

B. B. Imansakipova,
orcid.org/0000-0003-0658-2112,
Z. D. Baygurin,
orcid.org/0000-0002-6958-0707,
A. A. Altayeva,
orcid.org/0000-0002-1675-6828,
D. G. Kanapiyanova,
orcid.org/0000-0003-2819-3791,
B. Myngzhassarov,
orcid.org/0000-0001-6912-2303

Satbayev University, Almaty, the Republic of Kazakhstan, e-mail: imansakipova@mail.ru

DEVELOPMENT OF AN EFFECTIVE METHOD FOR ZONING THE EARTH'S SURFACE IN HETEROGENEITY OF THE ROCK MASS

Purpose. Development of a method for zoning the field surface according to the degree of problem by the criterion based on changes in the geoenergy of the rock mass, determined by the difference between the sum of potential gravitational energies and elastic deformations of the rock mass in the initial and current states.

Methodology. The research was performed using methods of cause-effect analysis, physical modeling and geomechanics.

Findings. The method for zoning the field surface according to the degree of problem is developed on the basis of energy parameters determining the state of a heterogeneous rock mass and characterizing the general laws of manifestation and development of geomechanical processes. The method allows us to identify potentially dangerous areas on the earth's surface that are at the stage of involvement in the process of displacement, and therefore cannot be identified by ground observations and remote sensing methods. Based on the method, recommendations for optimizing geodetic monitoring have been developed.

Originality. A method has been developed that increases the reliability of the zoning of the earth's surface of the field according to the degree of problematicity, based on a criterion involving parameters that determine the geoenergy of the rock mass in the current and initial states.

Practical value. The method improves the quality of situational control, predicts the occurrence of risk situations and their development, and optimizes geodetic monitoring.

Keywords: *deposit occurrence, energy criteria, potential energy, geoenergy, zoning criteria*

Introduction. On the territory of fields under development, as a result of natural-technogenic and geomechanical processes in the rock mass, abnormal deformations of the geological environment may occur, the stability of the host rocks is violated; as a result, rock mass shifts occur in the area of influence of mining workings [1].

The intensity, depth and scale of mining operations lead to changes in the stress-strain state of the massif, the manifestation of geomechanical processes is activated, and the amount of displacement increases with possible access to the earth's surface as subsidence or dips [2]. This creates a threat to the production and loss of minerals. Safe mining operations in these conditions require the organization of effective monitoring of the state of the rock mass on the basis of modern technologies of remote sensing, geodetic and surveying methods of observation. Combining the capabilities of various methods into a single system can significantly improve the quality of monitoring. A significant disadvantage of traditional methods of observation is the lack of opportunities to identify problem areas that are at the stage of involvement in the process of displacement.

Problem statement. The uncertain duration of such condition of the sections due to the ambiguity of the estimation of

the velocity vector of deformation disturbance propagation coming from the depth of the rock mass due to the complexity of geomechanical processes may lead to unforeseen consequences. This may result in an unpredictable occurrence of a crisis situation at an unexpected time in an uncertain place on the field surface in the form of subsidence or dips [3].

For example, currently, mining enterprises in China, South Africa, Chile, Ukraine, Russia and Kazakhstan ("Shakhterskaya-Glubokaya", "Mponeng", "Western Deep Levels Mine", "Witwatersrand", "Krasnoyarsk", "SUEK-Kuzbass", "Kazakhmys", and others) are experiencing sinkholes on the surface that are not predicted by regulatory methods [4].

Thus, the development and improvement of methods for detecting such sites are of considerable practical interest. One of the promising ways to solve this problem is the methods of zoning the field surface according to the degree of problems. The methods are based on the established causal relationship between states and processes in the rock mass and the surface. Zoning is carried out according to a criterion, whose basis consists of parameters that characterize the state of the massif. The control accuracy is determined by the selected criteria. Therefore, the success of the zoning method depends directly on the choice of parameters included in the basis of the criterion and which should fully characterize the state, physical

and mechanical properties and geomechanical processes in the rock mass [5].

