Application of professor D. Lobshire's geomechanical classification for in-depth zoning of the board of the Amantaytau mine

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Abstract. This study presents a comprehensive analysis of the physical and mechanical properties, structural disturbance, and stress-strain state of the rock mass in the Amantaytau deposit, situated in the southwestern part of the Muruntau ore field. The geomechanical classification rating (MRMR), as proposed by Prof. D. Lobshir, is employed to evaluate the geomechanical state and establish a zoning framework for the deposit's quarry in terms of depth. Furthermore, preliminary recommendations for stable slope angles are provided as an initial approximation based on the conducted investigations. The findings of this study contribute to a better understanding of the geomechanical characteristics of the Amantaytau deposit and offer valuable insights for optimizing slope stability in quarrying operations.

1 Introduction

The Northern and Central Amantaytau deposits, which have been subject to exploration, are situated in the Tamdy district within the Navoi region of the Republic of Uzbekistan. Administratively, these deposits fall under the jurisdiction of the city of Zarafshan, which holds regional subordination. The deposits are located approximately 30 km south-southeast of Zarafshan and are connected to the city via a well-constructed paved road.

The Central deposit is located towards the eastern end of this field and is connected to the northeastern part of the Auminzatau mountain range. On the other hand, the Northern deposit is situated within the intermountain plain, occupying the territory between the Auminzatau and Muruntau massifs. Notably, the Amantaytau deposits are flanked by other significant quarry deposits, namely Muruntau in the northeast and Daugyztau in the southwest.

Figure 1 provides an overview of the Amantaytau deposit, highlighting its geomorphological characteristics. The Auminzo-Amantai ore field, encompassing the deposits, is situated within the expansive Kyzylkum plateau. This plateau consists of low mountain uplifts comprising Lower Paleozoic formations, along with intermountain depressions filled with Meso-Cenozoic deposits. The slopes in these areas exhibit a relatively gradual incline (10-20^0), with slight variations in elevation between the watersheds and the basin bottoms. The intermountain leveled areas are characterized by loose and semi-fixed eolian sands.

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Figure 1 further illustrates that the Northern and Central Amantaytau deposits belong to distinct regional geomorphological structures. The Northern deposit is situated within the northern foothills of Auminzatau, encompassing the gradually descending denudation plain (peneplain) with consistent surface degradation towards the north.

Fig. 1. Satellite image of the territory of the Amantaytau field.

The relief of the Central Amantaytau deposit is primarily shaped by anthropogenic factors, specifically the operations of the Auminzo-Amantaytau Central mine, which commenced in 2016. As a result, the topography is influenced by five relatively small advanced quarry cuts, with depths ranging from 60 to 100 meters from the ground surface. These quarry cuts are oriented in a north-south (submeridional) direction.

The absolute elevation levels within the Central deposit exhibit variations. The highest elevations, reaching approximately +420 meters, are observed along the upper crest of the deposit. However, at the faces of the quarry cuts, the elevations range from +300 to +320 meters. This variation is a result of the mining activities conducted in the area.

In contrast, the relief of the northern section of the Amantaytau deposit is relatively flat, with surface elevations ranging from approximately +350 to +360 meters. In this section, the topography remains relatively consistent, displaying minimal changes in elevation.

The current relief of the Central Amantaytau deposit is predominantly influenced by human activities, particularly the mining operations of the Auminzo-Amantaytau Central mine. These activities have led to the creation of quarry cuts and alterations in the elevation levels within the deposit.

The Amantaytau ore field, as a whole, comprises a succession of linear ore-bearing structures that collectively constitute the cohesive Amantaytau ore zone. This geological zone exhibits notable dimensions, with a significant thickness ranging from 600 to 800 meters and an extensive lateral extent of approximately 2.8 kilometers. These ore-bearing structures within the Amantaytau ore field are notable for their substantial vertical extent and significant lateral continuity, making them a prominent feature of the region.

2 Materials and methods

The Amantaytau ore field exhibits distinct geological characteristics in different locations. In the Central area, the Paleozoic deposits primarily consist of subformations of Besapan, which are composed of clay, mudstone shale, sandstones, and siltstones. These rock formations exhibit intense folding and shearing, forming small folds that can be isoclinal in nature. The strata generally dip towards the east-southeast direction at angles ranging from 20 to 55^0 degrees or even steeper (approaching subvertical orientation). These structural features have been confirmed through geological and structural surveys conducted during mining operations.

