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Studying rock mass jointing to provide bench stability while Northern Katpar deposit developing in Kazakhstan

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Abstract

Purpose is to identify the basic joint systems, their characteristics, distribution within the rock mass, and determine impact of the joints on the bench stability.

Methods. The risks of strain emergence in the form of blocks sliding along weakness surfaces within the local areas were determined based upon the definition of rock stability loss. The results of large-scale measurements of jointing were processed using circular and bar diagrams as well as stereographic grids. In the context of the paper, kinematic analysis was implemented through Dips Rocscience Inc. Software.

Findings. Five basic joint systems have been identified; joints of 2nd and 5th systems are the most commonly encountered among them. The results of the jointing determination within the open pit boundaries have been represented as well as the open pit wall stability in terms of each site inclusive of consideration of potential strains along the sliding surface.

Originality. For the first time, zoning of the open pit wall in terms of slide types has been performed. It has been identified that potential shear of a prismatic block is 33%; at the same time, 66% are bench destruction with the block toppling. The risk of wedge-shaped block shear is minimal.

Practical implications. The research findings may be helpful to define and select both parameters and conditions of safe mineral extraction under the specific mining and geological conditions. In turn, the abovementioned will help reduce the risk of accidence while providing scientifically substantiated approach to select quarrying sequence, techniques, and system.

Keywords: *jointing, open pit, rock mass, stability, bench*

1. Introduction

Extraction of minerals is an important branch of economy in many countries; nevertheless, it is often connected with certain mining risks [1]-[4]. Rock mass stability is the key factor which should be taken into consideration while developing deposits to avoid accidents and provide reliable protection of human life and health in addition to the saved facilities [5].

The development of modern open pits is characterized by their deepening as well as extraction of deep-lying ore [6]. Depth of open-pit mining has broken the mark of one thousand meters deep into the earth [7], [8].

To identify optimum parameters of deep open pit benches and walls, complex analysis of important mining and geological as well as mine engineering factors is required. The factors include study of physicomechanical characteristics of rocks; analysis of structure and tectonics; assessment of hydrogeological conditions; and other aspects influencing rock mass stability [9]-[11]. The studies help define capacity of open-pit walls and benches which prevents from accidents and ensure safety of miners.

In terms of open-pit practices, the factors, impacting stability of open-pit benches, can be divided into the four groups (Fig. 1): geotechnical, hydrogeological, physiographic, and mining ones. Classification of the factors, influencing stability of open-pit benches and walls, is very important in the context of a mining sector. Their understanding helps substantiate the ultimate parameters of benches and walls in the deep open pits. Moreover, the classification of factor makes it possible to develop efficient strategies preventing accidents resulting from slides and falls, and improving both quality and efficiency of mineral mining [11]-[13]. At the same time, it is required to focus on the probable strain processes [14].

It is possible to forecast the strain processes based upon the comprehensive approach involving analysis of structural and tectonic composition as well as strength characteristics of the rock mass.

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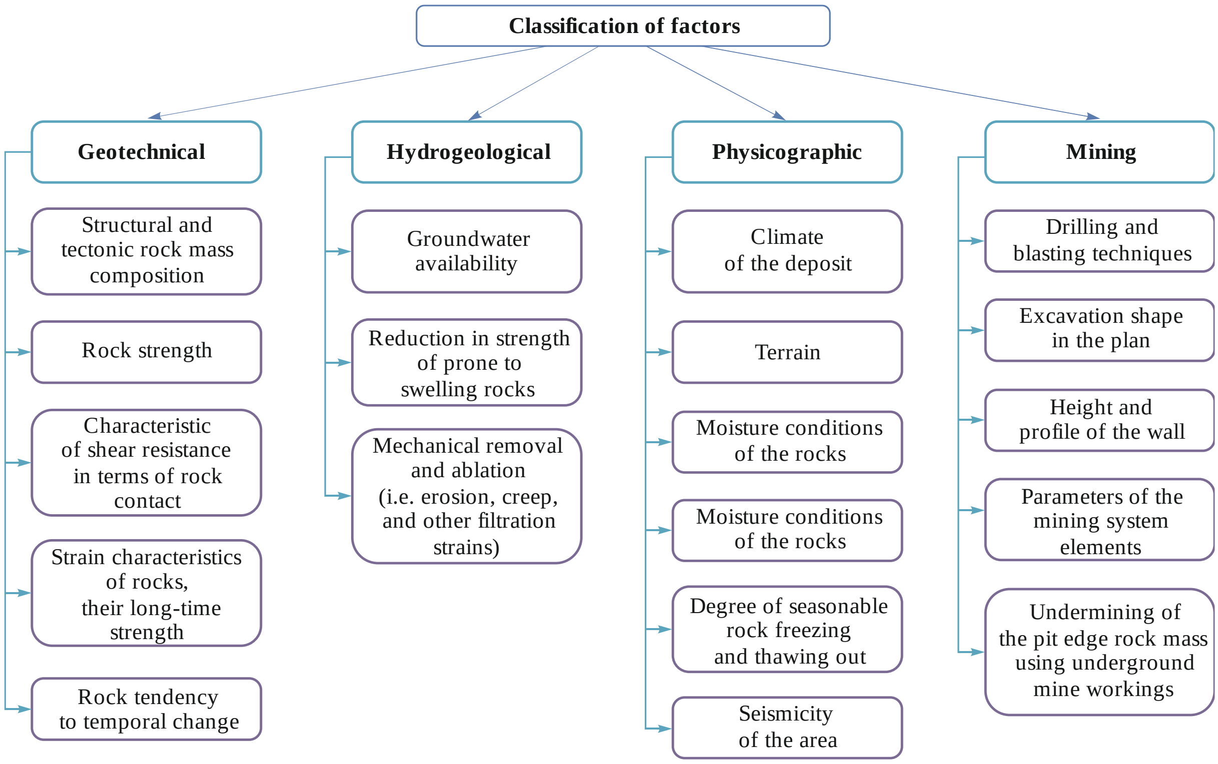

Figure 1. Classification of factors influencing stability of open-pit benches and walls

Instrumental observations over straining of different areas of pit edge rock mass; assessment of both level and direction of tectonic force action; and geomechanical calculation of stability [15]-[18].

Mining operations in an open pit, following design plans and specifications, cannot always prevent from deformation of walls as well as local areas of walls and benches. Especially it concerns shaping of the ultimate open-pit boundary. The reasons, depending upon which pit edge rock mass becomes unstable, differ from the viewpoint of geological, geotechnical, hydrogeological conditions, and the wall parameters within the specific site of an open-pit field [19], [20]. Hence, in terms of rock mechanics, each mineral deposit is unique; it requires an individual approach for determination of factors, influencing its stability, and assessment of the influence degree [18].

Open-pit mining may result in different strains of quarry walls and waste dumps in the form of slides, falls, cavings, flows of ground, and subsidence [21]-[23]. As Fisenko [24] has mentioned in his paper there is no clear boundary between individual strain types. Cavings and falls differ in terms of relative values of rock masses being strained; falls and slides differ in the strain velocity depending upon the slide surface angle as well as upon stress nature of the rocks along the slide surface.