As practice shows, the most effective methods of zoning are those that use energy parameters as a criterion. Geoenergy is a universal quantitative measure of the movement and interaction of bodies, so its change, transition to other types of energy most fully reflect the state of an inhomogeneous massif and characterize the general physical laws of geomechanical processes [2]. In this regard, to ensure the reliability of the assessment of risk situations and their possible prediction, we propose a method of zoning the surface according to the criterion based on the change in geoenergy, determined by the difference between the sum of potential gravitational energies and elastic deformations of the rock mass in the initial and current states under conditions of its heterogeneity.

Critical analysis. Most of the known methods for predicting risk situations are based on an analytical approach, while identifying patterns of influence on changes in the properties and state of the rock mass of the violation of its continuity [6]. The methods allow us to evaluate the manifestation, intensity, and direction of development of geomechanical processes, including displacement processes. The main drawback of the methods is the limited orientation of research on local areas of the field. In zoning methods, this disadvantage is eliminated by simultaneously ranking the surface of the field. Zoning is performed using the same algorithm for all methods [5], so the accuracy of zoning is determined by the choice of parameters of the criterion basis that characterize the state and properties of the rock mass [7].

At the Zhezkazgan field, to forecast the collapse, there is used a method based on the well-known fact that the parameters of a geodynamic event and the time of its development depend mainly on the height of the worked area and the underlying rocks from the boundary of the worked space to the surface H and the capacity of the work m . The criterion for predicting collapses is the value $H/m = 10$ [5].

The main disadvantage of this method is that the resulting criterion is defined only by the geometric parameters H and m . At the same time, it is known that the parameters of a geodynamic event mainly depend on the pressure on the working area from the overlying rocks, which is proportional to their mass, determined by the density distribution in this volume [7].

Therefore, in areas of the massif located in different parts, but at the same depth from the surface, due to the difference in density, the pressure is different and, consequently, the expected geodynamic events will differ significantly in all parameters. At the same time, the H/m criterion set in the method is the same for these sections.

In the method [5], to account for the anisotropy of the massif density, the N in the criterion is replaced by the H_{pr} – the reduced depth by the density of the underlying rocks. Zoning criterion is the H_{pr}/m value. In this form, the criterion is density-invariant and thus correct for the entire field.

This method is especially effective for such areas of the field where there is no possibility of using monitoring of the rock mass. The share of such sections of the field is currently more than 30%. In areas where monitoring is carried out, hazardous areas identified by this method are subject to special control to determine their lifetime using monitoring tools, including strain monitoring, seismic monitoring and monitoring of local areas.

In another method [8], values such as H and m are replaced by the vertical component Z_c coordinates of the gravity center of the massif element in the form of a column extending vertically up from the base to the ground surface of the field.

The gravity center characterizes the distribution of mass in the column, and its displacement during mining operations characterizes its redistribution over the entire depth of the massif. During such changes, due to internal and external factors, the instability of the system is observed. Based on these

physical assumptions, changes in the position of the gravity center of the rock mass in the column can serve as a local indicator of abnormal areas. The zoning criterion is the relative displacement of the vertical component of the coordinate of the gravity center of the massif column [5].

The method [9] uses the value of the relative change in the potential energy of the rock mass as a criterion ε

$$\varepsilon = \frac{\Delta P}{P_0} = \frac{\sum_{i=3}^6 \rho_i h_i m_2 + \sum_{i=7}^k \rho_i h_i (m_2 + m_6)}{\sum \rho_i h_i Z_{ci}},$$

where ΔP is the change of potential energy of gravitation when the massif moves from the initial to the current state; P is potential energy of gravity in the initial state; ρ_i is density; h_i is altitude; Z_{ci} is the vertical coordinate of the center of mass in the i^{th} layer; m is the height of the excavation.