The core samples obtained from drilling exploration wells indicate that the Paleozoic deposits are predominantly composed of mudstones and siltstones, with sandstones occurring less frequently. During the geological and structural mapping conducted at the advanced quarry faces and ledges of the Central area, the predominant lithology of these deposits was classified as clay shale (argillite) due to the predominant presence of shale textures. This classification is supported by the extensive exposure of shale in the majority of the quarried rock volumes, as depicted in Figures 2-3.

Fig. 2. Thickness clayey shale Eastern fall at an angle of 40^0 northern entry in career 1A on Central plot.

Fig. 3. A sequence of shale beds within the eastern dip, inclined at angles ranging from 20 to 25^0 degrees, at the face of the southern working slope in the Central quarry.

The rock formations observed in the drill cores, namely aleurolites, sandstones, and argillites, are primarily characterized by a massive texture and have a relatively limited distribution. These lithological units are predominantly encountered on the slopes of the western flank.

The variations encountered in the classification of rock formations within the Central and Northern deposits (Central - from outcrop, Northern - beneath the Meso-Cenozoic cover) can be readily comprehended. The accurate depiction of the true structural composition of the investigated rock mass solely based on fragmented core samples extracted from small-diameter drill holes with limited core recovery poses a considerable challenge. However, a more comprehensive and precise representation of the rock formations is attained through quarrying activities, which offer a clear and detailed view of the exposed lithological units on the quarry walls.

Nonetheless, in the assessment of slope stability, the specific typology and nomenclature of the constituent rock formations bear limited significance. The primary factors governing the future stability of excavated slope faces in rocky formations are:

- The character and spatial orientation of fissuring (in this context, schistosity) within the rock mass.
- The physical and mechanical properties of the rock mass, as determined by the multidirectional anisotropy exhibited by different orientations.

These factors assume paramount importance in establishing the stability of the rock mass, while the precise identification and nomenclature of the individual lithological units hold secondary significance within this framework of analysis.

The Northern deposit, in contrast to the Central deposit, exhibits a bicomponent structure comprising Paleozoic formations overlain by a substantial sedimentary cover of Mesozoic-Cenozoic deposits, consisting primarily of weak rock types that can be classified as "soils" according to the standards outlined in GOST 25100-2011. These deposits encompass argillaceous clays, marly clays, sandy clays, and sands. Superficially, they are overlaid by a thin layer of Quaternary soils, predominantly consisting of dusty, light-gray sands. The considerable thickness of the Mesozoic-Cenozoic deposits will pose significant challenges in the development of the slopes of the Northern quarry.

Based on a visual assessment conducted during the geological survey of the northern working face, the dominant clay deposits within the Mesozoic-Cenozoic sequence are characterized by a relatively low natural moisture content ($W0 \approx 10\text{-}15\%$), a firm consistency (with the flow index J consistently below 0), and isotropic properties. The absence of stratification and the presence of a massive texture are notable features of the rock mass, with sporadic iron-stained fractures and discontinuities dividing the rock into nearly regular block-like parallelepipeds measuring 0.5-1.5 m in size. The color of the clays exhibits considerable variation, ranging from light yellow and light gray with traces of iron staining to a pinkish-brown hue in the upper horizons. The fracture surfaces resulting from hammer impacts display a conchoidal morphology, a characteristic feature of shales.

Within the clay deposits, as determined from drilling data obtained from exploratory boreholes, intercalations of clayey marls with thicknesses ranging from 15 to 30 m are encountered, predominantly measuring approximately 18-25 m in thickness.

The most critical factor concerning the stability of the slopes in the planned Northern quarry is the widespread occurrence of significant sand horizons within the clay deposits. The initial field documentation occasionally characterizes the sands as loose and granular, while in other instances, they are referred to as lightweight sandy rocks (essentially sands with slightly higher density). The sand layers are found at considerable depths, posing substantial challenges in slope construction. For example, on the western slope of the future quarry (wells No. 1652, 1745), the sand horizon is encountered at depths ranging from 55 to 85 m below the surface, with an average thickness of approximately 23-28 m (equivalent to at least two benches).

