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«Қазақстан Республикасы Ұлттық ғылым академиясының Хабарлары. Геология және техникалық ғылымдар сериясы» ғылыми журналы 2016 жылдан бастап халықаралық реферативтік және ғылыметриялық Scopus дерекқорында индекстеледі және тұрақты библиометриялық көрсеткіштерді көрсетіп келеді.

Сонымен қатар журнал Web of Science платформасының (Clarivate Analytics, 2018) халықаралық реферативтік және наукометриялық дерекқоры Emerging Sources Citation Index (ESCI) тізіміне енгізілген.

ESCI дерекқорында индекстелуі журналдың халықаралық ғылыми рецензиялау талаптары мен редакциялық этика стандарттарына сәйкестігін растайды, сондай-ақ Clarivate Analytics компаниясы тарапынан басылымды Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) және Arts & Humanities Citation Index (AHCI) дерекқорларына енгізу қарастырылуда.

Scopus және Web of Science дерекқорларында индекстелуі жарияланымдардың халықаралық деңгейде жоғары сұранысқа ие болуын қамтамасыз етеді, олардың дәйексөз алу көрсеткіштерінің артуына ықпал етеді және редакциялық алқаның геология мен техникалық ғылымдар саласындағы өзекті, бірегей және ғылыми тұрғыдан маңызды зерттеулерді жариялауға ұмтылысын айқындайды.

Научный журнал «News of the National Academy of Sciences of the Republic of Kazakhstan, Series of Geology and Technical Sciences» с 2016 года индексируется в международной реферативной и наукометрической базе данных Scopus и демонстрирует стабильные библиометрические показатели.

Журнал также включён в международную реферативную и наукометрическую базу данных Emerging Sources Citation Index (ESCI) платформы Web of Science (Clarivate Analytics, 2018).

Индексирование в ESCI подтверждает соответствие журнала международным стандартам научного рецензирования и редакционной этики, а также рассматривается компанией Clarivate Analytics в рамках дальнейшего включения издания в Science Citation Index Expanded (SCIE), Social Sciences Citation Index (SSCI) и Arts & Humanities Citation Index (AHCI).

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*Tashkent State Technical University named after Islam Karimov,
Tashkent, Uzbekistan.
*****E-mail: zafarzafar2066@gmail.com

EFFECT OF ROCK MASS DISCONTINUITIES ON UNDERGROUND MINE STABILITY (UZBEKISTAN)

Kazakov Aziz — PhD, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan,
E-mail: Azlik19@yandex.ru, https://orcid.org/0000-0001-9862-6594;
Khakberdiyev Muzaffar — PhD, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan,
E-mail: zafarzafar2066@gmail.com, https://orcid.org/0000-0002-8386-4036;
Qurbonov Hasan — PhD Student, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan,
E-mail: kimqx92@gmail.com, https://orcid.org/0009-0004-2077-0798;
Turgunov Shokhruh — PhD Student, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan,
E-mail: shohruxmirzo789@icloud.com, https://orcid.org/0009-0004-6100-1207;
Obidov Muqbil — Master's student, Tashkent State Technical University named after Islam Karimov, Tashkent, Uzbekistan,
E-mail: muqbilobidov98@gmail.com, https://orcid.org/0009-0000-4893-9699.

Abstract. This study evaluates the influence of rock mass fracturing on the stability of underground mine workings at the Zarmitan gold deposit. The topic is particularly relevant for Uzbekistan, where steeply dipping ore bodies, significant mining depths, and high seismotectonic activity create challenging geomechanical conditions. Under such circumstances, a precise characterization of fracture systems becomes essential for accurate stability assessment and safe mine design.

The objective of this work was to determine the geometry, spatial orientation, and intensity of fracture systems and to provide a quantitative evaluation of their impact on excavation stability. The research methods included field measurements of fracture orientation, construction of rose diagrams, statistical classification of

zones by fracture density, and calculation of the Factor of Safety (FoS) based on the physico-mechanical properties of the rock mass.

The results indicate that 60–65% of all measured fractures form angles of 10–20° to 69° with bedding and represent oblique-cutting joints, while the remaining 35–40% form angles of 70–76° and belong to normal-cutting joints. The rock mass is divided into weakly fractured (1.4–1.6 joints/m), moderately fractured (2.5–2.6 joints/m), and highly fractured zones (>5 joints/m). Corresponding FoS values are 1.45–1.65, 1.10–1.30, and 0.85–1.05, reflecting a transition from stable to unstable conditions.