According to research by Galperin [25], two thirds of open pits undergo strain processes. In this vein, a tendency is observed in the number of cases increase when benches are becoming unstable after an open pit becomes deeper. If mining is performed at down to 100 m depth, 50% of the studied open pits experience strain; their share increases up to 80% if mining deepens [26]. The analysis, performed in paper [27], has shown that 75% of the strains take place in sandy-argillaceous deposits; and only 25% fall on the benches consisting of hard and half-hard fissured rocks. The process of mineralization plays an important role here [28]-[30].

Open-pit mining considers safety and efficiency as its topical problem [31]. It can be solved on the basis of geomechanical analysis of rock mass and mathematical modelling [32], [33] as well as regular monitoring of surface subsidence [34]-[37].

The deepening of modern open pits and the extraction of deep-lying ore present significant challenges when it comes to ore transportation. As open-pit mines extend deeper into the earth, the distance between the extraction point and the processing plant or storage area increases, requiring efficient and reliable methods of moving the ore. The deepening of open pits and the extraction of deep-lying ore have necessitated the evolution of ore transportation methods. Haul trucks, conveyor systems, rail transport, and emerging technologies like autonomous systems all play significant roles in efficiently moving ore from the extraction point to the processing plant or storage area. As open pits continue to reach unprecedented depths, the mining industry will continue to innovate and adapt to meet the challenges of transporting ore in increasingly demanding conditions [38]-[41].

In both underground mining and open-pit mining operations, the concept of ore backfilling is widely employed to optimize the mining process and mitigate the environmental impact. Ore backfill refers to the practice of using waste materials or processed tailings to fill underground voids or previously excavated open pits, providing stability to the mining area and maximizing resource recovery [42], [43]. Waste rock backfilling not only helps in stabilizing the slopes of the open pit, preventing potential collapses, but also improves the overall efficiency of the mining operation. It reduces the hauling distance for waste rock and optimizes the extraction of valuable ore by providing stable working platforms for mining equipment and facilitating access to deeper ore zones [44]. Ore backfilling techniques in both underground and open-pit mining operations play a vital role in maximizing resource recovery, improving safety, and minimizing the environmental impact.

By utilizing waste mate-rials effectively, mining companies can enhance the sustainability and efficiency of their operations while ensuring the long-term stability of the mining areas.

For decades, researchers have been engaged in the problem how to improve stability of open-pit walls and benches. During the period, several basic scientific schools have been established with different and related tendencies to solve the problem of rock mass stability [45], [46]. Lately, intensive studies have been conducted in the field of rock mass stability during mineral mining. In the course of studies, researchers developed different methods and techniques helping define rock mass stability and prevent probable risks connected with bench instability [47]-[49].

Moreover, in recent years, the world researchers have conducted numerous studies to analyze rock mass stability while mineral mining [50]-[53]. Various procedures were developed to assess stability of rock masses and prevent such hazardous phenomena as falls and slides [54]. Computer modelling becomes more and more popular while studying rock mass stability. Such models help analyze different factors impacting stability of rock masses and identify optimal procedures preventing the dangerous phenomena [55].

Despite the numerous studies, the problem how to provide stability of open-pit walls is still topical. The reason, making it impossible to define the standard unified approach to the problem solving, is a joint impact by many factors differing in their degree of influence; the matter is that the factors define individual characteristics of each deposit [56], [57]. Such factors include mining and geological as well as hydrogeological conditions; changes in physicomechanical properties within the open pit; effect by explosions and earthquakes; stress-strain state etc. [58]-[60].

Development of methods and recommendations, involving the required data collection, interpretation of the obtained research data, and mathematical modelling of stability, is a possible way out of the situation.

The paper represents the results of analysis of rock mass jointing within a mining site of the Northern Katpar deposit in Kazakhstan. The research objective was identification of the main joint systems, their characteristics, and distribution in the rock mass, and impact by the joints on the stability of benches.

2. Study area

The chapter delivers the basic structural and tectonic features of the analyzed area. Previous paper [61] considered thoroughly general mining and geological characteristics of the Northern Katpar deposit.

The abovementioned field, located in Kazakhstan, is among the largest mineral deposits in the region. Its development is a complex engineering challenge since it is connected with high risks related to stability of the rock masses.

Mainly, the two systems of tectonic abnormalities are developed within the Northern Katpar deposit: north-eastern sublatitudinal abnormalities of Uspensk direction (i.e. deep faults among which numerous pressure faults, pressure faults-overlaps, fissure displacements, and thrust block are the most developed), and the north-west regional faults (i.e. high-angled faults, pressure faults, and border faults). Other abnormalities are of minor nature; they are branch derivatives of the two main systems.

Tectonic block, including the deposit, is restricted from the north by Domeke-Kushuksk fault where limes contact with Frasnian volcanites as well as with granites transecting them. Its extension azimuth within the western part is NE 60°; and NE 45° in the eastern part with 65-70° inclination angle. Within the deposit, the fault is complicated by postintrusive displacements of a throw type.

The rocks are poorly brecciated between ore-hosting limes of a hanging wall and aleurites of the upper Famennian Stage. Extension azimuth of the contact is east-northeast at an angle of 80° in the western part, and at an angle of 65-70° in the eastern one. Southward inclinations of the contact are 60-65° (sometimes 80°).

The area, within which the Northern Katpar deposit is placed, is of a complex structure. It used to be a tectonically active unit, originated at the intersection of latitudinal Uspensk shear zone with the faults of 20° north-easterly direction and 320° north-westerly one. Morphology and internal structure of the mineralization depend completely upon a mechanism of rotation of blocks resulting from their displacement along boundary faults, and shaping of sigmoid crumpling folds. During a dynamomorphic process, initially disordered bending folds transformed into the ordered isoclinal linear folds of a laminar flow complicated through an axial plane cleavage.

Internal structure of the deposit is characterized by the folded cleavage and manifestation of tectonites, boudinage, and ptigmatite folding. All types of hard rock within the deposit are fissured. Mostly, their jointing is in the disturbance zones as well as in the oxidation zone. The jointing becomes more obvious with depth.

According to geological and structural features of deposits, physicomechanical characteristics of rocks in terms of degrees of their stability within open-pit walls are as follows:

– very unstable state demonstrated by Neogene clays as well as clay and granitic soils of a weathering core within the areas where the total thickness of loose sediments is more than 20 m;

– unstable state demonstrated by the crushed zone as well as weathering zone; rocks within the zones are characterized by a high fracturing degree influencing their stability in the rock mass in addition to the strength reduction;

– average stable state demonstrated by moderately jointed rocks in the zone where transition takes place from heavily jointed weathering zones to weakly jointed and those ones being almost monolithic;

– stable state demonstrated by weakly jointed and almost monolithic rocks beyond the weakened zones.

