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ИЗВЕСТИЯ

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Қазақстан Республикасы Ұлттық ғылым академиясы «ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналының Web of Science-тің жаңаланған нұсқасы Emerging Sources Citation Index-те индекстелуге қабылданғанын хабарлайды. Бұл индекстелу барысында Clarivate Analytics компаниясы журналды одан әрі the Science Citation Index Expanded, the Social Sciences Citation Index және the Arts & Humanities Citation Index-ке қабылдау мәселесін қарастыруда. Webof Science зерттеушілер, авторлар, баспашылар мен мекемелерге контент тереңдігі мен сапасын ұсынады. ҚР ҰҒА Хабарлары. Геология және техникалық ғылымдар сериясы Emerging Sources Citation Index-ке енуі біздің қоғамдастық үшін ең өзекті және беделді геология және техникалық ғылымдар бойынша контентке адалдығымызды білдіреді.

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FEATURES OF THE BEHAVIOR OF ROCKS IN THE UNDERGROUND FIELD DEVELOPMENT

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Abstract. The article is devoted to detailing the principles of geological management based on the assessment and consideration of the geomechanical features of the behavior of rocks during the underground mining of ore deposits. Goals and objectives. The problem of mining of mineral raw materials is insufficient consideration of structural factors when assigning parameters of ore extraction technology. The purpose of the article is to systematize the main provisions of environmental and resource-saving geological management in relation to underground mining of ore deposits. Methods – generalization and systematization of theory and practice, analysis of the results obtained and forecasting the possibility of their application in underground mining. The results of the study – summarized the principles of geological management based on the consideration of geomechanical features of rocks. Information is given on the theory of the processes of development of subsurface reserves, management of the state of arrays, and ensuring the stability of workings in discrete rocks. The condition of the strength of the wedging of structural blocks of rocks is formulated. The conditions for ensuring the geomechanical balance of the massif due to the separation into safe sections and methods for calculating stable spans of flat roof outcrops are given. A classification of methods for calculating roof outcrops from the conditions of the formation of the arch of natural rock equality is proposed. The classification of array management methods in the repayment stage has been clarified. Options for combining technologies with insulation, laying and leaching of ores are considered. A technology is recommended with the issuance of the richest ores on the surface and the processing of the rest in underground blocks, in which the movement of solutions is carried out and controlled with the prevention of contact of solutions with the biosphere. Conclusions – the problems of completeness of the development of mineral resources, waste-free extraction of valuable components, the creation of new environmental technologies are becoming a priority criterion for the effectiveness of mineral extraction technologies. Taking into account structural factors when assigning parameters of ore extraction technology contributes to the humanization of the processes of environmental and resource-saving geological management.

Keywords: Geological management, geomechanics, underground mining, ore deposits, structure, management, condition of massifs.

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ЖЕР АСТЫ КЕН ОРЫНДАРЫН ИГЕРУ КЕЗІНДЕГІ ТАУ ЖЫНЫСТАРЫНЫҢ МІНЕЗ-ҚҰЛЫҚ ЕРЕКШЕЛІКТЕРІ

