25. Mazurek K., Szyguła M., Turczyński K. Development of technology for withdrawal of the powered roof support from a row and its relocation from the liquidated longwall system. *IOP Conference Series: Materials Science and Engineering*. 2019. Vol. 679. ID 012003.
26. Świątek J., Janoszek T., Cichy T., Stoiński K. Computational fluid dynamics simulations for investigation of the damage causes in safety elements of powered roof supports—A case study. *Energies*. 2021. Vol. 14, Iss. 4. ID 1027.
27. Szolc P., Szurgacz D., Styrylski K. Comparative analysis of hydraulic power systems for a powered roof support aimed at obtaining optimal power parameters. *IOP Conference Series: Materials Science and Engineering*. 2019. Vol. 679. ID 012018.
28. Gao M., Xie J., Gao Y. et al. Mechanical behavior of coal under different mining rates: A case study from laboratory experiments to field testing. *International Journal of Mining Science and Technology*. 2021. Vol. 31, Iss. 5. pp. 825–841.
29. Szurgacz D., Zhironkin S., Cehlár M., Vöth S., Spearing S., Liqiang M. A step-by-step procedure for tests and assessment of the automatic operation of a powered roof support. *Energies*. 2021. Vol. 14, Iss. 3. ID 697.
30. Wang B., Dang F., Chao W. et al. Surrounding rock deformation and stress evolution in pre-driven longwall recovery rooms at the end of mining stage. *International Journal of Coal Science & Technology* . 2019. Vol. 6. pp. 536–546. EM

M. B. NURPEISSOVA[1], *Doctor of Engineering Sciences, Professor, marzhan-nurpeissova@rambler.ru*
Sh. K. AITKAZINOVA[1], *Candidate for a Doctor's Degree*
B. M. ISKAKOV[1], *PhD student*
N. A. FEDOTENKO[2], *Candidate of Engineering Sciences, Senior Researcher*

[1]*Satbayev University, Almaty, Kazakhstan*
[2]*Academician Melnikov Institute of Comprehensive Exploitation of Mineral Resources–IPKON, Russian Academy of Sciences, Moscow, Russia*

APPLICATION OF ADVANCED TECHNOLOGIES IN SLOPE STABILITY MONITORING IN OPEN PITS IN THE ZHILANDY ORE FIELD

The features of geomechanical processes in mines of the Zhilandy ore field in Kazakhstan are discussed. The ways of preventing hazardous events in the course of mineral mining are proposed. The procedure of integrated geodynamic monitoring is developed. A new method of the structural analysis of rock mass and the method of creating a geodynamic testing site is put forward.

The research findings are introduced at operating mines within the framework of the projects: High-Effective Monitoring Procedure for Geotechnical Conditions of Rock Masses for the Assessment and Prediction of Deformation Processes in Mineral Mining; Geotechnical Monitoring of Geodynamic Condition of Geological Environment in Rock Masses Toward Industrial Reliability of Subsoil Use, and are included in the education process at the Satbayev University.

Keywords: *induced seismicity, geodynamics, tectonic structure, stress–strain behavior, rock mass, geomechanical monitoring, geodynamic testing site*
DOI: *10.17580/em.2026.01.03*

Introduction

One of the most critical problems in large-scale mining at structurally complex rock masses is induced seismicity. It can involve both catastrophic technical and economic consequences, including triggered earthquakes, rock bursts and landslides, and also deaths of people. This fact was highlighted at the International Symposium on Rockbursts and Seismicity in Mines [1–3]. The problems of control over such processes draw heightened attention, which is proved by the growing number of publications [4–6].

Reduction of risk of induced catastrophes is a topical question in Central Kazakhstan which is a region of actual large-scale mining. High-intensity mineral production is carried out in the Zhilandy field of copper ore deposits such as Eastern and Western Saryoba, Kipshakpay, Karashoshak and Itauz.

All deposits of the Zhilandy group adjoin grey sandstone strata of the Taskuduk Formation and bottomset beds with grey-greenish and grey sandstone interbeds, intra-formation conglomerates, dark grey or black siltstone and argillite with bands of limestone with fauna. The subsoil is complicated by faults and rock interfaces, which makes mining largely difficult [7–9].

