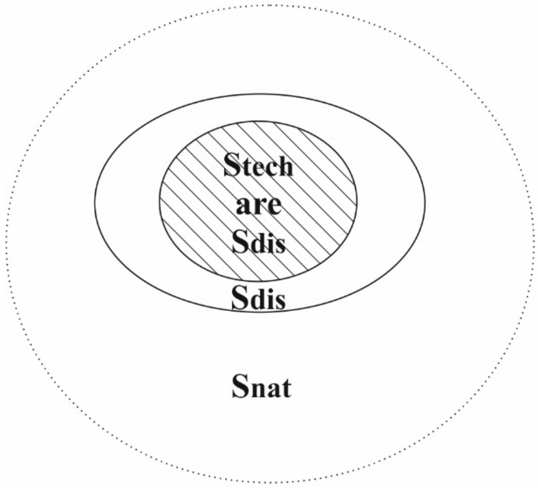
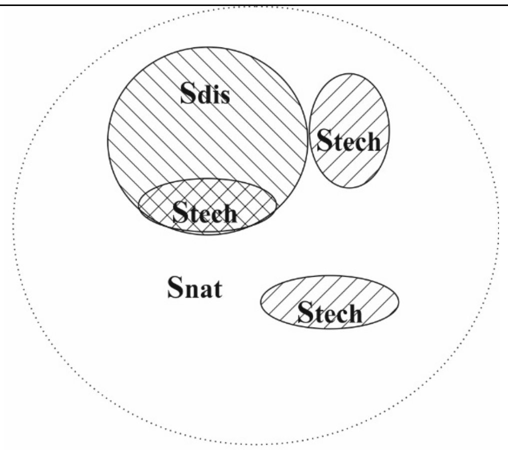
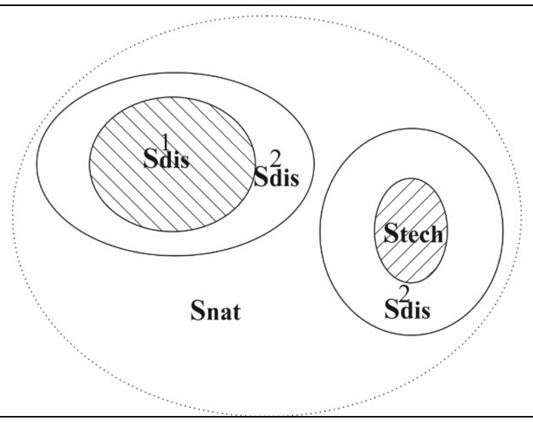
The analysis of factual materials regarding the development of negative natural and man-made phenomena during the development of mineral deposits made it possible to substantiate the models of interaction of different types of environments - natural, disturbed and man-made, which are briefly described in Table 1.

To predict changes in the state of the geological environment based on the above, it is necessary to determine the existing boundaries of different types of environments.

Each of the environments has some area, which can be finite, intermediate or infinite.

The area of the technogenic environment of S_{tech} is limited by its boundaries and may change with projects. Before the emergence of a disturbed environment, that is, until the moment when $S_{dis}>0$ occurs, the area of the technogenic environment $S_{tech} =0$ and, accordingly, the area of the secondary disturbed environment is zero.

Table 1 – Brief description of models of interaction of natural, man-made and disturbed geological environments in the mining region

Schematic image	Model description	Changes in the state of the geological environment
	The formation of a technogenic and disturbed environment always leads to the formation of a disturbed environment under and around it	Flooding or draining of the territory, pollution of soils, underground and surface water, air, changes in the physical and mechanical properties of soils and mining rocks in a disturbed environment. The formation of new (technogenic) forms of relief and, accordingly, the change of natural geomorphological and hydrographic, climatic processes, which in aggregate will lead to the formation of a new natural complex
	The creation of a disturbed environment (extraction of a mineral from the massif) is accompanied by the formation of technogenic environment. At the same time, technogenic environment can be contained both directly in the disturbed area and at some distance from it	
	The disturbed environment can be primary (as a result of mineral extraction) and secondary (under and around the technogenic and disturbed environment).	