3. Methods

3.1. The basic factors reducing rock mass stability

Earlier analytical studies of structural and geomechanical deposit conditions have helped identify the basic factors reducing rock mass stability:

– availability of surfaces of weakening (i.e. loose deposits and hard rock jointing);

– rock tendency to weathering. Rock weathering cores are observed everywhere within the deposit; their thickness varies from several centimetres where hard rock outcrops up to 220 m where tectonic disturbances perform their conjugation;

– non-uniform structure of the rock mass. Walls of the open pit have zones with the high rock jointing; in the majority of cases, they are in line with tectonic disturbances. Large tectonic abnormalities and joint systems, associated with them

(Fig. 2), result in structural rock mass weakening as well as in significant decrease of adhesion values which degree influences heavily the stability coefficient. Moreover, outcrop of the rock mass areas, activates weathering processes also affecting adversely stability of slope structures of the open pit;

– water content of the studied area factoring into the reduce in the available stability margin.

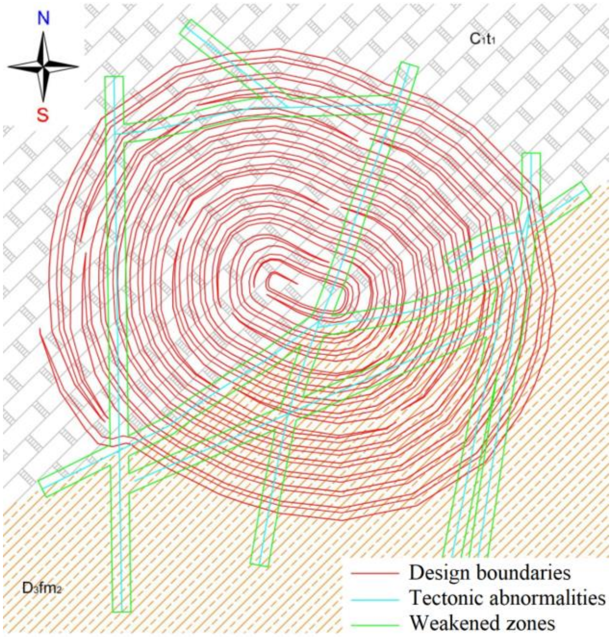

Figure 2. Structural and tectonic field map

The listed adverse factors, resulting in the reduced rock mass stability, cannot be considered directly while identifying the stability margin coefficient; nevertheless, it is possible to mitigate them drastically while implementing measures to dewater the open pit walls (i.e. underground water capture) or while identifying them in the course of geological, deformational, and hydrogeological monitoring.

Under the circumstances, role of geological as well as geomechanical support of mining increases. It is expressed by regular monitoring of transformation of a wall-adjacent rock mass structure inclusive of remote techniques using three-dimensional models.

3.2. Analysis of the rock mass structure

Jointing of hard rocks and half-rocks is among the key factors that should be taken into consideration while defining stability parameters of open pit walls and benches. Surfaces of weakening within wall-adjacent rock mass in the form of joints decrease sharply the hard rock strength [62]-[66].

Research of jointing of the deposit rock masses followed the procedure by [67]. As a result, the basic joint systems have been identified (Table 1). Outcrops have helped single out five key joint systems (Fig. 3). Joints of 2^{nd} and 5^{th} systems are the most abundant (their dip azimuths are 150 and 332°, respectively). Joints of the basic systems are steep and vertical.

The 3^{rd} and 4^{th} systems look like less developed; they have lower azimuth (about 50 and 260°, respectively) and flatter dip.

The 1^{st} system joints are less in number; their curvature is strong. All the joint systems are represented in the form of lines, varying in their length, shaping together series. Generally, all joints are of dislocation nature; they resulted from horizontal tectonic forces in the process of the rock mass formation.

Table 1. Data to study hard rock jointing relying upon the information by Akbar JSC

No.	Occurrence elements of the systems, degrees		Distance between joints of the systems, cm	Degree of the system intensity
	Dip azimuth	Dip angle		
I	53 ± 13	68 ± 13	Single 3-50	Weakly expressed, indistinct
II	130.5 ± 17.5	72 ± 12	Single 1-40	Strongly expressed, rather compact
III	227 ± 8	78 ± 7	Single 1-15	False, indistinct
IV	271 ± 15	77 ± 13	1-10	Weakly expressed, indistinct
V	332 ± 17.5	72 ± 12	1-25	Strongly expressed, rather compact

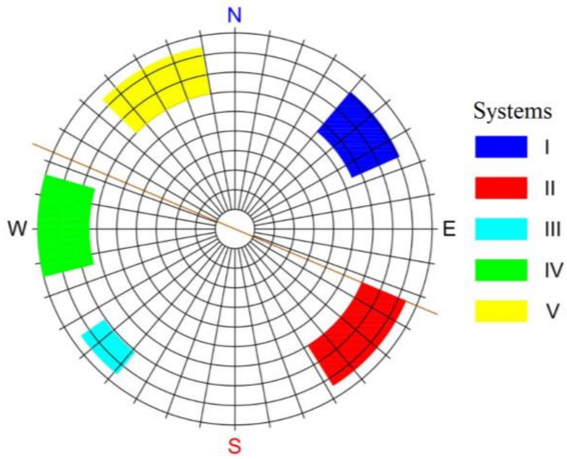

Figure 3. Jointing scheme on the data by [67]

The open pit is of following geometry; its depth is 51 m; size across the surface is 450×630 m; size across the floor is 100×125 m; and wall angles are 25-37°. It is partially floo-ded; mainly, Quaternary, and Neogene deposits are mined as well as formations of the Mesozoic weathering core (Fig. 4).

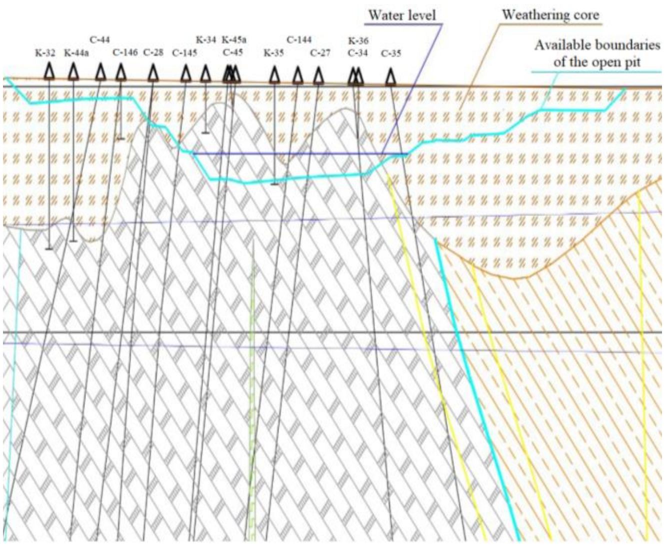

Figure 4. Available boundaries of the open pit

To introduce the influence by structural disturbances and irregularities into geomechanical calculations taking into consideration the basic regularities of distribution and correlation of jointing, belonging to different systems, core-based analysis has been performed; the cores resulted from geotechnical well drilling within the field in 2018. Figure 5 explains arrangement of the geotechnical GT_18 wells.