On the northern slope (wells No. 1651, 1355), the depth of the sand horizon within the clay thickness is recorded at 61-96 m below the surface, with the roof of the sand layer dipping towards the north. The average thickness of this horizon, based on drilling data, is approximately 24 m [1], indicating a downward trend of the sand horizon in the northern direction.

While considerable research has been conducted on the physico-mechanical properties of the Paleozoic bedrock exploited in the Central quarry, the weak rock types and soils of the Mesozoic-Cenozoic deposits have received relatively limited investigation (particularly considering their significance and role in the stability of the slopes and benches in the planned quarry). This necessitates additional drilling, testing, and laboratory analyses at the Northern deposit.

The tectonic characteristics of the Central and Northern deposits have been thoroughly examined during the detailed exploration phase [1]. More detailed information regarding the nature and spatial orientation of the slaty and fractured features within the rock mass was acquired during the geological-structural survey. These valuable insights will be integrated into the development of three-dimensional models of the deposits and the subsequent stability calculations of the quarry slopes

3 Results

During the geological-structural survey conducted on the slopes of the benches in the Central quarry, a comprehensive evaluation was carried out to assess the orientation and characteristics of the attenuation surfaces at 20 points, distributed relatively evenly across the studied quarry area. The survey revealed that the main direction of crack propagation and shale detachment predominantly occurred in the eastern and southeasterly directions. The dominant angles of inclination were found to range from 40 to 600, with a lesser occurrence of gently and steeply declining fractures.

Additionally, Table 1 [2] presents the physico-mechanical properties of selected rock formations, providing valuable insights into the surveyed lithological constituents within the scholarly context of this study.

Table 1. The Physico-Mechanical Characteristics of Mesozoic-Cenozoic Deposits in the Northern Field.

Name	W_0, %	Volumetric the weight, t/m^3	Specificthe weight, t/m^3	Clutch, kPa	Corner inside him friction, deg.	Limit strength when compressed, MPa	
						in natural - veinnom state	in water - saturated - nom state
Clay solid	9.3-14.2	1.76-1.92	2.71-2.74	Not def.	12-19	Not def.	Not def.
Siltstones	Not def.	2.37-2.56	2.61-2.72	Not def.	Not def.	0.6-27.0	0.4-18.0
Mergeli	Not def.	2.16-2.38	2.63-2.71	53	33	26.6	Not def.

The absence of pertinent information on the strength and physical characteristics of the significant sand horizon within the relatively cohesive and robust clay stratum presents a fundamental limitation in the original data of the upper stratum of the Northern deposit. This limitation hampers the accurate quantitative assessment of the stability of both the benches and individual ledges.

Detailed exploration findings indicate that the Paleozoic complex of the Central and Northern deposits primarily comprises quartz-feldspar-mica sandstones (50%), carbonaceous-mica-quartz aleurolites (35%), and slates of comparable composition (15%), exhibiting significant dislocations, extensive quartzification, and sulfidization. Notably, the geological-structural survey of the benches in the Central quarry predominantly encountered slate formations, whereas sandstones were relatively less prevalent.

The values of key physical parameters for various lithological varieties of rocks within the Paleozoic complex are presented in Table 2.

Table 2. Physical and mechanical characteristics of rocks within the Paleozoic complex.

Name	Volume weight,t/m^3	Limit strength at compression, MPa		Coefficient for stresses by M.M. Protodyakonov
		in naturalable	in water saturated - nom able	
Sandstones	2.52 - 2.69	2.7 - 123.2	4.6 - 81.2	2.5 - 12.3
Siltstones	2.53 - 2.71	6.8 - 100.2	1.3 - 53.7	1.7 - 10.0
Slates	2.61 - 2.71	6.6 - 109.7	3.2 - 79.8	4.1 - 10.0

The obtained data, particularly the significantly high values of ultimate strength, indicate that all the primary rock types belong to the category of robust rocks. The coefficient of brittleness (σ_{com}/σ_r ratio) for all cases, except monchekite, exceeds 10, signifying the propensity of these rocks towards brittle fracture. The velocity value V_p in the rocks falls within the range of 2.3 to 5.8 km/s, which is also typical for sturdy rock formations.