In the method [9], for zoning of the surface of an ore deposit according to the degree of potential danger of collapse, the authors proposed a method based on measuring the gravitational acceleration g , for which the data of exploratory (initial) and geodetic (current time) gravimetry were used.

Gravimetric survey in real conditions is always discrete. In this connection, the problem arises of interpolating the magnitude of the acceleration due to gravity at intermediate points and evaluating the accuracy of the solution, taking into account the measurement error.

The determined parameters of zoning are the selected difference between the values of the acceleration of gravity Δg between the initial (initial) g_0 , the current value of g , and the relative value of β .

From gravimetry, it follows that g characterizes the distribution of mass in a given state, and Δg is its redistribution as a result of processes occurring inside the array during the transition from one state to another. The use of the difference Δg allows one to avoid determining the absolute value of the acceleration due to gravity, which greatly simplifies the process of zoning. The criterion for zoning is the value of the relative measurement of acceleration β .

The criterion for each method and field is established on the basis of a retrospective causal analysis of the occurring geodynamic events, taking into account the structural features of the rock mass (geological structure, tectonic disturbance, fracturing of the applied development systems) of physical and mechanical properties and the stress-strain state of the rock mass. Zoning of the surface of the field allows one to concentrate geomechanical monitoring of problem areas, improving the quality of control by increasing the intensity and accuracy of the measurement.

Comparative analysis with other zoning methods has shown that the use of potential gravitational energy as a criterion and its changes considering the heterogeneity of the rock mass most accurately characterize its state, which improves the quality of zoning. At the same time, a significant disadvantage of the method is the absence of an important component of the geoenergy of the massif in the criterion – the energy of elastic deformation. At the same time, it should be noted that the part of the potential energy of elastic deformation increases significantly with the depth of the field development.

Thus, taking this energy into account when calculating the energy criterion makes it possible to increase the efficiency of ranking and its capabilities.

Research methodology. To eliminate these shortcomings, we propose a method for zoning the surface of mineral deposits according to a criterion based on relative changes in an inhomogeneous rock mass determined by the difference between the sum of the potential energies of elastic deformation and gravity. To calculate the criterion for the proposed zoning method, we consider an element of a mountain range in the form of a column extending from the base to the ground surface of the field in various states (Fig. 1).

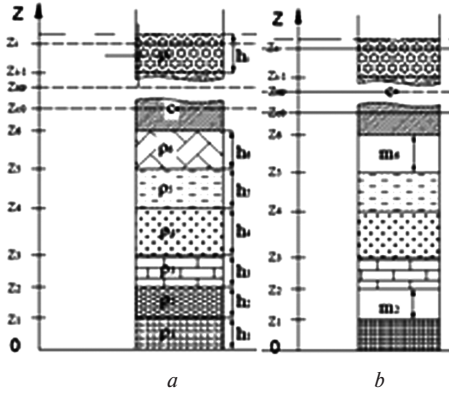


Fig. 1. Element of the mountain mass:

a – in the initial state; *c* is the center of mass; Z_i is the coordinate of the upper boundary of the i^{th} layer; ρ_i is the density in the i^{th} interval of the column; *b* – in the current state of unstable equilibrium, m_i is the power of the i^{th} workings

The array is assumed to be heterogeneous. Therefore, when calculating the criterion, the column is conditionally divided into layers, within each of them such values as density (specific gravity), mechanical stress, Young's modulus, volume density of gravitational energy and elastic deformation can be considered constant. For comparison, the calculations for a homogeneous array are given.

The main part of geogeneity of rock mass in the column W is the potential energy of elastic deformation W_D and gravity W_T

$$W = W_D + W_T. \quad (1)$$

From the properties of energy additivity it follows

$$W = \sum W_i = \sum W_{Di} + \sum W_{Ti},$$

where W_i is the total energy; W_{Di} is the potential energy of elastic deformation; W_{Ti} is the potential gravitational energy of the i^{th} column layer.