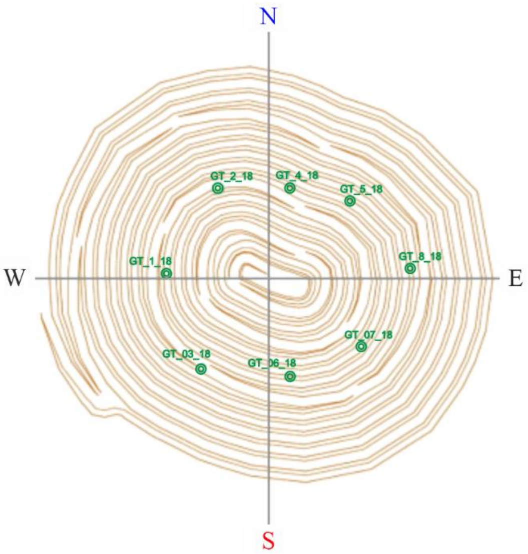

Figure 5. Arrangement of the geotechnical GT_18 wells

Papers [68]-[70] describe the available procedures analyzing both jointing and tectonic disturbance of the rock mass as well as assessment of their influence of the stability of the open pit benches and walls.

The abovementioned authors believe that the available procedures to analyze rock mass jointing are divided into five groups: direct measurements within the areas of rock outcropping; study of cores taken from the exploratory wells; observation of water flow within rock mass or the compressed air movement through fissures while specific research performing; geophysical methods; and methods using ultrasound.

Joint systems are classified through spatial position and geometry of a joint, its origination, shape, and structure [71]. Table 2 shows parameters used by the research to classify joint systems in the open pit of the Northern Katpar deposit.

Table 2. General geometrical and generic classification of the joints

Angle, degrees	Vertical	75-90
	Steep	45-75
	Flat	15-45
	Slightly dipping	0-15
Length, cm	Short	$10\text{-}10^2$
	Middle	$10^2\text{-}10^3$
	Long	$10^3\text{-}10^4$
Depending upon width, cm	Narrow	$10^{-1}\text{-}10^{-2}$
	Middle	$10^{-2}\text{-}1$
	Wide	1-10
Extension	Meridional, latitudinal, and diagonal	
Depending upon technological factor	Longitudinal, diagonal, and lateral	
Depending upon formation	Endogenic, exogenic/tectonic, weathering, and pressure-based	
Depending upon shape	Straight, curved, and undulating	
Depending upon surface nature	Rough, smooth, and textural	
Depending upon filling degree	Full, and partially filled	

The results of the large-scale jointing measurements are processed using circular and bar diagrams, and stereographic grids. The research has applied Dips Rocscience Inc. Software for kinematic analysis.

Risks of strain origination in the form of block slides along weakening surfaces within the local areas have been identified based upon determination of stability loss of hard rocks.

Taking into consideration hard rock characteristic within the Northern Katpar deposit, loss of bench stability is mainly possible along the available weakening surfaces. As it has been mentioned before, rock mass of the deposit is of a block structure. Numerous joint systems may factor into the possibility of rock block displacement able to bench damage.

Determination of the damage type is important stages while assessing its stability [72]. Foreign scientific sources denote the three key types of stability losses: in the form of planar sliding of certain rock mass share; wedge-shaped shear; and rock block toppling towards the mined-out area [73]-[74].

One of deformational types of an open pit bench is shaped through intersections of joints. Shear may take place in the neighbourhood of a rock block if there is planar sliding, inclined towards the slope plane, as well as other disturbances, which separates the block from rock mass and shapes its lateral surfaces (Fig. 6a). A prismatic block shear happens if there is no sufficient adhesion between the rock layers.

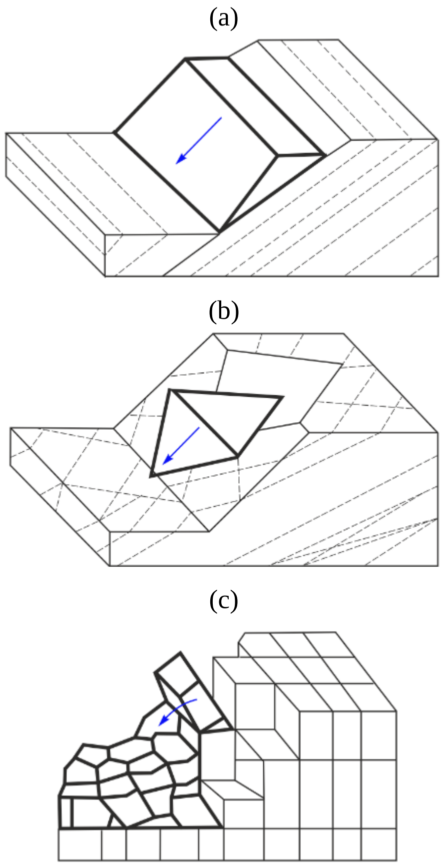

Figure 6. Three basic types of rock stability losses: (a) prismatic block shear; (b) wedge-shaped block shear; (c) bench failure with block toppling

Wedge-shaped block shear is possible if two planes intersect in such a way that tetrahedron is shaped. In this context, the shear is stipulated by the rise of an intersection line of discontinuity planes to the bench surface (Fig. 6b).

Loss of a slope stability results from rock block toppling towards the slope if the rock stratification steeps down the slope (Fig. 6c). Slope failure with block toppling takes place due to insufficient rock strength, and occurrence of stresses exceeding the rock strength. Each of the processes (Fig. 6a-c) needs individual approach while analyzing rock mass stability as well as using adequate efforts to avoid the failures. It is also important to take into consideration geological environment, characteristics of rocks, availability of joints, and other factors capable of influencing the rock stability.

The failure process can follow two scenarios: direct toppling and toppling with a bend. Direct block toppling is developed in the stratified rocks having a subvertical joint system being complementary towards direction of the seams; the system divides the seams into blocks. Toppling with bend happens if rock mass stratification rises to the slope surface; in this situation, the basic normal compressive stresses are parallel to the bench surface [21], [22]. In both cases, block toppling may result in a caving; moreover, it is among the key mechanisms of rock mass failure.

4. Results and discussions

Change in rock mass jointing with depth is a common phenomenon connected with such different factors as pressure, temperature, and geological processes. Generally, surface rock jointing is more pronounced than the deep one. In this context, rocks become denser and more compact with the increasing depth; the fact may result in the decreased number of joints and their dimensions.

Nevertheless, in some cases the deep-seated joints may be more dangerous than surface ones since they experience higher pressure, which can factor into rock mass failure. Hence, rock study and analysis should involve change in jointing with depth. Relevant research and monitoring are required.

According to the engineering and geological data, average jointing of rock mass is 1.09 joints/m; in addition, a tendency towards the rock mass increase in blockiness with depth is observed. Within the deep levels (starting from -300 m), rock areas with minor jointing, approaching monolith rocks, have been found (Fig. 7). The rock mass jointing is of irregular nature, i.e. from weakly fractured areas with 1-3 joints/metre within the unweathered rock zone to the intensively fractured ones with up to 35 joints/metre within the zones of tectonic disturbances.