The practical significance of the study lies in identifying hazardous zones, optimizing the orientation of mine workings, and selecting appropriate support measures, thereby contributing to enhanced safety of underground mining operations.

Key words: rock pressure, fracturing, geomechanics, geodynamics, mine workings, rockburst hazard, rock structures, geodynamic hazard, stress field

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И.Каримов атындағы Ташкент мемлекеттік техникалық университеті,
Ташкент, Өзбекстан.
*E-mail: zafarzafar2066@gmail.com

ТАУ ЖЫНЫСТАРЫ МАССИВІНІҢ ЖАРЫЛУЫНЫҢ ЖЕРАСТЫ ТАУ КЕН ҚАЗБАЛАРЫНЫҢ ТҰРАҚТЫЛЫҒЫНА ӘСЕРІН БАҒАЛАУ (ӨЗБЕКСТАН)

Казаков Азиз — PhD, Маркшейдерлік іс және геодезия кафедрасының меңгерушісі, И. Каримов атындағы Ташкент мемлекеттік техникалық университеті, Ташкент, Өзбекстан,
E-mail: Azlik19@yandex.ru, https://orcid.org/0000-0001-9862-6594;
Хакбердиев Музаффар — PhD, И. Каримов атындағы Ташкент мемлекеттік техникалық университеті, Ташкент қ., Өзбекстан,
E-mail: zafarzafar2066@gmail.com, https://orcid.org/0000-0002-8386-4036;
Құрбонов Хасан — PhD докторант, И. Каримов атындағы Ташкент мемлекеттік техникалық университеті, Ташкент, Өзбекстан,
E-mail: kimqx92@gmail.com, https://orcid.org/0009-0004-2077-0798;
Тургунов Шохрух — PhD докторант, И. Каримов атындағы Ташкент мемлекеттік техникалық университеті, Ташкент, Өзбекстан,
E-mail: shohruxmirzo789@icloud.com, https://orcid.org/0009-0004-6100-1207;
Обидов Мукбиль — Магистрант, И. Каримов атындағы Ташкент мемлекеттік техникалық университеті, Ташкент қ., Өзбекстан,
E-mail: muqbilobidov98@gmail.com, https://orcid.org/0009-0000-4893-9699.

Аннотация. Шпинельді ферриттер, соның ішінде кобальт ферриті ($CoFe_2O_4$), жоғары химиялық және термиялық тұрақтылығы, реттелетін магниттік қасиеттері және меншікті беткі ауданының дамығандығының үйлесуі арқасында функционалдық магниттік материалдар ретінде үлкен ғылыми қызығушылық тудырады. Антропогендік жүктеменің артуы және экологиялық талаптардың қатаюы жағдайында ағынды суларды тазартуға арналған тиімді әрі регенерацияланатын материалдарды әзірлеу өзекті мәселе болып табылады. Осы тұрғыдан алғанда, кобальт ферриті негізіндегі магниттік наноматериалдар сыртқы магнит өрісін қолдану арқылы су ортасынан тез бөлініп алыну мүмкіндігіне байланысты перспективалы сорбенттер мен катализаторлар ретінде қарастырылады.

Аталған жұмыстың мақсаты – бірфазалы $CoFe_2O_4$ нанобөлшектерін синтездеу және оларды экологиялық ремедиация үдерістерінде қолдану мүмкіндігін бағалау үшін құрылымдық және физика-химиялық қасиеттерін зерттеу. Нанобөлшектер золь-гельдік жану әдісімен алынды, бұл әдіс құрамның біртектілігін, кристалдық фазаның бақыланатын қалыптасуын және морфологиялық параметрлердің қайта өндірілуін қамтамасыз етеді. Материалдардың құрылымдық және элементтік сипаттамалары рентгендік дифракция (XRD), энергодисперсиялық спектроскопия (EDS) және Фурье инфрақызыл спектроскопиясы (FTIR) әдістерімен зерттелді.