Potential gravitational energy of the i^{th} layer [8]

$$W_{Ti} = \gamma_i h_i S z_{ci}, \quad (2)$$

where γ_i is the specific weight of the rock mass; h_i is the height; z_{ci} is the vertical coordinate of the mass center of the i^{th} layer; S is the cross-sectional area of the column (taken $S = 1$, so $v_i = h_i$). The plane $z = 0$ is chosen as zero level of potential gravitational energy.

The energy of elastic deformation of the mass of the i^{th} layer of the column W_{Di} , is equal to

$$W_{Di} = \omega_i h_i S, \quad (3)$$

where ω_i is the volume energy density of the elastic deformation of the mass in the i^{th} layer

$$\omega_i = \sigma_i^2 / 2E_i, \quad (4)$$

where σ_i is mechanical stress; E_i is Young's modulus in the i^{th} layer.

The value of σ_i is determined by the weight of the layers lying on it

$$\sigma_i = \sum_{k=i}^l g_k h_k^2, \quad (5)$$

where l is the number of layers in the column.

Taking into account (3, 4 and 5), the elastic deformation energy of the i^{th} layer will be equal to

$$W_{Di} = \frac{\left(\sum_{k=i}^l (\gamma_k h_k) \right)^2}{2E_i} h_i.$$

Accordingly, the total energy of elastic deformation of the mass in the column in the initial state W_{d0} is equal to

$$W_{d0} = \sum_i \frac{\left(\sum_{k=i}^l (\gamma_k h_k) \right)^2}{2E_i} h_i. \quad (6)$$

For a homogeneous mass, the elastic deformation energy of the column in the initial state is equal to

$$W'_{d0} = \frac{\gamma^2}{2E} \int_0^H z^2 dz = \frac{\gamma^2 H^3}{6E},$$

where H is the height of the column.

The potential gravitational energy of the mass in the column in the initial state and W_{T0} taking into account (2) is equal to

$$W_{T0} = \sum_i \gamma_i h_i Z_{ci}.$$

For a homogeneous array the potential gravitational energy of the column in the initial state W'_{T0} is equal to

$$W'_{T0} = \gamma \frac{H^2}{2}. \quad (7)$$

Substituting in (1) the value W_{d0} from (6), W'_{T0} (7) we get the geogeneity of the mass in the column in the initial state W_0

$$W_0 = W_{d0} + W_{T0} = \sum_i \left[\frac{\left(\sum_{k=i}^l (\gamma_k h_k) \right)^2}{2E_i} + \gamma_i Z_{ci} \right] h_i. \quad (8)$$

For a homogeneous mass, the geogeneity of a column W'_0 has the form

$$W'_0 = \gamma \frac{H^2}{2} + \frac{\gamma^2 H^3}{6E}.$$

In the process of mining a mountain mass, the mass of the column and its energy decrease proportionally to the volume of the developed space and the decrease in the position of the gravity center [10]. In this case, the column rock mass as a system goes from the initial (initial) state of stable equilibrium with energy W_0 to the current state of unstable equilibrium with energy W_{UE} simultaneously losing energy ΔW equal to

$$\Delta W = W_0 - W_{UE}.$$

As a result of the physical and mechanical processes accompanying such a transition, energy is redistributed in the volume of the rock mass surrounding the workings, causing the activation of existing and initiating the manifestation of new geomechanical processes, which can provoke crisis situations. The probability of such situations increases with the growth of ΔW . Thus, the energy difference between the initial and current states of the rock mass can be used as a zoning criterion. The value ΔW is determined by the method of calculating the geogeneity W_0 , and taking into account Fig. 1, *b*

$$\Delta W = \sum_j \left[\frac{\left(\sum_{k=j}^l (\gamma_k h_k) \right)^2}{2E_j} + \gamma_j Z_{cj} \right] m_j, \quad (9)$$

where l is the number of column layers and m_j is the output power.