At the same time, this tectonically active area of Central Kazakhstan yet remains understudied. It is required to implement an integrated research of seismicity and geodynamics in order to evaluate more accurately the nature and parameters of tectonic stresses (especially in the region of high-output mining), and to undertake reasonable measures of geodynamic risk reduction.

Globally, the leading part in the safe and efficient subsoil use is assigned to mine surveying. At the present time, objectives of surveying are much more complex due to deeper level mining and field expansion, which requires scrupulous, highly precise and well-timed survey-based monitoring. It is possible to handle problems connected with geodynamic prediction and monitoring in the high-output ore mining regions in Central Kazakhstan with the help of the integrated monitoring procedure using geological and tectonic information, advanced equipment and authorial seeing aids, developed at the Department of Surveying and Geodesy of the Satbayev University.

Methods

The research used an integrated approach including: engineering-geological studies of structure and tectonics of rock mass with mapping of dislocations, faults and crushed rock zones; surveying using up-to-date equipment and authorial monitoring devices; stress–strain analysis of rock mass with modeling structure and geometry of pitwall rock mass.

The difficult geological and geomechanical conditions at the Zhilandy group of deposits dictated prevention of hazardous events induced by high rock pressure. In this connection, in 2020–2025, the integrated monitoring was implemented by researchers of the Department of Surveying and Geodesy, Satbayev University, and was fully supported by the Ministry of Science and Higher Education of the Republic of Kazakhstan.

The research objective was creation of a geodynamic testing site and integrated geodynamic monitoring of geological structure of rock mass using advanced technologies to ensure industrial safety. Such testing site can unite various measurement methods and equipment into a single integrated observational network.

Descriptions and discussions

Geological conditions

The thickness of the commercial-value ore strata in the Zhilandy group ranges from 0.1 to 20 m, and is averagely 3–8 m for the deposits of Eastern and Western Saryoba, and Kipshakpay. The dimensions of the ore bodies vary from 200×100 m to 3200×1400 m (Western Saryoba) and 3000×750 m (Itauz). The Zhilandy field holds 11 ore deposits, including 109 proven ore bodies. The largest deposits adjoin the Taskuduk Formation. They stretch northeastward to a length up to 3200 m, are from 0.5 to 17 m thick, and their size along the dip is to 1400 m (**Fig. 1**).

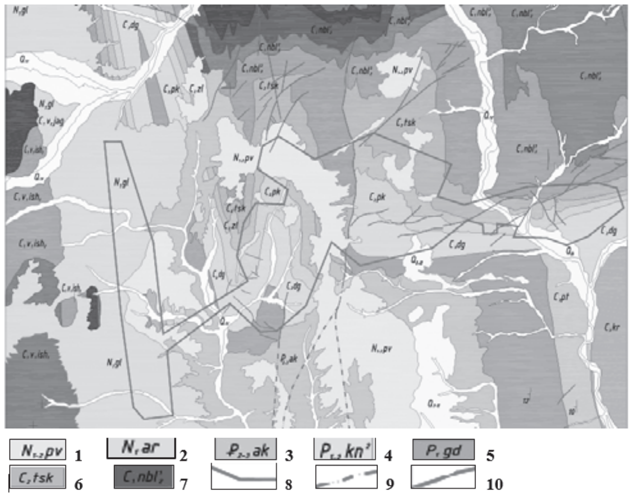

Fig. 1. Geological structure map of the Zhilandy group deposits:
1—pebblestone, loam, clay; 2—grey and brown gypsum-bearing clay; 3—poorly consolidated sandstone, ferruginous conglomerates; 4—grey limestone, marl; 5—rich-red and brown limestone, marl; 6—brown argillite, siltstone and fine-grained sandstone; 7—grey and grey-brownish sandstone, siltstone and argillite; 8—boundary of the Zhilandy mining lease; 9—faults traced from geophysical data; 10—zone of small faults

Structural features of rock mass

Rock movement in underground mining and slope stability in open pits are directly connected with tectonics and structural features of rock mass. In open pits, in case of large-area rock exposures, the most effective and widely applied method of direct observation and measurement is laser scanning. Diagnostics of jointing involves laser scanners that determine coordinates of surface points at a high velocity—dozens of thousands of points per second [10].