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Аннотация. *Кіріспе*. Мақала кен орындарын жерасты өндіру кезінде тау жыныстарының мінез-құлқының геомеханикалық ерекшеліктерін бағалау және есепке алу негізінде геопайдалану принциптерін егжей-тегжейлі көрсетуге арналған. *Мақсаттар мен міндеттер.* Минералды шикізатты өндіру мәселесі кен өндіру технологиясының параметрлерін белгілеу кезінде құрылымдық факторларды жеткіліксіз ескеруден шығады. *Мақаланың мақсаты* - кен орындарын жерасты игеруге қатысты экологиялық және ресурс үнемдейтін гео пайдаланудың негізгі ережелерін жүйелеу. *Әдістері* теория мен практиканы жалпылау және жүйелеу, алынған нәтижелерді талдау және оларды жерасты кен орындарын игеруде пайдалану мүмкіндігін болжау. *Зерттеудің нәтижелері* тау жыныстарының геомеханикалық ерекшеліктерін ескере отырып, гео пайдалану принциптерін жалпылайды. Жер қойнауы қорларын игеру процестерінің теориясы, массивтердің жай-күйін басқару және дискретті жыныстардағы жұмыстардың тұрақтылығын қамтамасыз ету туралы ақпарат берілген. Тау жыныстарының құрылымдық блоктарының кептелу беріктігінің шарты тұжырымдалған. Қауіпсіз аймақтарға бөлу арқылы массивтің геомеханикалық тепе-теңдігін қамтамасыз ету шарттары және шатырдың тегіс беткейлерінің тұрақты аралығын есептеу әдістері келтірілген. Тау жыныстарының табиғи тепе-теңдік қоймасының қалыптасу жағдайынан шатырдың беткейлерін есептеу әдістерінің классификациясы ұсынылған. Өтеу сатысында массивті басқару әдістерінің классификациясы нақтыланды. Технологияларды кендерді оқшаулаумен, төсеумен және шаймалаумен біріктіру нұсқалары қарастырылады. Ерітінділердің биосферамен жанасуын болдырмай, ерітінділердің қозғалысы бақыланатын жер асты блоктарындағы ең бай кендерді жер бетіне шығару және қалғандарын өңдеу технологиясы ұсынылады. Жер қойнауын толық игеру, құнды құрамдас бөліктерді қалдықсыз алу, жаңа экологиялық технологияларды құру мәселесінің – қорытындылары пайдалы қазбаларды өндіру технологияларының тиімділігінің басым критерийіне айналады. Кен өндіру технологиясының параметрлерін белгілеу кезінде құрылымдық факторларды есепке алу экологиялық және ресурстарды үнемдейтін гео пайдалану процестерін ізгілендіруге ықпал етеді.

Түйін сөздер: Геологиялық пайдалану, геомеханика, жер асты игеру, кен орындары, құрылымы, басқаруы, массивтердің жағдайы.

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ОСОБЕННОСТИ ПОВЕДЕНИЯ СКАЛЬНЫХ ПОРОД ПРИ ПОДЗЕМНОЙ РАЗРАБОТКЕ МЕСТОРОЖДЕНИЙ

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Аннотация. *Введение.* Статья посвящена детализации принципов геопользования, основанных на оценке и учете геомеханических особенностей поведения скальных пород при подземной разработке рудных месторождений. *Цели и задачи*. Проблемой добычи минерального сырья является недостаточный учет структурных факторов при назначении параметров технологии добычи руд. Целью статьи является систематизация основных положений природоохранного и ресурсосберегающего геопользования применительно к подземной разработке рудных месторождений. *Методы* – обобщение и систематизация теории и практики, анализ полученных результатов и прогнозирование возможности их применения при подземной разработке месторождений. *Результаты исследования* – обобщены принципы геопользования, основанные на учете геомеханических особенностей скальных пород. Приведены сведения о теории процессов освоения запасов недр, управлении состоянием массивов, и обеспечении устойчивости выработок в дискретных породах. Сформулировано условие прочности заклинивания структурных блоков пород. Приведены условия обеспечения геомеханической сбалансированности массива за счет разделения на безопасные участки и методы расчета устойчивых пролетов плоских обнажений кровли. Предложена классификация методов расчета обнажений кровли из условия образования свода естественного равновесия пород. Уточнена классификация способов управления массивом в стадии погашения. Рассмотрены варианты комбинирования технологий с изоляцией, закладкой и выщелачиванием руд. Рекомендована технология с выдачей на поверхности наиболее богатых руд и переработкой остальных в подземных блоках, при которой движение растворов осуществляется и контролируется с предотвращением контакта растворов с биосферой. *Выводы* – проблемы полноты освоения недр, безотходного извлечения ценных компонентов, создания новых природоохранных технологий становятся приоритетным критерием эффективности технологий добычи минерального сырья. Учет структурных факторов при назначении параметров технологии добычи руд способствует гуманизации процессов природоохранного и ресурсосберегающего геопользования.