Practical expediency in the implementation of zoning has shown the advantage of using relative values in the criteria. In the method, the relative value is selected as the criterion ε

$$\varepsilon = \frac{\sum_j \left[\frac{\left(\sum_{k=j}^l (\gamma_j h_j) \right)^2}{2E_j} + \sum_j \gamma_j Z_{cj} \right] m_j}{W_{d0} + W_{T0} = \sum_i \left[\frac{\left(\sum_{k=i}^l (\gamma_k h_k) \right)^2}{2E_i} + \gamma_i Z_{ci} \right] h_i}$$

Zoning is carried out in the specialized geoinformational model of geomechanical risks (GMGR) [11]. GMGR – an expanded geographic information model of geomechanical risks – provides a comprehensive analysis of the results of space-based radar interferometry (CWI) and topographic and geodetic measurements. On the basis, “duty map” of geomechanical risks is built [12]. Analysis of the obtained situational maps of various mining plans allows one to choose a plan option that meets the minimum risks. All changes that occur are reflected in the corresponding functional layers. The GMGR simulates the current and predicts the prospective conditions of the field, which allows solving such problems as assessing the consequences of developing the field to the surface in order to take preventive measures to protect them, to identify the possibility of finalizing the remaining reserves, including in the supporting pillars, the choice of mining technology and their planning. As a result, a continuous situational map and a forecast zoning map are built.

To eliminate inaccuracies associated with averaging data when determining the zones of displacement of the earth’s surface, the theoretical calculation of the expected displacements and deformations was carried out in two ways, with the correction of the results with the data of field measurements and a situational map of GMGR [13]. The criterion for assessing the quality of zoning is to check the conditions for compliance with the result of a causal model. The solution does not refute the model if the following conditions are true:

1. Compatibility: the result is not disproved on the data.
2. Significance: the criteria for the quality of the solution in the test cases indicate the presence of a causal relationship.
3. Consistency: the result can be explained and justified using available knowledge and data.

When solving the tasks set, all the components of the model can change. Models are being developed and refined as additional data are obtained and new hypotheses about a causal relationship appear. The model is focused on the assessment of dangerous risks using zoning methods (Fig. 2).

The values of the coordinates of layers Z_i , height h_i , density ρ_i , Young’s modules E_i and power generation m_j are received and stored in the database management system (DBMS) of the model. The DBMS is represented by client-server and object-relational PostgreSQL with the PostGIS extension, which guarantees storage and processing of large arrays of geospatial data. Based on the data obtained, the GMGR determines the relative changes in geoenergy e for each point on the field surface and places them on the plan. Points with the same value e are connected by isolines that divide the surface into zones.



Fig. 2. Geoinformational model of geomechanical risks

To predict the development of problem situations, it is optimal to divide zones into three levels. For example, for the Annenskoye field, this is:

- Level 1. $\varepsilon < 10$ – non-dangerous (green).
- Level 2. $10 < \varepsilon < 15$ – low-risk (orange).
- Level 3. $\varepsilon < 15$ – dangerous (red).

This division allows not only seeing areas that are currently dangerous, but also tracking territories that may become so.

Using GMGR, it is possible to study and model various situations caused by the current or expected (according to the plan) results of mining operations. This allows optimizing the mining planning process. In the model, other criteria can be used to improve the effectiveness of zoning, which can be applied together with the main criterion (complementing it), or independently.

Accounting the potential of geoenergy for solving some problems associated with zoning (for example, optimization of geodetic monitoring), it is preferable to use its potential as a criterion [14].

Each element of the rock mass, being in the geoenergetic field, has an energy proportional to its mass M . Given that all the components of geoenergy are potential, it is also potential and for its characteristics, you can introduce the value φ – the potential of the geoenergetic field

$$\varphi = \frac{W}{M},$$

where W is the potential energy of the mass M at a given point in the energy field.