Ground-based laser scanning is widely applied to obtain information on geometrical parameters of open pits, joints and faults, and overburden dumps placed on ground surface. Aiming to enhance efficiency of joint surveying in rock mass, the authors used 3D Leica ScanStation scanner which provided a detailed study of elements of joints and faults (**Fig. 2*a***). The laser scanning results were processed in software MaptekI-Site Studio meant to calculate values of joint occurrence: azimuth of strike, angles of dip and sizes of blocks (**Fig. 2*b***).

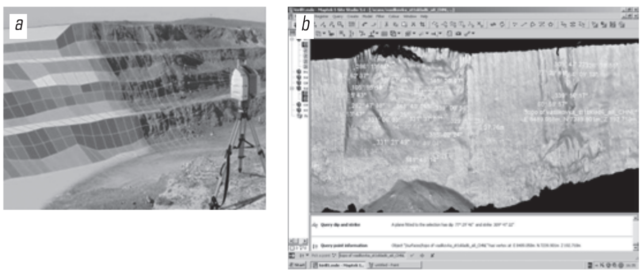

Fig. 2. Mine surveying of rock jointing and survey results:
a—laser scanning; *b*—elements of occurrence of joints in MaptekI-Site Studio

The sizes of blocks between joints are calculated from the difference of the coordinates of points taken along a normal between the joints, and the elements of occurrence of joints (azimuth of strike and angle of dip) are found from plotting of joint faces [11].

A digital model of pitwall rock mass can be obtained using the same software. The model contains full information about pitwall rock mass. With the help of the program for processing data on jointing, the systems of joints are identified and the sizes of blocks are determined to be used later on in the rock mass strength certificate.

The developed procedure of automated jointing diagram plotting is a computer-assisted structural modeling technology. In this procedure, the relation between the objects of an analytical set (observation points) Z is defined by a triangular jointing plot (XOY). The azimuth of strike (A) is plotted along the axis OX, the slope angle δ—along the axis OY, and the position of an observation point is unambiguously described by a regular discrete function given by:

$$Z = (X, Y, n), \quad (1)$$

where X and Y are the current values of the azimuth of strike and the angle of slope of the observation point Z, respectively; n is the number of joints recorded at this point, i.e. the coefficient of relevance (density).

Statistical processing of jointing measures is carried out in the program in three stages. The first stage is identifying domains of the highest density of observation points, and these domains are then used to find an optimized variant of the initial set decomposition into systems of joints. At the second stage, by grouping the rest measurements, the systems of joints are identified and certain measurements are related with certain systems. The third stage is evaluation of the statistical characteristics of the systems of joints. After that, by interpolation, broken lines are plotted between the corners of grid, which are then smoothed using splines (curves that pass through all density points).

The procedure is implemented in Golden Software Surfer 8.0. The software is meant for operation with geographical and topographical maps. The authors used the software to model structural features of rock mass [12]. The file can be saved in Microsoft Excel or in Surfer (.dat). The results can be printed out directly from the software or saved on a disk drive for the further use, and can be presented in two types: 2D (**Fig. 3*a***) and 3D (**Fig. 3*b***).

As a result of the automated plotting of jointing, it is found that the Eastern Saryoba deposit contains four basic systems of joints with the average values of the elements of their occurrence (azimuth, angle of dip) as follows: I (30°, 55°), II (125°, 81°), III (220°, 75°) and IV (310°, 89°).

Thus, digital modeling of pitwall rock mass is possible using the software that calculates the elements of occurrence of joints (azimuth of strike, angle of dip) and sizes of rock blocks. The digital model contains full information on pitwall rock mass.

The physical and mechanical properties of rocks were studied; the results allowed graphoanalytical dependences of the strength characteristics and depths of occurrence of rocks, and made it possible to adjust the level-by-level stability calculations for mine roadways in real time [12, 13].

The most important characteristics of rock mass is its stress–strain behavior. To date, there are many different methods of the stress–strain measurement and control [14]. For instance, the method of stress relaxation by VNIMI, core discing, etc. For the stress–strain analysis of rock mass, the authors developed a seismoacoustic method of the stress–strain prediction in rocks [15].