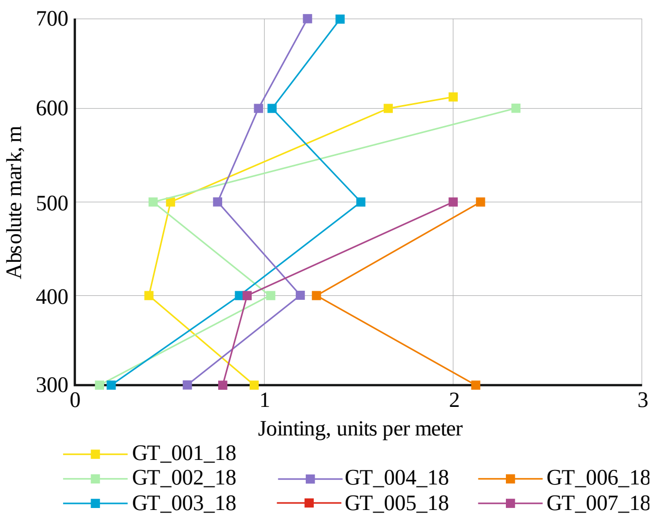

Figure 7. Change in rock mass jointing along with depth

As a rule, rocks in such intervals are represented by crushing, fissuring, and brecciation zones. A prevailing part of the closed-type joints are the steeply dipping ones of both sublatitudinal and submeridional strike (almost 67%). Usually, cavities of the closed-type joints are filled with carbonate and rarely with clinkstone; ferruginization is observed.

On the whole, hard enclosing rocks of the deposits are solid and stable. Within the areas of tectonic disturbances, stability of ore and rock decreases due to metasomatic changes and jointing; the weakened areas of rock crushing and brecciation originate. Thickness of such weakly stable areas may vary from several dozen centimetres up to several metres. Location of the weakening surfaces relative to a bench influences both type of strains as well as their probability. Consequently, control of the benches within such fissured rock masses needs individual approach for each specific case.

Figures 8 and 9 demonstrate jointing diagram in terms of cores of GT_18 wells and a jointing strike diagram obtained as a result of large-scale fissility measurements processed by Dips Rocscience Inc. Software. Figures 8 and 9 make it possible to conclude that the cores from GT_18 wells are of high jointing degree which is among the factors influencing stability of the pit walls. The diagram of jointing strike shows how the joint systems are placed within the open pit while explaining their impact on the wall stability.

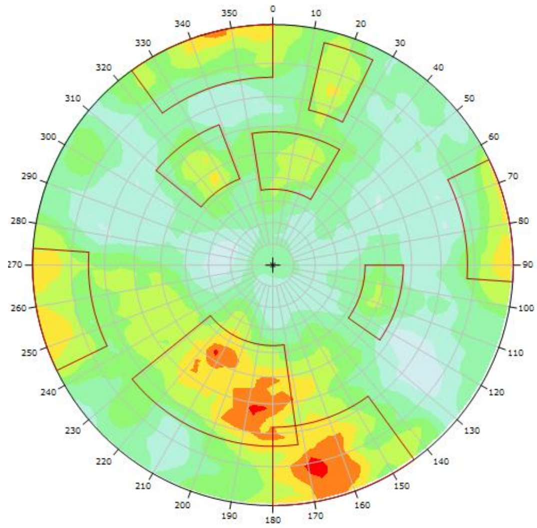

Figure 8. Jointing diagram in terms of cores of GT_18 wells

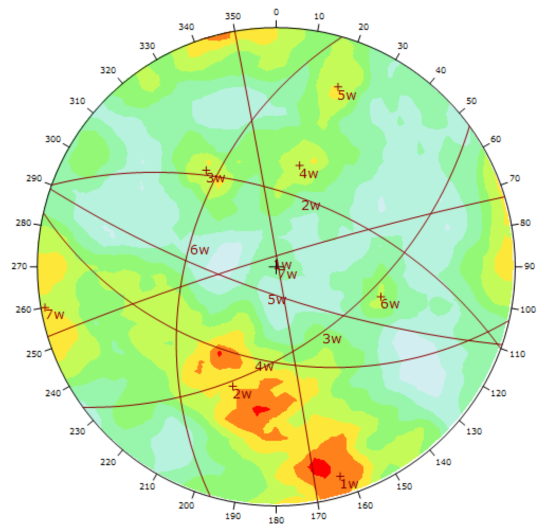

Figure 9. Strike of jointing

The diagram analysis may help schedule operations within the open pit as well as select methods and procedures controlling risks and ensuring safety of the operations.

The analysis of the jointing strike (Fig. 9) made it possible to assess rock stability as well as risks of such a hazard occurrence as falls. The process study is quite an important component while planning and conducting operations on the sustainable deep mining scheduling.

Table 3 represents the generalized occurrence parameters of the basic rock mass tectonic joint systems within the Northern Katpar field.

Table 3. Characteristics of the basic joint systems as a result of analysis of cores from geotechnical GT_18 wells

No.	Elements of occurrence of the systems, degrees		Distance between joints of the systems, cm	Manifestation degree of the system
	Dip azimuth	Dip angle		
I	158 ± 20	58 ± 20	40	Very pronounced
II	75 ± 13	51 ± 13	50	Very pronounced
III	266 ± 17	83 ± 3	30	Weakly pronounced, rather compact
IV	231 ± 15	46 ± 20	45	Very pronounced
V	14 ± 20	51 ± 15	50	Very pronounced
VI	332 ± 10	49 ± 15	60	Very pronounced
VII	333 ± 23	3 ± 6	60	Weakly pronounced, blurred

The 1st joint system is oriented towards sub-lateral direction; it has a steep south-east dip. The joint system has been registered in eight geotechnical wells.

The 2nd joint system is oriented towards sub-meridional direction; it has a steep north-east dip. The joint system has been registered in eight geotechnical wells.

The 3rd joint system is oriented towards sub-meridional direction; it has a vertical dip. The joint system has been registered in eight geotechnical wells.

The 4th joint system has a diagonal orientation and 26-66° (46° on the average) south-west dip. The joint system has been registered in eight geotechnical wells.

The 5th joint system has sub-lateral orientation and 36-56° (51° on the average) north-east dip. The joint system has been registered in eight geotechnical wells.

The 6th joint system has a diagonal orientation and 34-64° (49° on the average) north-west dip. The joint system has been registered in eight geotechnical wells.

The 7th joint system has a diagonal orientation as well as low-inclined north-west dip. The joint system has been registered in five geotechnical wells.

While comparing parameters of the identified joint systems, obtained as a result of analysis of cores, taken from geotechnical wells, and based upon the processing of historical materials, it has become possible to conclude that occurrence characteristics of the 1st, 2nd, 3rd, 4th, and 6th joint systems, connected with natural structure of the rock mass, coincide completely. The 5th and 7th joint systems have been identified for the first time.

To define the most dangerous ones from the viewpoint of bench stability, the defined joint systems are compared with a strike direction of the bench plane. The joints are divided into longitudinal, diagonal, and lateral ones being strike and on-strike joints.

Geometrical classification of the fissured rocks in a paper by V.V. Belousov [75] is based upon a line of joint surfaces-stratification crossing. Having modified the classification, V.N. Popov divides all joints towards strike direction into longitudinal, diagonal, and lateral ones with regard to the strike of bench slopes and open-pit walls [76].