XRD талдауы қоспасыз таза кубтық шпинель құрылымындағы $CoFe_2O_4$ фазасының қалыптасқанын растады. EDS нәтижелері материал құрамында Co, Fe және O элементтерінің ғана стехиометриялық арақатынаста бар екенін көрсетті, ал FTIR спектрлері металл–оттек байланыстарына тән тербеліс жолақтарының болуын анықтады. Алынған нанобөлшектер $(Fe^{3+})_a(Co^{2+}Fe^{3+})_\beta O_4$ типіндегі шпинельді катиондық конфигурациямен сипатталады, бұл олардың жоғары құрылымдық тұрақтылығын және қолайлы магниттік қасиеттерін қамтамасыз етеді.

Алынған нәтижелер $CoFe_2O_4$ нанобөлшектерінің ағынды суларды тазарту, ластаушы заттарды сорбциялау және магниттік басқарылатын бөліп алу үдерістерімен байланысты экологиялық қолданбалар үшін перспективалы функционалдық материал екенін көрсетеді.

Түйін сөздер: тау қысымы, жарылу, геомеханика, геодинамика, тау-кен қазбалары, соққы қаупі, тау-кен құрылымдары, геодинамикалық қауіп, шиеленіс өрісі

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Ташкентский государственный технический университет имени И. Каримова, Ташкент, Узбекистан.
*E-mail: zafarzafar2066@gmail.com

ОЦЕНКА ВЛИЯНИЯ ТРЕЩИНОВАТОСТИ МАССИВА ГОРНЫХ ПОРОД НА УСТОЙЧИВОСТЬ ПОДЗЕМНЫХ ГОРНЫХ ВЫРАБОТОК (УЗБЕКИСТАН)

Казаков Азизи — PhD, заведующий кафедрой Маркшейдерского дела и геодезии, Ташкентского государственного технического университета им. И. Каримова, Ташкент, Узбекистан,
E-mail: Azlik19@yandex.ru, https://orcid.org/0000-0001-9862-6594;
Хакбердиев Музаффар — PhD, Ташкентский государственный технический университет имени И. Каримова, Ташкент, Узбекистан,
E-mail: zafarzafar2066@gmail.com, https://orcid.org/0000-0002-8386-4036;
Курбонов Хасан — PhD докторант Ташкентского государственного технического университета имени И.Каримова, Ташкент, Узбекистан,
E-mail: kimqx92@gmail.com, https://orcid.org/0009-0004-2077-0798;
Тургунов Шохрух — PhD докторант Ташкентского государственного технического университета имени И. Каримова, Ташкент, Узбекистан,
E-mail: shohruxmirzo789@icloud.com, https://orcid.org/0009-0004-6100-1207;
Обидов Мукбиль — Магистрант, Ташкентский государственный технический университет имени И. Каримова, Ташкент, Узбекистан,
E-mail: muqbilobidov98@gmail.com, https://orcid.org/0009-0000-4893-9699.

Аннотация. Шпинельные ферриты, в частности кобальтферрит ($CoFe_2O_4$), представляют значительный интерес как функциональные магнитные материалы благодаря сочетанию высокой химической и термической стабильности, регулируемых магнитных характеристик и развитой удельной поверхности. В условиях возрастающей антропогенной нагрузки и ужесточения экологических требований актуальной задачей является разработка эффективных и регенерируемых материалов для очистки сточных вод. В этом контексте магнитные наноматериалы на основе кобальтферрита рассматриваются как перспективные сорбенты и катализаторы, обеспечивающие возможность быстрого извлечения из водной среды с использованием внешнего магнитного поля. Целью настоящей работы являлись синтез однофазных наночастиц $CoFe_2O_4$ и исследование их структурных и физико-химических характеристик для оценки потенциального применения в процессах экологической ремедиации. Наночастицы получены методом золь-гель горения, обеспечивающим однородность состава, контролируемое формирование кристаллической фазы и воспроизводимость морфологических параметров. Структурные и элементные характеристики материалов исследованы с использованием рентгеновской дифракции (XRD), энергодисперсионной спектроскопии (EDS)

и Фурье-ИК-спектроскопии (FTIR). Результаты XRD-анализа подтвердили формирование чистой кубической шпинельной фазы $CoFe_2O_4$ без примесных соединений. Данные EDS свидетельствуют о присутствии исключительно элементов Co, Fe и O в стехиометрических соотношениях, а FTIR-спектры демонстрируют характерные полосы колебаний металл-кислородных связей. Установлено, что полученные наночастицы обладают типичной шпинельной катионной конфигурацией $(Fe^{3+})_a(Co^{2+}Fe^{3+})_\beta O_4$, обеспечивающей высокую структурную устойчивость и благоприятные магнитные свойства. Полученные результаты подтверждают перспективность наночастиц $CoFe_2O_4$ в качестве функционального материала для очистки сточных вод и других экологических применений, связанных с сорбцией и магнитоуправляемым извлечением загрязняющих веществ.