Monitoring of rock mass during mining operations at large deposits composed of a few ore bodies at different depths requires creating a Geodynamic Testing Site (GTS). For the Zhilandy field of deposits, the junctions of control points and deformation levelling points were created. All GTS points were arranged in conformity with the local ore bodies and referenced with the triangulation points of the State Geodetic Network (SGN): Taskuduk, Aslanbek, Burovaya and Poselkovaya (**Fig. 4**).

Practical monitoring of ground surface deformation in the course of mineral mining and undermining uses various types of benchmarks and control points. Long-term instrumental observations involve high labor content of field works, particularly, transfer of instruments (indicator, tripod, rod) from one point to another.

In this connection, for the instrumentation installation and acceleration of measurements, the authors designed a permanent forced centering point (PFC) set at a control station during geomonitoring [16]. The facility is a geodetic center for instrumentation and signaling. PFC improves centering accuracy, accelerates measurements, needs no tripods to be installed, and ensures simplicity and positional location accuracy of geodetic equipment and navigation. The point is visible from afar in monitoring of large areas.

All coordinates and heights of survey monuments are determined using GNSS equipment via taking measurements at initial points and at a spacing at not more than 5 km from them. The satellite measurements used state-of-the art receivers GS16 in the mode of statics with a network method [17].

Simultaneously, surveying using UAV model MATRICE 300 RTK was carried out. The drone is designed on the basis of a modified hardware/software platform and has a wide range of AI-based functions. It has a built-in RTK module that provides extra accurate positioning data. Furthermore, the position location accuracy is ensured owing to the joint use of DJI D-RTK 2 High Precision GNSS Mobile Station [18, 19].

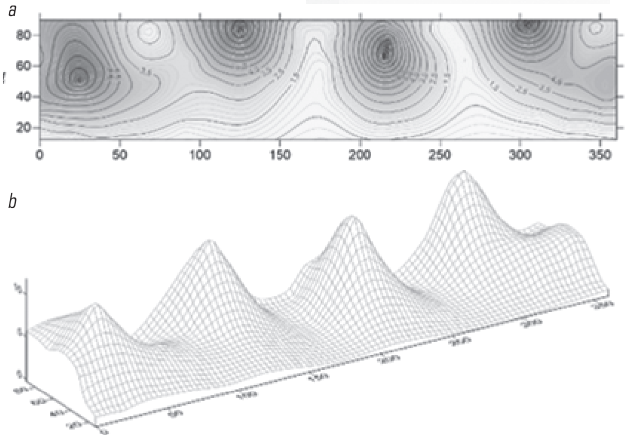

Fig. 3. Modeling of rock jointing

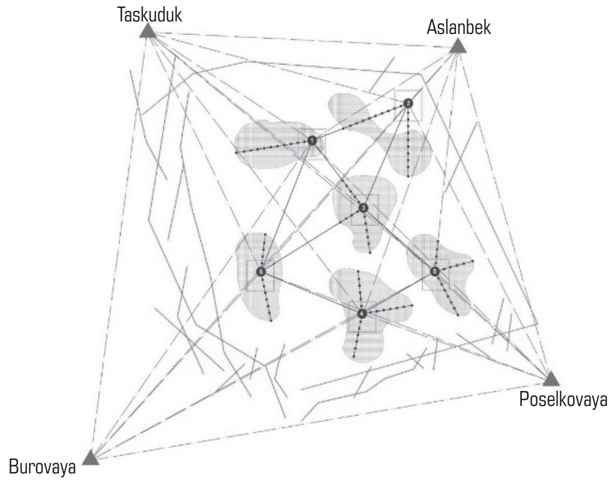

Fig. 4. Arrangement of GTS points and reference with SGN

The instrumental research revealed deformation in rock mass in the form of sloughing of slopes mostly in the south and east of the Vostochny pit at the Eastern Saryoba.