Having correlated all the joint systems, identified within the area, with a bench strike, one can understand which of them are the most dangerous from the viewpoint of stability (Fig. 10). Longitudinal and diagonally slanting strike joints have the greatest impact on the stability of bench slopes and walls (Table 4).

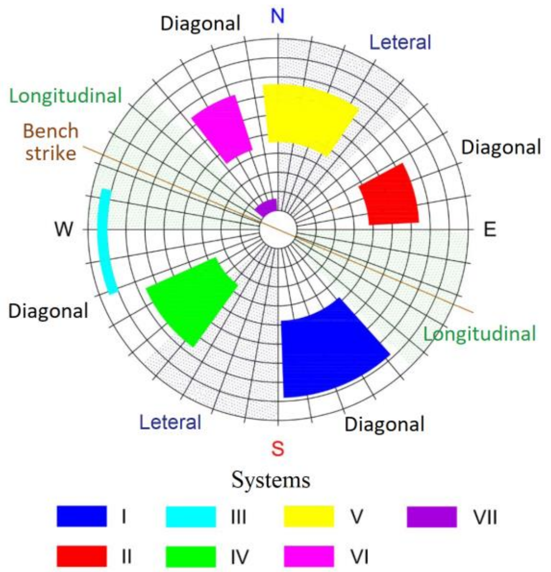

Figure 10. Comparison between joint systems and strike direction of the bench

The joints, oriented in parallel (i.e. strike) to a slope striking as well as those ones dipping towards the mined-out area, are potentially the most dangerous.

In addition, potential slide surface for slopes can be identified by the conjugated joint systems being longitudinal, steeply pitching strike ones relative to the slopes. The joints may stipulate rock lamination of a bench resulting in its strains but not in its complete stability loss.

Analysis of the results of jointing processing supports the idea that following joint systems are potential weakening surfaces of the North Katpar open pit:

– the 2nd, 4th, and 5th joint systems for the Northern pit wall;

– the 1st, 2nd, and 5th for the North-east and Southern pit walls;

– the 1st, 4th, and 5th joint systems for the South-western and Western pit walls.

The data of the structure studies have become the basis to analyze stability of benches in the Northern Katpar open pit. Seven joint structures, classified as tectonic, have been identified. The areas were assessed in terms of geodetic 45° compass points in the horizontal plane and in terms of H = 100 meters in the vertical plane (Fig. 11a-d).

The research results have shown that the seven joint systems are of a tectonic nature; their location is within the areas, which have been analyzed within the geodetic courses. In this context, structural stability analysis is critical since any instability may result in severe effects inclusive of falls and landslides.

Table 4. Classification of the joint system towards the bench

Site	Course	Wall parameters			Joint system	System location relative to
		Dip azimuth of the wall	Dip angle of the wall	Wall height		
1	North	180	39	390	1st, 4th	Diagonal, steep, strike
					2nd, 5th	Lateral, steep, non-strike
					3rd	Lateral, vertical, strike
					6th	Diagonal, steep, non-strike
					7th	Diagonal, slightly-inclined, non-strike
2	North-east	225	39	390	1st	Lateral, steep, strike
					2nd, 5th	Diagonal, steep, non-strike
					3rd	Diagonal, vertical, strike
					4th	Longitudinal, steep, strike
					6th	Lateral, steep, non-strike
					7th	Lateral, slightly-inclined, non-strike
3	East	270	40	390	1st, 2nd, 5th	Lateral, steep, non-strike
					3rd	Longitudinal, steep, strike
					4th, 6th	Diagonal, steep, strike
					7th	Diagonal, slightly-inclined, strike
4	South-east	315	39	390	1st	Longitudinal, steep, non-strike
					2nd, 5th	Diagonal, steep, non-strike
					3rd	Diagonal, vertical, strike
					4th	Lateral, steep, non-strike
					6th	Longitudinal, steep, strike
					7th	Longitudinal, slightly-inclined, strike
5	South	360	40	390	1st, 4th	Diagonal, steep, non-strike
					2nd, 5th	Lateral, steep, strike
					3rd	Lateral, vertical, non-strike
					6th	Diagonal, steep, strike
					7th	Diagonal, slightly-inclined, strike
6	South-west	45	40	390	1st, 4th	Lateral, steep, non-strike
					2nd, 5th	Diagonal, steep, strike
					3rd	Diagonal, vertical, non-strike
					6th	Lateral, steep, strike
					7th	Lateral, slightly-inclined, strike
7	West	90	39	390	1st, 5th	Lateral, steep, non-strike
					2nd	Longitudinal, steep, strike
					3rd	Longitudinal, vertical, non-strike
					4th, 6th	Diagonal, steep, non-strike
					7th	Diagonal, slightly-inclined, non-strike
8	North-west	135	39	390	1st	Longitudinal, steep, strike
					2nd, 5th	Diagonal, steep, non-strike
					3rd	Diagonal, vertical, non-strike
					4th	Lateral, steep, non-strike
					6th	Longitudinal, steep, non-strike
					7th	Longitudinal, slightly-inclined, non-strike

Geological features of the rocks, involving joints and conjugated joint systems, are among the factors of slope stability. In addition, inclination angles of the slopes as well as non-strike joints also influence heavily the stability of slopes.

Table 5 represents analytical results of each site of the open pit. Probability of each strain type is represented as a percentage; sliding surfaces is represented in the form of joint systems.

Below, you can find short explanation of the four different rock instability types: prismatic block shear (planar sliding); wedge-shaped block shear (wedge sliding); flexural toppling; and direct toppling. Explain each of the instability nature specifying possible aftereffects if the instability happens at a mining site:

– prismatic block shear (planar sliding) happens if the whole prismatic rock block shifts along a fault plane. In this context, the block is shifting integrally; its disintegration does not take place which may result in dangerous consequences for miners and mining operations;

– wedge-shaped block shear (wedge sliding) occurs in the process of the wedged-shape rock block shift along a fault plane. As contrasted with a prismatic block shear, the block may disintegrate increasing risks of cavings as well as other emergencies;

– flexural toppling is vertical tilting of rock top around lower support point. The abovementioned often happens on the open rock mass slopes and may factor into large falls and landslides;

– direct toppling is rock top tilting down around its support point. The abovementioned also often happens on the open rock mass slopes and may factor into large falls and landslides.

Relying upon the description of the four rock instability types, it is possible to conclude that mining operations as well as construction of engineering facilities within the extraction sites should take into consideration potential risks connected with rock instability.