Ключевые слова: горное давление, трещиноватость, геомеханика, геодинамика, горные выработки, удароопасность, горные конструкции, геодинамическая опасность, напряженное поле

Introduction. When studying the stress state of the rock mass during the underground development of deposits in Uzbekistan at great depths, it is necessary to pay special attention to problems related to the stability of underground mine workings and pillars, since the rationality and safety of mining operations depend on the correct prediction of the behavior of the field mass under load. And with difficult development indicators in the conditions of gold deposits in Uzbekistan, a large depth of development and increased seismotectonic activity, the regional stress field plays a decisive role in excavation stability (Markov et al., 2021), and therefore the assessment of the stability of mine workings is of primary importance for the efficiency of the mining enterprise.

The importance of ensuring industrial and geodynamic safety in underground conditions has been emphasized in earlier works (Sayyidkosimov et al., 2018).

Genetic and geometric classifications of cracks are known (Mukhitdinov et al., 2019; Qurbonov H et al., 2025).

In general terms, all cracks can be classified according to two characteristics: genetic and geometric.

Among the available genetic classifications, the most convenient for practical use, in our opinion, is the classification proposed by V. V. Belousov (Sayyidkosimov, 2016). According to this classification, fractures are divided into tectonic and non-tectonic. Tectonic fractures include fractures with a break in the continuity of rocks and cleavage. Non-tectonic cracks include: primary cracks, landslide cracks, landslides and sinkholes, weathering cracks, rock expansion cracks during unloading, and artificial cracks (during bursts, impacts, etc.).

Of the geometric classifications, the most acceptable for practical application, from the point of view of assessing the role of fracturing in the stability of pillars and ceilings of chambers, is the classification proposed. VNMI, which is widely

used and is based on the orientation of the relative to the rock mass stratification the mountain massif stratification (Turesebekov et al., 2007).

According to this classification, cracks are divided into two groups:

1. Longitudinal, transverse and diagonal normally secant lines.

2. Longitudinal, transverse and diagonal oblique sections.

Normal-cutting cracks include those that form an angle of at least 70° with the stratification plane, while the remaining cracks belong to the group of oblique-cutting ones.

If the line of intersection of cracks with the stratification in the plane of the ore body forms an angle with the strike line not exceeding 20°, then these cracks are considered longitudinal.

Accordingly, for diagonal cracks, the mentioned angle is enclosed in the range from 20° to 70°, for transverse cracks-more than 70°.

The greatest influence on the stability of roof rocks is exerted by normal-cutting cracks falling towards the developed space, and for pillars - vertical or close to them cracks under the condition of a gentle fall of ore bodies.

Experimental research. In order to find out the degree of influence of fracturing of the massif on the stability of pillars and the roof of chambers, rock fracturing was studied at the Zarmitan deposit and its effect on the stability of mine workings was revealed.

It was necessary to determine some regularities of crack propagation within the existing mine fields, the degree and nature of the rock mass disturbance by macro- and micro-fracturing, and to study the stratification, as well as the nature of crack surfaces and contacts between layers.

Measurements of the geometrical parameters of cracks were carried out by cleaning and preparatory workings and pillars. Measurement points were selected at the interface of workings, where two mutually perpendicular planes are exposed. The azimuth of the strike line and the angle of incidence of cracks were measured using a mountain compass. The distances between cracks and their propagation lengths, as well as the binding of the observation area to the workings, were made using a steel tape measure. The frequency of measurement sites was taken depending on the complexity of the mining and geological structure of 25-40 m in the fall and 60-80 m in the strike of the ore body.

To determine the change in the spatial orientation of fracturing with the depth of development, measurements were made at different horizons.