Stress–strain modeling and geomechanical control

This section of the article focuses on detection of vulnerable slope sites by means of the stress–strain modeling of rock mass at the Vostochny pit of the Eastern Saryoba deposit of the Zhilandy group, which should be further reinforced. A feature of open pit mining is the extended service life of pit slopes at the ultimate pitwall limit. Intensification and concentration of mining operations in the test pit grow in complex geological and hydrogeological conditions [20–22].

For 3D modeling of the Vostochny pit at a millimeter accuracy, surveying and geodetic measurements were carried out to determine coordinates and heights of the control network points using technologies of the Global Navigation Satellite System. Later on, the digital outlines of the Vostochny pit were used to build a geomechanical model.

The geomechanical modeling used the digital outlines of the Vostochny pit (**Fig. 5*a***), Eastern Saryoba deposit of the Zhilandy group. Superimposition of the outlines in linkage to the coordinate system allowed building 3D finite-element model of the test deposit (**Fig. 5*b***).

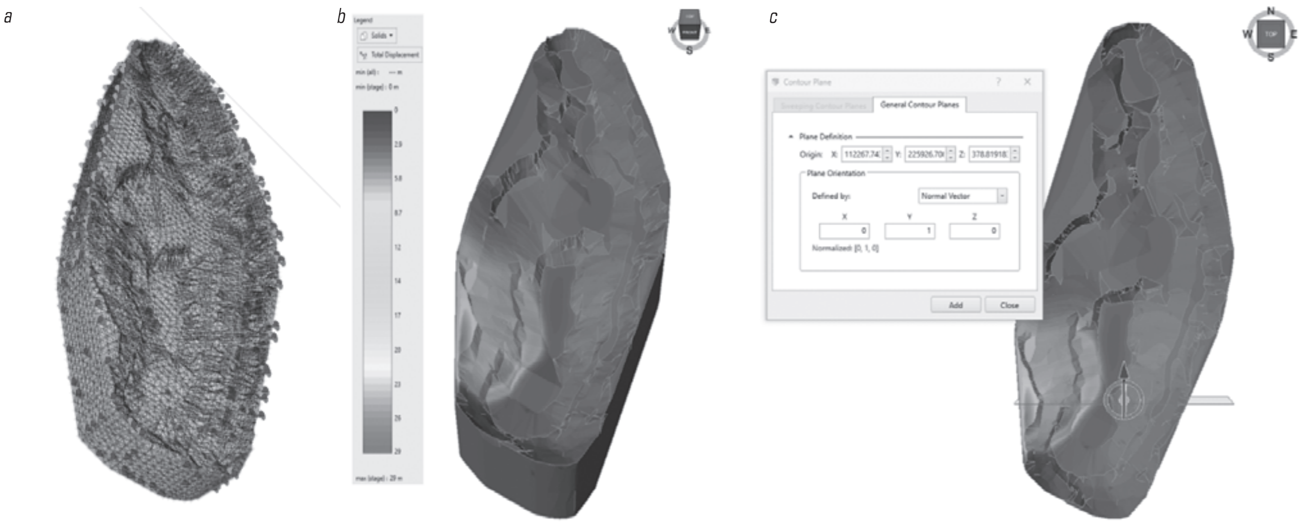

Fig. 5. Digital outlines of Vostochny pit (*a*); displacement patterns in model pit (*b*) and plane section to detect slide surfaces (*c*)

For the stress–strain assessment of rock mass, and to determine the main characteristic of pit slope stability—the safety factor, the well-tested numerical method of finite elements is implemented in license software RS3 (Rocscience, Canada). The problem was solved in the elastoplastic formulation using the Mohr–Coulomb failure criterion:

$$\tau = c + \sigma_n \mathrm{tg}\varphi \qquad (2)$$

where τ is the shear stress, MPa; σ_n is the normal stress, MPa; φ is the internal friction angle, deg; c is the cohesion, MPa.

Visual inspection of slopes in the Vostochny pit of the Eastern Saryoba deposit in the Zhilandy group identified softened sites. The physical and mechanical properties of a softened site 15 m high on the pit slope as per the geological exploration data are described in the **Table**.