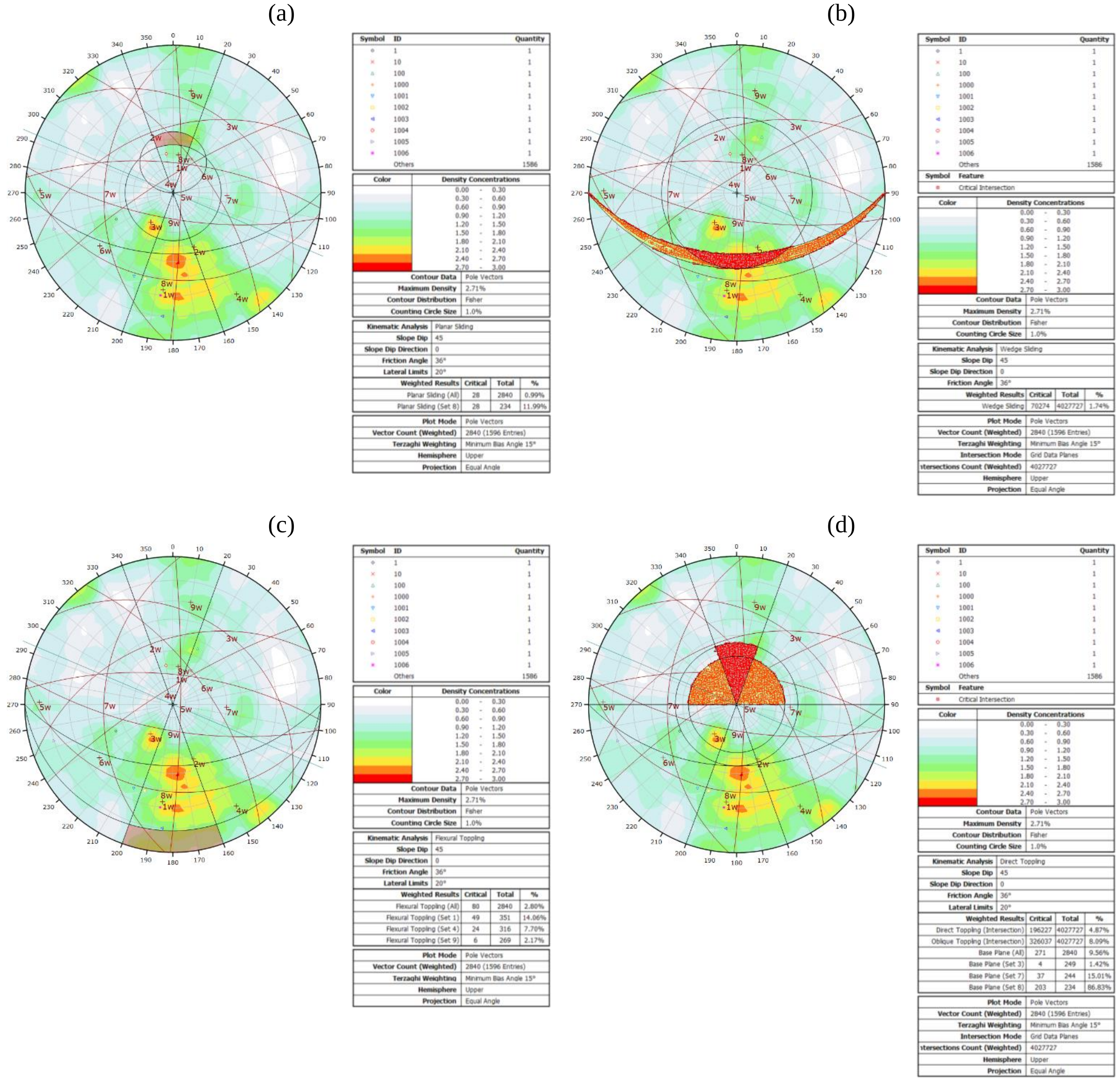

Figure 11. Jointing diagram of the northern 600-500 m level: (a) prismatic block shear (planar sliding); (b) wedge-shaped block shear (wedge sliding); (c) flexural toppling; (d) direct toppling

Different types of instability may result from various factors inclusive of orientation of joints, rock wedging etc. Hence, thorough analysis of geolo-gical situation within the site is required as well as determination of the instability types, and taking steps to promote safety of operations and structures. The abovementioned may involve diverse technique for rock strengthening and protective measures, e.g. control of access to danger zones.

To understand risks and hazards connected with mineral mining and take adequate measures reducing the risks and securing miners and equipment, the pit walls were classified in terms of deformation types. Figure 12 explains the process.

Classification of the pit walls in terms of caving types is a process of its territory division into zones or areas depending upon the potential caving types, which may happen within the territories.

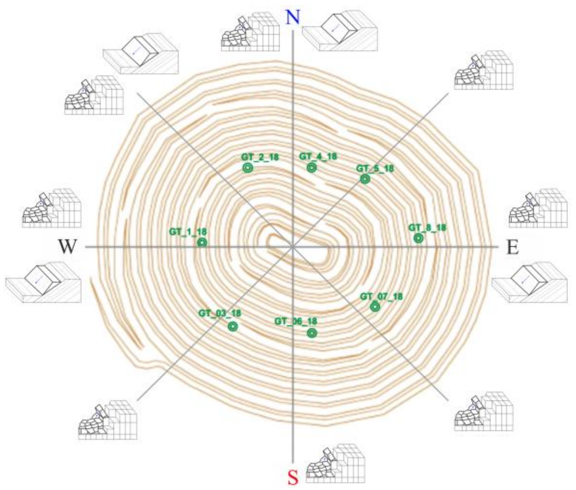

Figure 12. Classification of the pit walls in terms of caving types

Table 5. Results of the open-pit wall stability (probability, % / influencing joint systems)