Potential energy is a relative value determined with accuracy to a constant [15]. When selecting the geoenergy value of a rock mass in the initial state for the zero level, its energy in the current state is W'_{UE} in this frame of reference takes the form taking into account (8)

$$W'_{UE} = -\Delta W.$$

Accordingly, the potential φ of this state taking into account, (9)

$$\varphi = \frac{\sum_j \left[\frac{\left(\sum_{k=j}^l (\gamma_j h_j) \right)^2}{2E_j} + \sum_j \gamma_j Z_{cj} \right] m_j}{\sum_i \rho_i h_i},$$

where $\sum_{i \neq j} \rho_i h_i$ is the mass of the massif column in the current state; j is the number of the output; ρ_i is the density of the i^{th} layer.

For each point on the surface, the value of the potential selected as the zoning energy criterion is displayed on the plan. On the plan, using the extrapolation method points with the same potential value are connected by isolines. Such lines are equipotential and are described by the equation $\varphi(x, y) = \text{const}$. Equipotential lines are drawn so that the potential difference for two adjacent lines is the same. By the thickening of the isolines, we can judge about the intensity of the expected development of the rock process. The direction of the greatest thickening of lines by definition indicates the potential gradient. The greater the gradient is, the greater the density of the condensation is. To rank zones according to the degree of problem in accordance with the problem being solved, the number of problem levels at which it is necessary to zone the surface of the field is determined.

The numerical value of the zoning criterion for each field is established on the basis of a retrospective, causal analysis of the occurring geodynamic events, taking into account the structural features of the rock mass (geological structure, tectonic disturbance, fracture, applied development systems), physical and mechanical properties, and stress-strain state mountain range. The criterion is accepted uniform throughout the field.

When dividing zones into 3 hazard levels, two numerical values K_1 and K_2 are set. On the field plan, zones are separated by levels by the equipotential lines $\varphi(x, y) = K_1$ and $\varphi(x, y) = K_2$. For detailed zoning, levels can be quantized into sublevels.

The observation points of the surface located on the same isoline are identical in terms of zoning conditions with respect to the problem of the studied surface area. Moreover, areas of the surface that belong to different zones, but lie on equipotential lines of the same magnitude, are also identical in relation to the problem of their state. Therefore, geodetic observations of the surface displacement can be limited to monitoring the state of one randomly selected area, transmitting the results of measurements to the corresponding identical areas. This allows one to significantly reduce the time for monitoring the entire surface and increase the frequency of measurements due to its localization and significantly reduce costs. The information content and objectivity of the monitoring result directly depends on the optimal choice of geodetic observation sites on the field surface.

As the field is developed, the area of the surface that falls within the zone of influence of geomechanical processes initiated by mining operations and that are not monitored from the main profile lines is expanding. In this regard, to maintain the effectiveness of monitoring, it is necessary to build additional profile lines. They should be problem-oriented to dangerous areas that are highlighted by zoning. This corresponds to the profile of a line, tangent to which each point coincides with the gradient of geoenergy.

Conclusions. The method of zoning has been developed, which allows us to determine areas that are at the stage of involvement in the process of displacement and therefore undetectable by instrumental observations under conditions of heterogeneity of the rock mass. This significantly increases the reliability of predicting crisis situations and contributes to the development of technological solutions to prevent them. Based on the method, recommendations for optimizing geodetic monitoring have been developed.

Practical testing of the method was carried out at the Anenskoye field. The results of zoning were compared with the data obtained by ground geodetic measurements and space radar interferometry. Verification of the results based on a retrospective analysis showed an increase in the accuracy of zoning method by 20–25 % relative to traditional methods and by 15 % in comparison with the method that takes into account only the potential energy of gravity.

Note. This article is based on the results of scientific research on the topic “Development of a forecast system and methods of geomonitoring displacements of the mountain range on dangerous areas of the earth’s surface when developing subsurface resources on the basis of innovative methods of GIS technology” No. AR05133929.

References.