The area of the primary disturbed environment S^{1}_{dis} begins to increase with the construction of the enterprise up to a certain point (during the development of a mineral using deepening systems of development), or until the end of the development of the deposit (with constant demolition of the sides of the pits). When developing horizontal or positive deposits with internal dump formation, the area of the primary disturbed environment increases until the moment of the formation of the internal dump, then it decreases to the area of the working zone of the dump (technogenic environment) and becomes constant.

The area of the natural environment S_{nat} is infinite in the part of the atmosphere, in the part of land resources it is limited by the boundaries of the mining region, in the part of surface water it is equal to the catchment area, in the part of underground water it is limited by the boundaries of the corresponding aquifers (or unlimited).

The area of the secondary disturbed environment S^2_{dis} is determined by the borders of the contaminated lands, the borders of the depression funnel, the borders of the deformations on the earth's surface according to the maximum value. At the same time, the boundaries of contaminated land are determined by ecological monitoring, the boundaries of deformations and depression funnels are calculated or determined by observations.

According to the above, it is always possible to determine S^1_{dis}, S_{tech} and even forecast these areas for a certain period.

The area of disturbed geological environment for the planned period can be determined by the expression [3].

The area of the primary disturbed geological environment for the planned period can be determined through the development of mining operations by the expression [3].

At the same time, the future area of the secondary disturbed environment can be determined only by calculations. For the conditions of the underground mining method, the deformation area is determined according to GSTU 101.00159226.001-2003 [2].

The area of the secondary disturbed environment caused by the change in the groundwater regime can be determined by the radius of the depression funnel

$$S_{dis}^2 = \pi \cdot R_1 \cdot R_2 \tag{1}$$

where R_1, R_2 are the large and small radiuses of the depression funnel, which can be determined by the expression [3].

Negative natural and technogenic processes, such as landslides, flooding, dehydration, can occur within the disturbed environment.

Flooding or dehydration of the territory occurs with unevenness

$$P + C + Q_p + Q_{p.und} \neq (E_{eva} + Q_0^{dis} + Q_{0und}^{dis}), \tag{2}$$

where P is the average value of the precipitation layer for the entire area S; C is the average value of the condensation layer for the entire area S; Q_p - the average value of the water layer for the area S, which enters its boundaries during the time period T by surface watercourses; $Q_{p.und}$ - the average for the area *S* value of the layer of water entering its boundaries during the time period *T* by the underground tide; E_{eva} - the average value of the evaporation layer for the entire area *S;* Q_0^{dis} – the average value of the layer of water arriving outside the area of the disturbed territory S_{dis} during the time period *T*, carried away by surface watercourses; Q_{0und}^{dis} - the average value of the layer of water that flows beyond the area of the disturbed territory S_{dis} during the time period *T*, carried away by underground flow.

Here, the left part of the inequality is the revenue part of the water balance of the territory, the right part is the expenditure part.

When the income part of the water balance exceeds the expenditure part - there is a rise in the level of underground water, flooding and waterlogging of certain areas of the territory. In the case when the expenditure part of the water balance is greater than the income part, drainage (dehydration) of the area is noted.

Landslides occur when the massif of clay rocks is excessively wetted and their physical and mechanical properties change.

During the development of a mineral deposit and after its completion, the geological environment undergoes changes that negatively affect both anthropogenic and natural objects. Therefore, it is relevant to forecast such changes, that is, to predict the negative consequences of mining operations.

Forecasting consists in determining the successive changes in the state of the geological environment over a certain period of time under the influence of natural and technogenic processes, such as the extraction of rocks, the storage of waste in dumps and sludge accumulators, drainage, etc. At the same time, it is necessary to take into account the factors of all processes, their regime and power, as well as the state of the environment itself, which preceded the actions of these processes.

Forecasting is possible using geomechanical modeling of the state of a complex system. But any modeling needs a bank of current data. At the same time, the more and better are the data, the better is the forecast.

Obtaining data is possible by various methods of observation. However, geodetic methods that allow obtaining and visualizing data on the position and condition of all terrestrial components of the natural environment seem to be the most accurate.

Of all the applied geodetic methods, laser scanning (lidar surveying) is the most informative, as evidenced by its results at various mining sites (Figure 2).