Absolute level, m	Courses	Strain type			
		Planar sliding	Wedge sliding	Flexural toppling	Direct toppling
700-600	North	20.03 / 3rd	20.03 / 1st, 5th, 2nd	20.03 / 1st	20.03 / 5th
	North-east	9.10 / 3rd	2.49 / 1st, 5th, 2nd	1.19 / 1st, 5th, 2nd	47.12 / 5th
	East	0 / –	3.82 / 1st, 5th, 2nd	0 / –	38.84 / 5th
	South-east	0 / –	1.30 / 1st, 5th, 2nd	5.26 / 1st	9.43 / 1st, 5th, 2nd
	South	1.08 / 1st, 5th, 2nd	1.29 / 1st, 5th, 2nd	13.32 / 1st	8.21 / 1st, 5th, 2nd
	South-west	0 / –	2.7 / 1st, 5th, 2nd	0 / –	8.07 / 1st, 5th, 2nd
	West	0 / –	3.05 / 1st, 5th, 2nd	0 / –	7.91 / 1st, 5th, 2nd
	North-west	0 / –	1.28 / 1st, 5th, 2nd	1.85 / 1st	36.24 / 5th
600-500	North	11.99 / 5th	1.74 / 1st	14.06 / 1st, 5th	86.63 / 2nd, 4th, 5th
	North-east	8.36 / 5th	2.28 / 2nd, 4th	6.84 / 4th	71.77 / 2nd, 5th, 1st
	East	7.43 / 2nd	2.76 / 2nd, 4th, 5th	23.4 / 3rd	43.49 / 2nd, 4th, 5th, 1st
	South-east	12.96 / 2nd, 1st	3.42 / 1st, 2nd, 4th	3.70 / 1st	47.46 / 2nd, 4th, 5th, 1st
	South	16.17 / 1st, 4th	3.89 / 1st	16.69 / 1st, 5th	73.50 / 1st, 2nd, 4th
	South-west	15.59 / 4th	3.43 / 1st	1.37 / 2nd	88.94 / 4th, 5th, 1st
	West	2.30 / 4th	2.23 / 1st, 4th, 5th	9.39/ 3rd	70.44 / 4th, 5th, 1st
	North-west	0 / –	1.64 / 4th, 5th	23.40 / 1st	62.32 / 4th, 5th
500-400	North	9.70 / 5th, 6th	2.54 / 1st	20.35 / 1st	59.81 / 2nd, 4th, 5th, 6th
	North-east	8.81 / 2nd, 5th	1.91 / 4th, 1st, 6th	4.75 / 3rd	49.11 / 2nd, 5th, 1st, 6th
	East	12.46 / 2nd	2.11 / 1st, 5th	21.90 / 3rd	51.87 / 2nd, 1st, 6th
	South-east	14.97 / 1st	2.84 / 2nd, 4th	9.74 / 3rd	45.83 / 4th, 5th, 1st
	South	4.70 / 4th, 1st	3.10 / 4th, 1st	4.48 / 1st, 5th	35.53 / 2nd, 4th, 1st
	South-west	8.21 / 4th	2.68 / 4th	4.12 / 3rd, 5th	22.79 / 4th, 1st, 6th
	West	9.69 / 4th	2.82 / 1st, 4th	18.07 / 3rd	38.18 / 4th, 1st, 6th
	North-west	17.58 / 4th, VI	3.71 / 4th, 5th	10.06 / 1st, 3rd	66.35 / 2nd, 4th, 6th
400-300	North	4.40 / 5th	0 / –	7.47 / 1st, 6th	57.45 / 2nd, 5th, 6th, 7th
	North-east	2.45 / 5th	0 / –	2.08 / 3rd	51.16 / 2nd, 5th, 6th
	East	5.65 / 2nd	0 / –	16.39 / 3rd, 2nd	50.96 / 1st, 2nd, 5th, 7th
	South-east	1.96 / 1st, 2nd	0 / –	4.23 / 3rd	47.45 / 1st, 2nd, 4th, 5th, 7th
	South	1.71 / 4th	0 / –	4.83 / 6th	45.40 / 1st, 2nd, 4th, 7th
	South-west	3.20 / 4th	0 / –	8.38 / 3rd	49.57 / 1st, 2nd, 6th, 7th
	West	0 / –	0 / –	0 / –	59.97 / 4th, 5th, 6th, 7th
	North-west	6.03 / 6th	0 / –	10.94 / 3rd, 7th	60.33 / 4th, 5th, 6th, 7th

Caving is possible due to following factors: structural features of rocks, changes in ground conditions, effect by atmospheric environment etc. Potential caving types are determined for each pit zone. Every caving variation needs specific measures preventing its origination as well as different techniques and procedures to control the risks and provide safety for miners and equipment.

It should be mentioned that even if the strain potential is high, caving may not take place since in addition to spatial orientation of joint system, such factors as adhesion of joint material, bench height, water content and to some extent strength of rocks, composing the site, also exercise influence. The analysis shows the impact by joint systems on the wall stability within a local site. For instance, in terms of the Northern site, the probability of a prismatic block shear strain is more than 86%; nevertheless, a stability factor of the prismatic block is greater than unity.

The analysis helps conclude that caving probability in an open pit depends upon numerous factors; just high values of strain potential cannot be considered as an unavoidable caving risk. Accurate safety evaluation should involve every factor, monitor constantly the pit condition, and take appropriate measures mitigating risks and ensuring safety for miners and equipment.

To provide stability of the Northern Katpar open pit, the following should be considered as the recommended parameters for future mining operations:

– analysis of impact by drilling and blasting on the strain of rock mass neighbouring the open pit to develop the adapted operation schedules of bench slopes within the design boundaries;

– instrumental monitoring of bench slope and wall conditions within the design boundaries;

– updating of the common database, represented by a geomechanical block model, in the process of pit development and derivation of new research findings concerning condition of the pit edge rock mass (i.e. physicomechanical characteristics, geology, and hydrogeology). It is required for further adjustment of a wall stability margin.

5. Conclusions

The paper represents the results of study of geological structure of rock mass within the pit edge areas; the basic structural disturbances have been identified. Mainly, the two systems of tectonic abnormalities are available within the deposit: northeastern disturbances of a sub-lateral direction (i.e. deep faults and numerous pressure faults, pressure faults-thrusts, and joint shears being the most extensively developed), and north-eastern zonal faults (i.e. dip faults, pressure faults, and shears). Other disturbances are of a minor nature; they are branch derivatives of the two basic systems.

As a result of the research, slightly jointing rock areas have been identified in the open pit. They approach monolithic rocks at the mark of 300 m. Moreover, the data are represented characterizing both jointing and strike of the joint systems.

The basic joint systems have been identified (1st-7th). Comparison between the parameters of the identified joint systems, obtained while analyzing cores from geotechnical wells, and the processed results of geological exploration materials has shown that the 1st, 2nd, 3rd, 4th, and 6th joint systems, connected with natural structure of the rock mass, coincide completely in terms of their occurrence parameters. The 5th and 7th joint systems have been determined for the first time. Shear risks in the form of block slide along weakening planes within local areas have been defined.

Based upon the three types of stability losses, the pit walls have been classified depending upon caving types. In such a way, potential share of a prismatic block is 33%; at the same time, other 66% fell on a bench failure with block toppling. Potential of the wedge-shaped block shear (i.e. wedge sliding) is minimal.

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Вивчення тріщинуватості гірського масиву задля забезпечення стійкості уступів при розробці родовища Північний Катпар, Казахстан

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Мета. Виявлення основних систем тріщин, їх характеристик та розподілу у гірському масиві, а також визначення впливу тріщин на стійкість уступів.

Методика. Визначення ризику виникнення деформацій у вигляді ковзання блоків по площинах ослаблення на локальних ділянках здійснювалося з урахуванням визначення виду втрати стійкості скельних порід. Результати масових вимірів тріщинуватості оброблялися з використанням кругових, прямокутних діаграм та стереографічних сіток. У цій роботі кінематичний аналіз реалізовано у програмному забезпеченні Dips Rocscience Inc.

Результати. Виділено п’ять основних систем тріщин, серед яких найбільш поширені тріщини системи II і V. Наведено результати визначення тріщинуватості в межах кар’єру, а також результати стійкості бортів кар’єру по всіх ділянках з розглядом ймовірності виникнення деформацій по площині ковзання.

Наукова новизна. Вперше, на підставі трьох основних видів втрати стійкості, здійснено районування бортів кар’єру за видами обвалів. Встановлено, що можливість зсуву призматичного блоку становить 33%, тоді як на руйнування уступу з перекиданням блоків припадає решта 66%. Можливість зсуву клиноподібного блоку – мінімальна.

Практична значимість. Отримані результати дослідження можуть бути корисними для визначення та вибору параметрів і умов безпечної розробки родовищ корисних копалин у конкретних гірничо-геологічних умовах. У свою чергу це дозволить знизити ризики виникнення аварійних ситуацій та забезпечити науково-обгрунтований підхід до вибору черговості, способів і системи розробки кар’єру.

Ключові слова: *тріщинуватість, кар’єр, масив гірських порід, стійкість, уступ*