A comprehensive analysis was conducted in 2019 to evaluate the changes in uniaxial compressive strength (σ_{com}) in the near-contour zones of the pit wall, which serves as a key structural element within the Amantaytau deposit's quarry field [3]. Moreover, to account for the impact of stress-strain state parameters on the stability of the edge massif, a prediction was made in 2016 concerning the natural stress state of the deposit's rock mass. Consequently, three distinct zones were identified based on the prevailing stress levels [4]:

I - weakly stressed zone ($\sigma_3 \leq 20$ MPa) from the surface to a depth of 400 m.

II - medium stress zone (20 MPa $< \sigma_3 <$ 40 MPa) from 400 to 1000 m.

III - highly stressed zone ($\sigma_3 \geq 40$ MPa) beyond 1000 m.

Additionally, three zones were delineated along the depth of the deposit based on core fracturing indicators and the nature of its disking [5]: up to 400 m, from 400 to 1000 m, and over 1000 m.

Utilizing the available data on the geomechanical state of the deposit, it becomes feasible to determine the geomechanical rating of the rock mass. The recently employed geomechanical rating classification MRMR (referred to as R_L hereafter), developed by Prof. D. Lobshir and widely adopted in Western countries since the mid-1970s [7-9], proves instrumental in estimating key parameters of mining operations at the preliminary stage, based on the outcomes of geological exploration. This assessment is particularly valuable for evaluating stability parameters of mine workings, including an initial appraisal of open pit wall stability.

The algorithm for determining the R_L rating indicator is presented in Figure 4. From the diagram, it is evident that the R_L rating value is derived from the summation of partial ratings, incorporating the strength characteristics of the massif, quantitative and qualitative features of fracturing, and subsequently multiplied by correction factors accounting for weathering, fracture orientation, stress state, hydrogeology, among others.

The R_L rating value is expressed by the following formula:

$$R_L = (R_{\text{bs}} + R_{\text{cr}} + R_{\text{fc}}) \times k, \quad (1)$$

where R_{bs} is rock block strength, R_{cr} is the rating based on the number of cracks, R_{fc} is the rating of fracture conditions, and k refers to the coefficients incorporating weathering, crack orientation, stresses in the massif, blasting effects, and the presence of underground water inflows.

The calculations were based on the initial data derived from research conducted by VNIMI [6], focusing on the physico-mechanical properties of the rocks. Taking into account the zonation of stress levels within the rock mass and the observed variations in fracturing patterns with depth, the rating computation was performed for three distinct zones of the Amantaytau deposit, utilizing Formula:

For the uppermost section of the massif (up to a depth of 100 m),

$$R_L = (R_{bs} + R_{cr} + R_{fc}) \times k \approx 38; \quad (2)$$

Within the depth range of 100 - 300 m,

$$R_L = (R_{bs} + R_{cr} + R_{fc}) \times k \approx 54 \div 65; \quad (3)$$

At depths exceeding 300 m,

$$R_L = (R_{bs} + R_{cr} + R_{fc}) \times k \approx 60 \div 72. \quad (4)$$

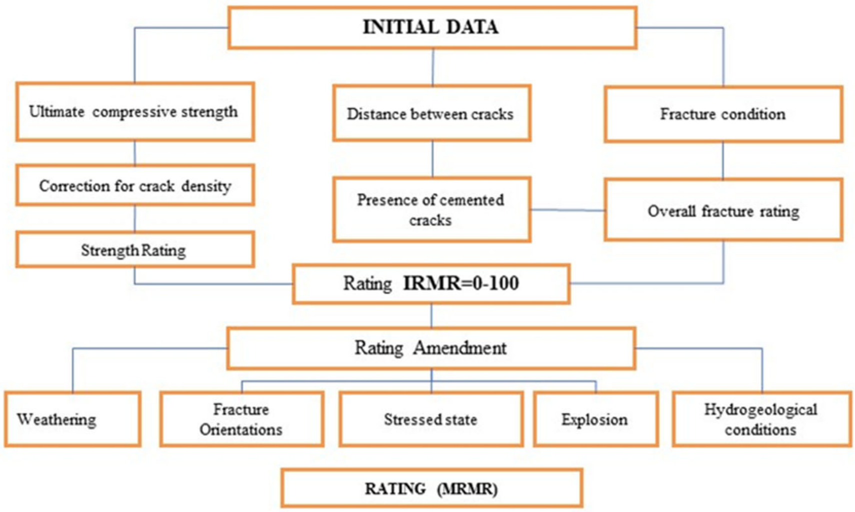

Fig. 4. Algorithm for determining the rating indicator R_L according to the classification by Professor D. Lobshir.