Ключевые слова: геопользование, геомеханика, подземная разработка, рудные месторождения, структура, управление, состояние массивов.

Introduction. In the volume of production of metal-bearing mineral raw materials there is a large share of ores from the massifs of deposits, which by their parameters are classified as complex-structured. These deposits owe their genesis to geotectonic processes, are characterised by complex geodynamic phenomena in the process of development and require attention during design and development (Palyanitsina, et al., 2021; Korshak, et al., 2019; Korshak, et al., 2020).

The ore-bearing massif is an energy-rich system that is stable as long as it is not disturbed by mining operations. As a guarantee of the safety of mining operations, the preservation of the area of the earth surface separating the zone of life and the zone of mineral extraction is accepted. Technologies that ensure the safety of the earth surface are both environmental protection and resource-saving (Golik, et al., 2015).

It has been theoretically substantiated and proved by centuries of practice that rocks of the rock type exposed by mine workings form stable structures when they are exposed by mining operations, provided that a natural collapse vault is formed above the workings from structural rock separations wedged along curvilinear surfaces (Pshenin , et al., 2023; Kusimova, et al., 2023; Korshak, et al., 2023).

The information about the massif accumulated during exploration and replenished during field operation allows optimising the development indicators at the design stage and adjusting them (Golik, et al., 2023; Sinitsin, et al., 2023).

Previously published works (Golik, et al., 2023; Sinitsin, et al., 2023; Malyukova, et al., 2023) show that the management of the state of stress-strain massif is reduced to the following:

* the parameters of mining operations are determined by the geomechanics of the array;

* filling voids with solidifying mixtures is a reliable way to control stresses;

* control efficiency is improved by increasing the volume compression of the deposit.

The purpose of research in this area of mining is to systematise the main provisions of geo-use in relation to underground mining of ore deposits represented by complex-structured rock massifs.

Methods. The basis of the management methodology of the developed ore-bearing massifs is the assessment of the state of the natural and technogenic system, the stability of which is disturbed by mining operations at the stage of clearance excavation. Many researchers take as a guarantee of environmental safety the preservation of the earth surface separating the zones of living matter habitat and the zone of mineral raw material extraction (Gridina, et al., 2023; Gridina, et al., 2022; Rodionov, et al., 2022).

The data bank of arrays is completed by systematisation of geo-use data in specific conditions of the developed deposit, obtained in the course of complex researches, the tools, volume and quality of which are regulated.

The possibility of forming load-bearing structures under the condition of a reliable natural cave-in vault from wedged rocks is determined at the design stage, specified during field development and used as a basis for optimisation and adjustment of ore extraction indicators (Karlina, et al., 2023).

The processes occurring in rock formations are described by models, including: the state of the rock massif when interfered with by mining operations, correction of the massif balance by dividing it into areas not dangerous in terms of stresses, etc (Rodionov, et al., 2022).

Since it is desirable to maintain a flat roof of the excavation to reduce clogging of ores separated from the ore massif by rock, the stability of mine workings is assessed differentially for the mining systems used.

The degree of environmental hazard of the technologies is determined by calculations depending on the ratio between the volume of voids formed by the excavation and the properties of the filler of the excavated space (Gridina, et al., 2022; Gendler, et al., 2016).

On the basis of the analysis of the theory and practice of the deposit development, recommendations are given to improve the performance of its development, taking into account the peculiarities of the behaviour of stress-strain rock massifs, which differ from other massifs by petrographic and structural heterogeneity.