1. Zhabko, A. V. (2018). Fundamental problems of practical geomechanics and possible ways to overcome them. *Bulletin of the Ural State Mining University*, 4(52), 98–107. <https://doi.org/10.21440/2307-2091-2018-4-98-107>.
2. Sashurin, A. D. (2018). Geomechanical processes and phenomena that determine the safety and efficiency of subsurface use, patterns of their development. *Problems of subsurface use*, (3), 21–27.
3. Issabek, T. K., Dyomin, V. F., & Ivadilina, D. T. (2019). Methods for monitoring the earth surface displacement at points of small geodetic network under the underground method of coal development. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (2), 13–20. <https://doi.org/10.29202/nvngu/2019-2/2>.
4. Panzhin, A. A., Sashurin, A. D., Panzhina, N. A., & Mazurov, B. T. (2016). Geodetic support for geodynamic monitoring of subsurface use objects. *SSGA Bulletin*, 4(36), 26–39.
5. Spitsyn, A. A., Imansakipova, B. B., Chernov, A. V., & Kidirbayev, B. I. (2019). Development of scientific and meth-

odological basis for identifying weakened zones on the earth’s surface of ore deposits. *Mining journal of Russia*, 9(2266), 63–66. <https://doi.org/10.17580/gzh>.

6. Mustafin, M. G., Grischenkova, E. N., Younes, J. A., & Khudyakov, G. I. (2017). Modern surveying and geodetic support for the operation of mining enterprises. *Bulletin of TUSU Earth Science*, (4), 190–202.
7. Satov, M. Zh. (n.d.). The Republic of Kazakhstan. Patent No. 8159-990265.1 Kazakhmys Corporation. Retrieved from https://yandex.ru/patents/doc/RU2153071C1_20000720.
8. Baygurin, Zh. D., Spitsyn, A. A., Imansakipova, B. B., Kozhaye, J. T., & Imansakipova, N. B. (n.d.). The Republic of Kazakhstan. Patent No. 33566.
9. Sadykov, B. B., Baygurin, Zh. D., Altayeva, A. A., Kozhaye, Zh. T., & Stelling, W. (2019). New approach to zone division of surface of the deposit by the degree of sinkhole risk. *Naukovyi Visnyk Natsionalnoho Hirnychoho Universytetu*, (6), 31–35. <https://doi.org/10.29202/nvngu/2019-6/5>.
10. Strokova, L. A., & Ermolaeva, A. V. (2016). Zoning of the territory according to the degree of danger of subsidence of the earth’s surface in the design of the main gas pipeline in South Yakutia. *Proceedings of Tomsk Polytechnic University. Engineering of georesources*, 327(10), 59–68.
11. Grazulis, K. (2016). Analysis of stress and geomechanical properties in the niobrara formation of wattenberg field, (pp.33–49). Colorado, USA. Retrieved from https://mountainscholar.org/bitstream/handle/11124/170240/Grazulis_mines_0052N_11023.pdf?sequence=1/.
12. Jan van, E., & Doornhof, D. (2015). Dynamic geomechanical modelling to assess and minimize the risk for fault slip during reservoir depletion of the groningen field, (pp. 46–51). Retrieved from <https://nam-feitenencijfers.data-app.nl/download/rapport/d32ec1fd-1d59-4f6c-a462-93e2515e9fd9?open=true>.
13. Wang, H., & Samuel, R. (2016). 3D geomechanical modeling of salt-creep behavior on wellbore casing for presalt reservoirs. *SPE Drilling and Completion, Society of Petroleum Engineers*, 31(04), 261–272. <https://doi.org/10.2118/166144-PA>.
14. Erasov, V. S., & Oreshko, E. I. (2017). Force, deformation, and energy criteria for failure. *Electronic scientific journal “Proceedings of VIAM”*, (10), 97–111. <https://doi.org/10.18577/2307-6046-2017-0-10-11-11>.
15. Kolesnikov, I. Y., Morozov, V. N., Tatarinov, V. N., & Tatarinova, T. A. (2017). Stress-strain energy zoning of the geological environment for the placement of environmental infrastructure objects. *Innovation and expertise*, 2(20), 77–88.