Rose diagrams for +780, +720, and +660 horizons of the Zarmitan mine field were constructed from the data of tectonic crack occurrence elements, and summary rose diagrams of fine-amplitude discontinuities were obtained (Fig. 1). Measurements of these crack parameters were grouped at intervals of 5 and 100.

When processing the data, 4 rose diagrams were obtained.

For the quantitative assessment of excavation stability, averaged physico-mechanical properties of the host rocks were used, based on laboratory testing and

geomechanical analysis. The key parameters included a density of approximately 2500 kg/m³, an elastic modulus of about 1.8×10^4 MPa, Poisson's ratio 0.23, lateral pressure coefficient 0.3, and compressive and tensile strengths of roughly 35 MPa and 3–4 MPa, respectively. These values characterize the actual deformation and strength behavior of the rocks at the Zarmitan deposit and were used as input parameters for the estimation of the Factor of Safety (FoS).

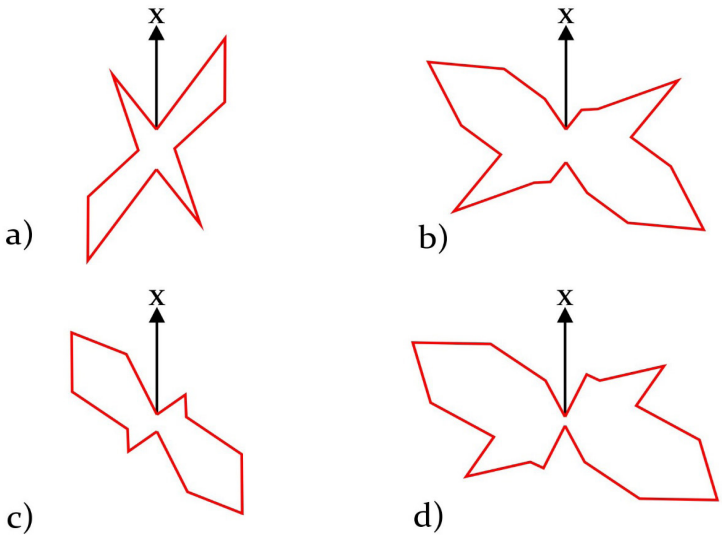

Figure 1. Diagram-distribution of discontinuous faults along the mining horizons: a) - 660 m horizon; b) – 720 m horizon; c) - 780 m horizon; d) Generalized horizons.

Based on the results of these diagrams, the directions of the main crack systems formed in these areas are revealed. A comparison of the fracture systems for different sites showed that their spatial orientation varies within insignificant limits, which makes it possible to identify the main fracture systems for the Zarmitansky field as a whole. The spatial orientation of these systems is given in Table 1.

Table 1

№	Azimuth of fall in hail	Angle of fall in hail	Classification of cracks by angle of fall
I	SW 20	4^0	Gentle
II	SW 108	57^0	Steep
III	NW 274	70^0	Very steep
IV	SW 210	80^0	Very steep
V	SW 20	77^0	Very steep

Studies of the morphology of fractures, their correlation with rock layers, folds, and faults allowed us to determine that the genesis of these cracks in the Zarmitan field is mainly tectonic.

Further, it was revealed that the field has three types of areas according to the degree of fracturing: weakly fractured – where the fracture modulus averages 1.4-1.6 tr/p. m.; medium-fractured-where the fracture modulus exceeds 2.6 tr/p. m.; strongly fractured – where the modulus is more than 5 tr/p. m.

The field is dominated by longitudinal and diagonal cracks. More dangerous, from the point of view of stability, will be workings that pass through them or intersect them at an oblique angle (Kazakov et al., 2023).

The greatest frequency of angles of incidence of cracks is from 21 to 40^0 and from 61 to 80^0. More dangerous are cracks with angles of incidence from 61 to 80^0, which in the case of their cross-section by workings can become sliding surfaces.

For comparison with the rose diagrams, pie charts are constructed that allow us to judge the joint distribution of occurrence elements and the degree of severity of fracture systems (Fig. 2).