Research results. In rocky rocks, rock fracture occurs with the formation of structural blocks that behave as rigid bodies with elastic contact in compression, which is described by the model (Komashchenko, 2015):

$$\sigma_1 \pm k\sigma_{2,3} \leq \sigma_{сж} = \begin{cases} \sigma^0_{сж} = \int_0^{Z_{0max}} fx(dx_1, dx_2 ... dx_n) \rightarrow \begin{cases} \sigma_{закл} = \int_0^{Z_{0max}} fx(dH_S) \\ \sigma_{закл} = \int_0^{Z_{0max}} fx(dH_S + dH_C) \end{cases} \\ \sigma^{ост}_{сж} \quad \text{при } H_C = H \rightarrow \sigma_{закл} = \int_0^{B} fx(dH) \end{cases}$$

where σ_1 - main stresses in vertical direction, MPa; $\sigma_{2,3}$ - main stresses (their horizontal component), MPa; σ_{comp} - stresses for the upper layer of previously undrained rocks, MPa; k - stress distortion coefficient by tectonic structures; - stresses in the zone of influence of cleaning works, MPa; - residual strength of rocks, MPa; Z_{omax} - span size (for the case when the flat form of outcrop is preserved), m; $x_1, ...x_n$ - characteristics of structural blocks; σ_{cemb} - compressive strength of the embedding massif, MPa; B - size of the collapse zone (width), m; H - size of the collapse zone (height), m; H_s - height of the embedding massif, m; H_c - height of the zone of influence of cleaning works, m.

The condition of the rock massif is described by the condition [12]:

$$\sigma \cdot K_з = \int_{l_{min}}^{l_{max}} fx(dx_1, dx_2.....dx_n) \rightarrow П, R = \int_{l_{min}}^{l_{max}} f \cdot x(dh_з + dh_n)$$

where σ - stresses in the zone of influence of mine workings, MPa; K_z - stress correction factor; l_{max}, l_{min} - spans of rock outcrop, m; $x_1 ... x_n$ - rock characteristics; P - ore losses, fractions of units; R - ore dilution, fractions of units; $h_з$ – height of the deposit massif, m; h_n – height of the zone of influence of mine workings, m.

Geomechanical balance for the massif under study during mining operations is ensured by its division into sections. In these sections, into which the array is divided, the stresses do not reach the critical value (Fig. 1).

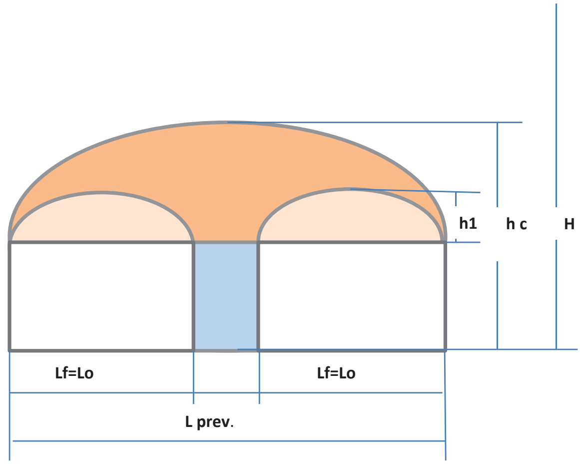

Fig. 1. Dividing the array into sections: L_{prev} – according to the condition of the formation of the arch of natural equilibrium; L_f – actual; L_o – flat roof; H– depth of work; h_c – height of the arch of natural equilibrium at the limit span; h_1 – height of the new building

In order to reduce clogging of ores with rock, it is important that the roof of the mine workings within the vault does not collapse, but maintains a flat shape. In homogeneous fractured rocks, the stability of the roof is determined by the ability of the bearing element of the rock structure in the roof (Fig. 2).