The accuracy of lidar scanning depends on the model of the used scanner and the frequency of scanning and can reach up to 5 mm. At the same time, the beginning of the deformation of the massif of rocks according to the surveying instructions is a shift of 15 mm. Thus, this type of shooting has sufficient accuracy.

The following order is suggested. Lidar scanning is performed on the research objects in the initial time period t_0. With the development of mining operations, after a period of time Δt, a repeated survey is performed within the estimated area of the secondary disturbance of the geological environment.

Depending on the size of the pit, shooting can be done from one or more points. Combine the obtained point cloud to create a complete 3D terrain model.

With the help of the appropriate software, the images are combined and the areas that have acquired changes are established. The scale of changes, direction, speed is determined. Several repeated series of images allow to analyze in more detail the changes taken place and, accordingly, to make a forecast of such changes for any period of time in the future ti, which will correspond to a certain situation of mining operations and the applied technology.

a)

b)

c)

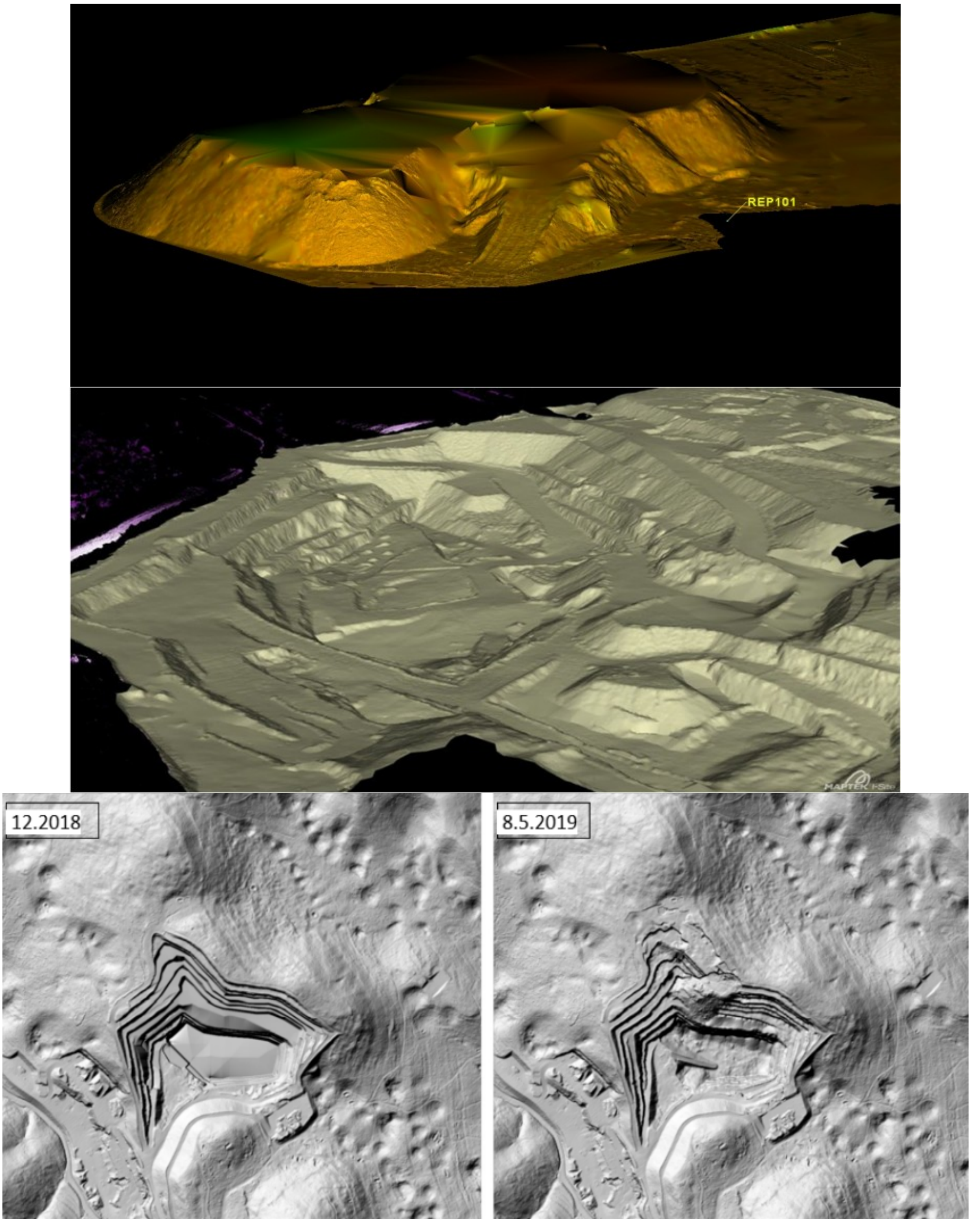


Figure 2 – Lidar survey results: a) coal formations [4]; b) quarry cup [4]; c) change in time of the working zone of the quarry [5]

The use of lidar surveying allows to determine the actual values of S_{tech}, S^1_{dis}, S^2_{dis}, l_P, L_F, V_{ov}, h_d, as well as the depth of disruption of the geological environment, and a series of repeated surveys makes it possible to assess changes in the state of rocks, natural complex, relief, surface water regime.

To predict changes in the water regime of the territory, it is suggested to perform numerous simulations in ModFlow on the basis of the obtained surface surveys and regime observation data on wells.

4. Conclusions

The development of negative natural and technogenic processes within the territories disturbed by mining activity is directly influenced by the processes of mining production (such as the extraction of rocks and minerals from the massif, the storage of empty rocks in dumps, the storage of beneficiation tailings in tailings), the factors of these processes (the order of working out the deposit , applied technology, productivity, mining technical and geometric parameters) and their mode of action (in time - constant, temporary; in terms of power - static, dynamic (intensive, extensive)). Negative processes include shifts, landslides, flooding, dehydration, karst processes, etc.