Розробка ефективного методу зонного районування земної поверхні в умовах неоднорідності породного масиву

Б. Б. Імансакіпова, Ж. Д. Байгурін, А. А. Алтаєва,
Д. Кананіянова, Б. Минжасаров

Satbayev University, м. Алмати, Республіка Казахстан,
e-mail: imansakipova@mail.ru

Мета. Розробка методу зонного районування земної поверхні родовищ за ступенем проблемності за критерієм на основі зміни геоенергії породного масиву, що визначається різницею сум потенційних енергій тяжіння та пружною деформацією гірського масиву у вихідному й поточному станах.

Методика. Дослідження виконувалися з використанням методів причинно-наслідкового аналізу фізичного моделювання й геомеханіки.

Результати. Розроблено метод зонного районування земної поверхні родовищ за ступенем проблемності на основі енергетичних параметрів, що визначають стан неоднорідного гірського масиву й характеризують за-

гальні закономірності прояву та розвиток геомеханічних процесів. Метод дозволяє виділяти на земній поверхні родовища потенційно небезпечні ділянки, що знаходяться на стадії залучення до процесу зрушення, і тому не фіксуються наземними спостереженнями й методами дистанційного зондування землі. На основі методу розроблені рекомендації щодо оптимізації геодезичного моніторингу.

Наукова новизна. Розроблено метод, що підвищує надійність зонного районування земної поверхні родовища за ступенем проблемності, на основі критерію, базис якого становить параметри, що визначають величину геоенергії породного масиву в поточному й вихідному станах.

Практична значимість. Метод дозволяє підвищити якість ситуаційного контролю, прогнозу прояву ризикових ситуацій та їх розвитку, оптимізувати геодезичний моніторинг.

Ключові слова: родовище, енергетичний критерій, потенційна енергія, геоенергія, критерій зонування

Разработка эффективного метода зонного районирования земной поверхности в условиях неоднородности породного массива

*Б. Б. Имансакипова, Ж. Д. Байгурин, А. А. Алтаева,
Д. Кананиянова, Б. Мынжасаров*

Satbayev University, г. Алматы, Республика Казахстан,
e-mail: imansakipova@mail.ru

Цель. Разработка метода зонного районирования земной поверхности месторождений по степени проблемности по критерию на основе изменения геоенергии

породного массива, определяемого разностью сумм потенциальных энергий тяготения и упругой деформаций горного массива в исходном и текущем состояниях.

Методика. Исследования выполнялись с использованием методов причинно-следственного анализа, физического моделирования и геомеханики.

Результаты. Разработан метод зонного районирования земной поверхности месторождений по степени проблемности на основе энергетических параметров, определяющих состояние неоднородного горного массива и характеризующих общие закономерности проявления и развития геомеханических процессов. Метод позволяет выделять на земной поверхности месторождения потенциально опасные участки, находящиеся на стадии вовлечения в процесс сдвигения, и поэтому нефиксируемые наземными наблюдениями и методами дистанционного зондирования земли. На основе метода разработаны рекомендации по оптимизации геодезического мониторинга.

Научная новизна. Разработан метод, повышающий надежность зонного районирования земной поверхности месторождения по степени проблемности, на основе критерия, базис которого составляют параметры, определяющие величину геоенергии породного массива в текущем и исходном состояниях.

Практическая значимость. Метод позволяет повысить качество ситуационного контроля, прогноза проявления рискованных ситуаций и их развития, оптимизировать геодезический мониторинг.

Ключевые слова: месторождение, энергетический критерий, потенциальная энергия, геоенергия, критерий зонирования

Recommended for publication by M. B. Nurpeisova, Doctor of Technical Sciences. The manuscript was submitted 29.12.19.