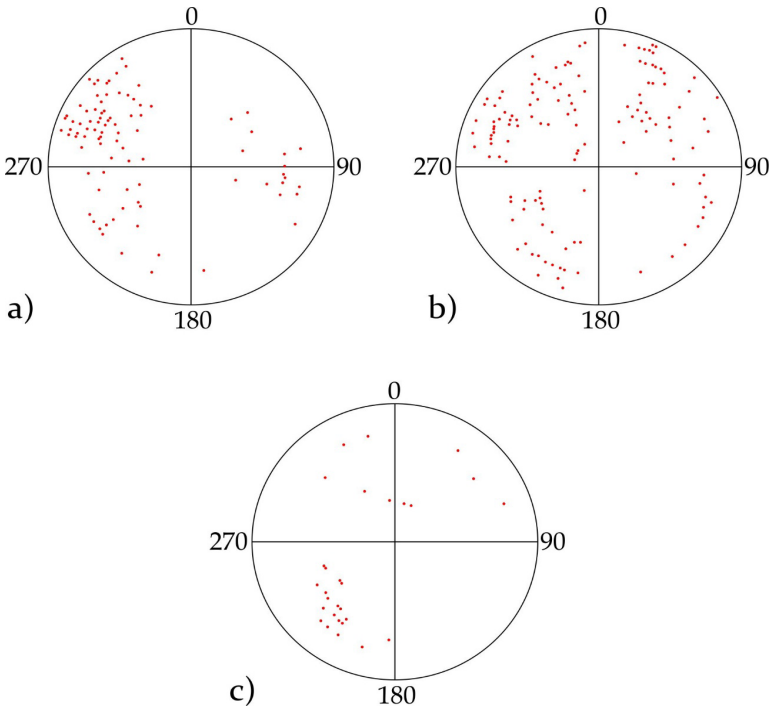

Figure 2. Pie charts of fracturing along mining horizons:
a) - Horizon 780 m; b) - Horizon 720 m; c) - Horizon 660 m.

Based on the structural data obtained for the Zarmitan deposit, an additional stability assessment was carried out to quantify the effect of discontinuities on the reliability of underground excavations. The Factor of Safety (FoS) was estimated for representative sections of the rock mass with different degrees of fracturing.

The analysis shows that weakly fractured zones (1.4–1.6 joints/m) retain most of their bearing capacity, with FoS values ranging from 1.45 to 1.65, corresponding to

a stable condition and low probability of failure. In moderately fractured sections, where structural weakening reaches 30–40 %, the FoS decreases to 1.10–1.30, indicating a transitional and potentially hazardous condition, especially when workings intersect diagonal fractures at an oblique angle.

The lowest values were identified in highly fractured areas (more than 5 joints/m), where the FoS drops to 0.85–1.05. These values indicate borderline or unstable conditions, particularly in zones dominated by steep (61–80°) normal-cutting fractures that may form sliding surfaces.

The quantitative analysis of the geometry and orientation of the fracture systems has shown that the Zarmitan rock mass exhibits distinct and statistically consistent patterns. Field measurements indicate that 60–65% of all documented fractures form angles of 10–20° to 69° with the bedding plane and belong to the oblique-cutting type, while the remaining 35–40% form angles of 70–76° and correspond to normal-cutting fractures. This proportion highlights the dominance of fracture systems capable of forming wedge- and shear-controlled failure surfaces.

Depending on the disturbance intensity, the rock mass is divided into three categories:

– weakly fractured (1.4–1.6 joints/m),

– moderately fractured (2.5–2.6 joints/m),

– highly fractured (more than 5 joints/m), where the rock mass breaks into blocks as small as 15 × 40 × 60 cm.

The observed FoS variations are consistent with numerical displacement modeling described in previous studies (Sayyidkosimov and Nizamova, 2022). Weakly fractured zones remain stable (FoS 1.45–1.65), moderately fractured zones show reduced stability (FoS 1.10–1.30), and highly fractured zones fall into borderline or unstable conditions (FoS 0.85–1.05). These unstable zones exhibit the highest concentration of roof falls and detachments, with failure surfaces coinciding with the most developed fracture systems.

Results. The measurement results show that the vast majorityшof the measured fractures (up to 63 %) form an angle from 10-20 to 69° with the rock stratification plane and are obliquely intersecting, while the remaining 37% of cracks form an angle in the range of 70-76° and are considered to be normal-intersecting.

The first system of cracks coinciding with the stratification of the false roof is more clearly traced in the examined areas of ore bodies.