To predict changes in the state of the geological environment, it is proposed to use lidar surveying with repetition after an interval of Δt, and to predict changes in the underground water regime by modeling in ModFlow.

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ГЕОМЕХАНІЧНІ ТА ГЕОДЕЗИЧНІ МЕТОДИ ПРОГНОЗУВАННЯ ЗМІНИ СТАНУ ГЕОЛОГІЧНОГО СЕРЕДОВИЩА В ГІРНИЧОДОБУВНОМУ РЕГІОНІ

Бубнова О.А.

Анотація. Гірничодобувна промисловість є однією із самих руйнівних для довкілля. Навколо родовища, що розробляється, на великій площі та по глибині суттєво змінюються властивості гірських порід, стан природного комплексу, рельєф, водний режим поверхневих та підземних вод, що призводить до розвитку негативних природно-техногенних процесів, таких як зсуви, зрушення, підтоплення тощо.

Тому необхідним та актуальним є розроблення прогнозів зміни стану геологічного середовища для завчасного розроблення та застосування мір, що дозволять зменшити негативний вплив або навіть попередити розвиток зсувів та підтоплень.

В статті розглянуто основні негативні природно-техногенні процеси, що розвиваються в гірничодобувних регіонах. Зазначено, що їх розвиток залежить від факторів всіх процесів гірничого виробництва, їх режиму та потужності, а також стану самого середовища, який передував дії цих процесів.

Показано, що на зміни стану геологічного середовища, впливають також параметри взаємодії різних типів середовищ, а також їх взаємне розташування. Зазначено, що площі первинного порушеного середовища для умов відкритої розробки родовища, а також площі техногенних середовищ розраховуються в період проєктування розробки родовища. А площа вторинного порушеного середовища індивідуальна для кожного об'єкту, її можна наближено розрахувати за представленими виразами.

Оскільки поведінка зміни геологічного середовища на кожному із родовищ, що розроблюється, різна та залежить від багатьох факторів, то пропонується виконувати прогнозування із застосуванням геомеханічного моделювання стану складної системи. В зв'язку із тим, що таке прогнозування потребує великого обсягу даних, запропоновано отримувати їх геодезичними методами, а саме шляхом виконання лідарного знімання, що дозволить отримати дані не тільки про положення у просторі всіх точок досліджувальної території, а й оцінити стан самої території, що неможливо іншими геодезичними методами.

Ключові слова: прогнозування, зміна стану, площа середовища, геодезичні методи, кар'єр, відвал, 3d-модель території, лідарне знімання, моделювання

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