Applying the classification scheme devised by Prof. D. Lobshir, as presented in Table 3, the computed R_L ratings provide valuable insights into the characteristics of the rock mass at the Oleniy Ruchey deposit. Specifically, within the uppermost section extending to a depth of 100 m, excluding the covering moraine deposits, the rocks belong to the fourth class, indicative of relatively lower stability. The rocks between depths of 100 and 300 m exhibit moderate stability under lower tectonic stresses, corresponding to the third class. However, higher tectonic stresses would reclassify them into the second class, signifying enhanced stability. Finally, the rocks at depths exceeding 300 m demonstrate good stability and predominantly belong to the second class.

Table 3. The rating values of R_L in accordance with the class of rock formations by Lobshir.

R_L Rating	81÷100	61÷80	41÷60	21÷40	5÷20
Class according to Lobshir	1	2	3	4	5

Recommendations for selecting approximate values of slope angles for quarry walls based on the calculated MRMR rating have been developed by A. Hainsom and P. Terbrugge [10]. These recommendations are presented in Table 4.

Table 4. Approximate slope angles of quarry walls according to rock class according to A. Hines and P. Terbrugge.

Breed class	1	2	3	4	5
Pit wall slope angle	75°±5°	65°±5°	55°±5°	45°±5°	35°±5°

Based on calculated rating R_L rocks of the Amaytaytau deposit for a quarry, as a first approximation, the following options for side slope angles can be recommended for consideration:

- for depths up to 100 m - 35÷50^0,
- for depths from 100 to 300 m - 50÷60^0,
- deeper than 300 m - up to 65^0.

Graphically, the zoning of the rating results by depth is presented in one of the sections (Figure 5) [11].

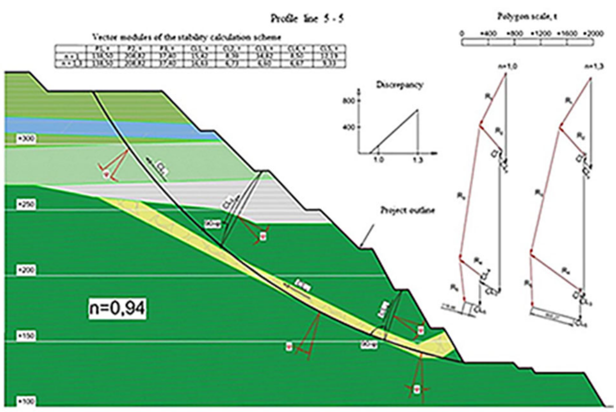

Fig. 5. Calculation of stability for cross-section 5-5.

It should be noted that when calculating the ratings R_L the type of drilling and blasting was not taken into account. The use of contour blasting will contribute to the correspondence of the real state of the near- contour part of the rock mass to the given results of the calculation of ratings.

4 Conclusion

The assessment of slope stability along cross-section 5-5 reveals valuable insights into the classification and recommended inclinations for the quarry walls in the studied deposit. The rock formations in the upper portion, extending up to a depth of 100 meters from the surface, are identified as belonging to the second class. Consequently, the quarry walls can be safely configured at angles of up to 50 degrees. As the depth increases from 100 to 300 meters, the rock formations transition from the second to the third class, warranting quarry wall inclinations of up to 60 degrees. Notably, for quarry depths exceeding 300 meters, classified as the second class, the recommended inclination angle for the quarry walls reaches up to 65 degrees.

It is important to note that the provided slope angle recommendations are applicable primarily to the hanging wall, as the footwall exhibits significant structural disruptions with estimated dip angles ranging from approximately 40 to 45 degrees towards the northwest direction. Thus, careful consideration and engineering analysis are required when designing and implementing quarry operations to account for the distinct geological characteristics and potential challenges posed by the footwall.

Overall, the findings presented in this study contribute to a comprehensive understanding of slope stability assessment and provide practical guidelines for slope design in quarrying operations, facilitating safe and efficient extraction of mineral resources while mitigating risks associated with unstable rock masses. Further research and site-specific investigations are encouraged to refine and validate these preliminary recommendations for slope angles, taking into account site-specific geological conditions and local regulations.

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