Cracks of this system can be traced along the length from 1.5to 60 m, usually they are slightly open, the dimensions in width are up to 0.5 cm - 55%, from 0.5 to 1.0 cm-40 % and more than 1.0 cm-less than 5 %, They are filled with calcite up to 55 %, friction clay 20 % and empty 25 %., as a rule, the largest fractures are mineralized.

The distance between cracks is normal from 35 cm to 2.0 m, the angles of incidence are not more than 20°. The surface of the crack walls is usually rough and there are straight cracks with lapped walls, the number of cracks in the measurement interval (6-10 m) varies from 20 to 50.

Cracks of the second system are developed in skarns and have variable azimuths of incidence from1.08° to 274°, the predominant angle of incidence is 5.7-80-80°, and the surface of most of them is flat and smooth.

The slightly open cracks of this system are not mineralized and have a length of 0.2 to 1.0 m, sometimes up to 8-10 m.

Wavy cracks in skarn with rough walls are spread out slightly, and have a length of 0.5 to 1.5m. The distance between cracks is from 5 to 20 cm, the width of cracks in most cases is insignificant and amounts to tenths of a millimeter. Cracks in this system cause columnar separateness of the ore skarn.

Cracks of the third systemюare present in all lithological variations; their length ranges from several tens to hundreds of meters, they are slightly open, and their dimensions in width range from 0.2 to 2 cm. Most of the cracks in this system are filled with calcite and friction clay. These patterns correspond well with destruction zone studies reported for similar lithologies (Ochilov et al., 2024).

Non-mineralized cracks have a smallж drop of water, the distance between the cracks of this system is from 0.5 to 2.5 m, and they can be traced both in the fall and in the strike of the entire mine field.

At the upper horizons, the rock mass has a higher degree of fracturing, these cracks break up the ore body into separate structural prismatic blocks with average dimensions of 15x40x60 cm; more intense fracturing is observed near the zones of displacement and crushing; here the size of structural blocks decreases to 15-22 cm, and at a depth of more than 100-1125 m, the average the dimensions of the structural block are 55x70x80 cm.

Almost all cases of self-collapse of the roof at the mines are confined to the places where gentle and inclined cracks intersect with vertical ones when they are cut by cameras. Experience in the development of the Dzhezkazgan, Mirgalimsay and Koitash mines shows that pillars are destroyed precisely by inclined cracks, and the collapse of roof rocks occurs along horizontal and gentle cracks (Sayyidkosimov et al., 2017; Sajjidkosimov et al., 2023).

A feature of the fracturing of the marbled limestone massif and the ore body of the Zarmitan deposit is a stepwise arrangement of individual cracks, both in the direction of their strike and in the direction of their fall, and it is characteristic of both normal-cutting and oblique-cutting cracks. Each subsequent crack is located in the direction of strike and fall of the crack system and is slightly shifted to the side relative to the previous crack, thus creating a complex stepped appearance of the general weakening surface, which is typical for all ore bodies. The size of the steps of neighboring cracks along the normal is equal to an average of 10 - 15 cm in the studied areas.

Spatial irregularities in fracture development significantly correlate with deformation monitoring data obtained in similar mining conditions (Rakhimov and Nizamova, 2022). The identification of an elementary structural block of the rock mass showed the need to take this factor into account when assessing the stability of mine workings and pillars.

The intensity of outbursts in mine workings is probably described by static models based on a quantitative assessment of inhomogeneities in the properties of the rock mass based on the data of fracture geometrization and the coefficient of structural weakening of rock strength indicators.

According to the spatial orientation and intensity of occurrence, all large cracks are naturally associated with the main elements of the geological structure of the area. Each structural block is characterized by different fractures. These cracks are very unevenly distributed, even in areas with the same structural position (Rakhimov and Nizamova, 2022).

Conclusions. Thus, in general, it should be noted that the conducted studies have confirmed a significant effect of fracturing on the stability of mine workings. The main manifestations of rock pressure, such as delamination and collapse, occur along the most developed crack systems, which makes it critical to take into account their spatial orientation when designing mining operations. Particularly dangerous are workings that cross longitudinal and diagonal cracks at an oblique angle, as well as zones with vertical or normally secant cracks with a gentle occurrence of ore bodies.

The revealed regularities in the orientation of cracks make it possible to predict potential areas of stability disturbance and optimize the direction of cleaning operations. This, in turn, contributes to improving the safety of mining operationsand reducing the risk of accidents.

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