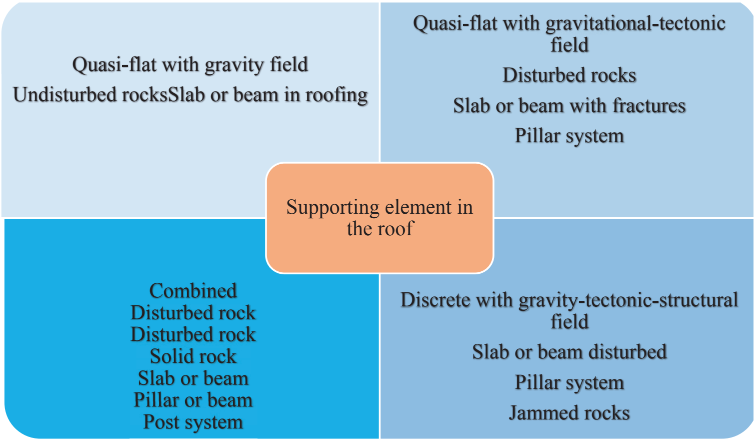

Fig. 2. Typification of rocks by the ability to form load-bearing structures in the roof

Classification of array management methods is carried out according to the principle of the mined-out space condition (Table 1).

Table 1 – Classification of void repayment methods

Classes	Groups	Options
With isolation of mine workings by enclosing them	Lintels	Wooden, rock Concrete
With rock caving to fill the excavated space	Forced collapse	Separate with ore or together
	Controlled self-collapse	Separate with ore or together
With filling of the excavated space with compensating materials	Solid mixtures	Chamber and layer systems
	Bulk solids	From surface and from mine workings
	Underground leach tailings	With natural colmatisation or hardening

The advantages of the isolation method are explained by lower costs, while the disadvantages include difficulties in controlling the condition of the extinguished massif to guarantee safety in case of a hypothetical rock collapse and alienation of land in the zone of influence of mining operations.

The main disadvantage of the hardening mixtures method is the relatively high cost and scarcity of embedding materials (Kondrat'ev, et al., 2022).

A special case of the technology with embedding is the formation of artificial massifs by natural solidification of block leaching tailings. Natural binders bind them into a concrete structure with a strength of up to 1 MPa.

Combined methods are based on the joint use of technologies with isolation, embedding and leaching of ores. The filling of voids with the embedding material reduces stresses in the required proportions, with the means of regulation being the embedding mass (Zhikharev, et al., 2023; Kaverzneva, et al., 2023).

The environmental hazard of the technology depends on the ratio of void volumes and the material used to fill the excavated space to compensate for the voids:

$$K_1 = \frac{V_{fill}}{V_{\Pi}}$$

where V_{fill} – excavation filling volume, m^3; V_{prod} – production volume,m^3.

A combination of two technologies (hardened tailings and hardened backfill) is shown in

Fig. 3

$$K_2 = \frac{V_{зак} + V_{пв}}{V_п},$$

where V_{fvoid} – total volume of voids that were filled with tailings.

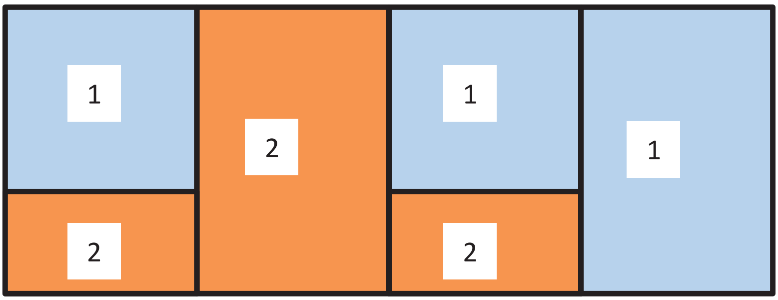

Fig. 3. Combination of technologies for repayment of the developed space: 1 – leaching tails; 2 – hardening mixtures

The general scheme of combining technologies (isolating voids and laying hardening mixtures) is shown in Fig. 4:

$$K_3 = \frac{V_{fill} + V_{void}}{V_{\Pi}}$$

where V_{void} – total void volume.