Table. Physical and mechanical properties of pit slope rocks

Type of rock	Cohesion, MPa	Internal friction angle, deg
Limestone	250	30
Limestone mass	350	29
Sandstone	388	31
Red limestone	488	32
Ore	900	34

The calculations showed that the most hazardous site of the Vostochny pitwall slope was the southwestern site (see Fig. 5*b*). However, in this case, we can only speak about a 'potential' hazard as the safety factor exceeds 3 (SF ≥ 3). In order to reveal a potentially hazardous slide surface, the 3D model section was carried out across the hazardous site (**Fig. 5*c***).

The stress–strain analysis of pitwall rock mass provides impersonal information on formation of a potential failure wedge in various periods of open pit mining. The main distinction of our scientific research is the stress–strain analysis of rock mass toward prediction and evaluation of deformations of pit slopes on the basis of geospatial data, namely, precise measurements, ground-based laser scanning and UAV-aided data, with a view to managerial decision-making on safety of the industrial-scale subsoil use.

The final objective of any geomechanical study is industrial safety. So, for the prevention of the further failure of the pitwall slope, the authors developed a reinforcement method, and the technical novelty of the method was proved by the patent of the Republic of Kazakhstan [23]. At the present time, the method undergoes commercial testing at the open pit mine, and the tests demonstrate sufficient capability of the method to provide additional bracing of rocks and to maintain stability of the pitwall slopes.

The uniqueness of the proposed procedure is its integrated social and economic value. The social value consists in prevention of induced catastrophes initiated by adverse geomechanical processes. Reinforcement of unstable slopes at the ultimate pit limits can stave off large deformations and rescue people engaged in deep-level mining operations. The economic value consists in early prediction of adverse geomechanical situations and in well-timed reinforcement of pitwall slopes, which can enable avoiding colossal expenses connected with elimination of consequences of manmade catastrophes in subsoil use.

Conclusions

The integrated monitoring of the area of the Zhilandy group deposits and the interpretation of data obtained over the period of 2021–2025 has allowed verbalizing some conclusions listed below.

1. The preliminary analysis of geological structure, blocks and faults in the earth's crust reveals the spatial nonuniformity of geodynamic processes, as well as the active faults and tectonic stress zones.
2. The geospatial data base on ore deposits in Central Kazakhstan is created. The strength and structural features, as well as the stress–strain behavior of rock mass on the lower mining levels are investigated for 3D modeling of geological and mining objects with regard to their alteration in the course of the subsoil use.
3. A new nodal method is developed for geodetic surveying on a geodynamic testing site, which is a reliable framework for the long-term monitoring of slow deformations of ground surface in large-scale mineral mining in Central Kazakhstan.
4. The designed permanent ground-based forced centering point enables enhanced capacity and accuracy of observations.

5. For the prevention of slope deformation at the ultimate pit limit in the operating pit of the Eastern Saryoba, the slope reinforcement method is developed and actually implemented, and serves for the additional maintenance of the pit slope stability.

Acknowledgement

The study was supported by the Ministry of Science and Higher Education of the Republic of Kazakhstan, Grant No. AP26100471.