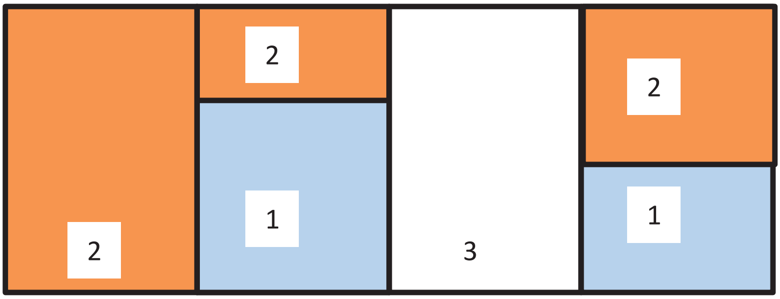

Fig. 4. Combination of technologies with hardening bookmark and leaching tails: 1 – leaching tails; 2 – hardening mixtures; 3 – unfilled voids

The discussion of the results. The possibility of increasing field development indicators is determined by the reserve extraction project. This project must be optimized according to a number of criteria (ecological and economic criteria). The result of this optimization is that the goal of the project changes. Instead of developing and selectively extracting reserves as quickly as possible, the goal is shifting towards obtaining maximum total income from field development (Kondrat'ev, et al., 2016; Kondratiev, et al., 2022; Evdokimov, et al., 2024).

The optimal combined technology is one in which the richest ores are brought to the surface for processing, and the rest are processed by underground leaching. In this case, the movement of solutions is carried out in a closed environment of pipelines, which prevents the possibility of their contact with the biosphere.

For rock masses, vertical stresses are most often less than horizontal stresses. In this case, the geostatic distribution law can be well used to calculate such vertical stresses. This is due to the fact that structural and petrographic heterogeneities also influence the emerging gravitational and tectonic forces, their character and nature. Such stresses that arise in arrays can be regulated by changing the direction of the stresses and changing the magnitude of these same stresses. Another way to influence stress is to adjust the bearing capacity of rocks. It can be carried out in space and time.

Stresses can be converted to static from dynamic by preventive weakening of the array. At the same time, it is possible to significantly reduce the cost of backfilling work by up to 1.4 times. This can be done by transferring this backfill mass into a state of triaxial compression from a uniaxial state. The load-bearing capacity of the void-filling material at 2–3-fold volumetric compression increases according to A.L. Trebukov at 2–3.7, D.M. Bronnikov – 2–3, M.N. Tsygalov - 3.5 times.

Thus, technologies with ore breaking by exploding explosive charges provide stress control by varying the parameters of drilling and blasting operations. The uniformity of ore crushing is ensured by optimizing the value of the line of least resistance by regulating the time of crack formation. If the deceleration interval is less than the optimal time, the energy consumption for crack opening increases.

If it becomes more necessary to expend energy to restore the previously achieved equilibrium (Gendler, et al., 2018).

The parameters of seismic waves are controlled by changing the boundary conditions on the external and internal fracture contours and the acoustic rigidity of the medium. Loosening is created by selecting the deceleration values and the specific charge consumption in the wells. Loosening is formed between the contour of the ore-bearing massif and the charge. It plays the role of a screen. The deceleration interval time should be no more than 25 ms. With such a time, the superposition of stresses from neighboring series of explosions of charges will be eliminated.

The regulation of natural and man-made stresses in the massif makes it possible to increase work safety, reduce ore dilution and improve its beneficiation rates.

The results of the study echo the conclusions of specialists in this area of mining (Ilyushin, et al., 2019; Demenkov, et al., 2023).

Conclusion. As the Earth's population increases, the relevance of the problems of complete development of subsoil, waste-free extraction of valuable components, creation of new environmental technologies, etc. will increase. Nature and resource conservation is becoming the main criterion for the efficiency of mineral extraction technologies.

The conditions for developing deposits will become more complex, and competition in the mineral resources market will intensify. Special methods of extraction will be further developed, as they are more consistent with the principles of a humane attitude to the subsoil.

The criterion for the correctness of ore mining technologies will be the preservation of the earth's surface, as a guarantor of the isolation of dangerous underground mining processes.

The implementation of the principles of geouse contributes to the humanization of the processes of environmental and resource-saving geouse.

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