References

1. Nedlands W. A. Controlling Seismic Risk. *Sixth International Symposium on Rockburst and Seismicity in Mines Proceedings*. Australia : Australian Centre for Geomechanics, 2005.
2. John V. S. Geotechnical risk management in open pit coal mines. *Australian Centre for Geomechanics Newsletter*. 2012. No. 22. pp. 1–4.
3. Melnikov N. N. Environmental problems in XXI century and the development of subsoil. Development of the Subsoil and the Environmental Problems of XXI century. Moscow : IPKON RAN, 2001. pp. 26–45.
4. Trubetskoy K. N. The state and main directions in the development of earth's interior resources. Problems and Prospects of Integrated Development and Conservation of the Earth's Interior. Moscow : IPKON RAN, 2020. pp. 5–12.
5. Snelling P. E., Godin L., McKinnon St. D. The role of geologic structure and stress in triggering remote seismicity in Creighton Mine, Sudbury, Canada. *International Journal of Rock Mechanics and Mining Sciences*. 2013. Vol. 58. pp. 166–179.
6. Mikhailova N. N., Uzbekov A. N. Tectonic and man-made earthquakes in Central Kazakhstan. *News of NAS RK. Series of Geology and Technical Sciences*. 2018. No. 3. pp. 137–145.
7. Rylnikova M. V., Yun A. B., Terentyeva I. V. Replenishment of retired capacities of mines at the stage of finalizing balance reserves of the deposit—Condition for the environmentally balanced development of the Zhezkazgan region. *Mine Surveying Bulletin*. 2016. No. 5. pp. 6–10.
8. Rysbekov K. B., Kyrgizbayeva D. M., Miletenko N. A., Kuandykov T. A. Integrated monitoring of the area of Zhilandy deposits. *Eurasian Mining*. 2024. No. 1. pp. 3–6.
9. Borshch-Komponiec V. I. Rock Mechanics and Rock Pressure. Moscow : MGI, 1968. 484 p.
10. Nurpeisova M. B., Kirgizbayeva G. M., Nukarbekova Zh. M. Innovative Methods of Diagnostics of Rock Jointing. Certificate of entry into the state register of rights to objects protected by copyright. No. 62699. Published: 06.12.2025.
11. Makarov A. B. Applied Geomechanics. Mining Engineer's Tutorial. Moscow : Gornaya Kniga, 2006. 391 p.
12. Aitkazinova Sh. K., Baigurin Zh. D., Adilov J. G., Bergengaliev A. B. Geodynamic monitoring on Kenkiyak field (Republic of Kazakhstan). *Mine Surveying and Subsurface Use*. 2024. No. 2. pp. 62–68.
13. Kyrgizbayeva G. M., Nurpeisova M. B. Method for predicting FMS and SSS of an array. Certificate of entry into the state register of rights to objects protected by copyright. No. 19300. Published: 12.07.2021.
14. Kuldeev E. I., Rysbekov K. B., Donenbayeva N. S., Mietenko N. A. Modern methods of geotechnically effective way of providing industrial safety in mines. *Eurasian Mining*. 2021. No. 2. pp. 18–21.
15. Nurpeisova M. B., Bitimbaev M. Zh., Rysbekov K. B., Kyrgizbayeva G. M. Seismoacoustic method for predicting the stress–strain behavior (SSB) of rock mass. Patent RK No. 35898. Published: 14.10.2022.
16. Nurpeisova M., Rysbekov K., Aitkazinova Sh., Donenbayeva N., Nukarbekova, Zh. et al. Ground permanent geodetic point for forced centering of instruments. Patent RK No. 35798. Published: 11.03.2021.
17. Panzhin A. A., Panzhina N. A. Satellite geodesy-aided geodynamic monitoring in mineral mining in the Urals. *Journal of Mining Science*. 2012. Vol. 48. pp. 982–989.
18. Terentiev B. D., Melnik V. V., Abramkin N. I. Geomechanical Substantiation of Underground Mining: Text Book. Moscow : NUST MISIS, 2018. 279 p.
19. Tyo S., Zeitinova Sh. Optimizing the contours of open pit mining with the use of mining and geological information systems and technologies. *Complex Use of Mineral Resources*. 2023. Vol. 327, No. 4. pp. 50–56.
20. Zhe Y., Hou K., Liang W., Sun H. Research on sustainable mining and water prevention in large open-pit water deposits. *Sustainability*. 2023. Vol. 15, Iss. 13. ID 10238.
21. Saik P., Rysbekov K., Kassymkanova K. et al. Investigation of the rock mass state in the near-wall part of the quarry and its stability management. *Frontiers in Earth Science*. 2024. Vol. 12. DOI: 10.3389/feart.2024.1395418
22. Kassymkanova Kh., Jangulova G., Bekseitova R. et al. Express-assessment of geomechanic condition of the rock massive and development methods of its strengthening and reinforcing for safe ecological developing of the fields of mineral resources in hard mountain-geological and mining engineering conditions. *News of the NAS RK. Series of Geology and Technical Sciences*. 2018. Vol. 5, No. 431. pp. 37–46.
23. Bek A. A., Donenbayeva N. S., Nurpeissova M. B., Aitkazinova S. K. et al. Method of consolidating the slope of a quarry. Patent No. 36246 RK. Published: 02.06.2023. EM