*Mining of Mineral Deposits*
*Volume 18 (2024), Issue 2, 132-139*

https://doi.org/10.33271/mining18.02.132

# Geo-mechanical classification of the Ighrem Aousser rock mass mining site of the Touissit Mining Company

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**Abstract**

**Purpose.** The paper aims to classify the rock mass of the Ighrem Aousser (I/A) mine and analyze its fracturing to determine the appropriate excavation supports.

**Methods.** The study begins with a geo-mechanical classification of the mass using widely used methods: Rock Quality Designation (RQD), Rock Mass Rating (RMR), Q-Barton, and Geological Strength Index (GSI). Fracturing surveys were then conducted to identify the main fracture families using DIPS software. Finally, UNWEDGE software was used to measure the support systems.

**Findings.** The study provides a comprehensive geological study, including field observations, core drilling analysis, and structural analysis with DIPS software. Results indicate that the I/A mine rock mass is highly fractured and altered, as confirmed by mechanical tests at the Mohammadia School of Engineers' laboratory and empirical classifications. Based on these findings, appropriate support systems were identified using UNWEDGE software.

**Originality.** This study provides a detailed classification and structural analysis of the I/A rock mass to propose and measure excavation supports. Integrated approach not only advances understanding of rock mass behavior, but also ensures optimized safety, stability, and productivity of mining operations, setting a new standard in sustainable mining development.

**Practical implications.** In the mining industry, classifying rock masses and designing excavation supports enhances safety, increases site productivity by reducing contamination and lowering mining costs.

***Keywords:*** *empirical classifications, rock mass, fracturing, support, DIPS, UNWEDGE*

## 1. Introduction

The Touissit Mining Company (TMC) continues its exploration activities to achieve sustainable development, similar to the practices used in the Kazakhstan mining industry [1]. Geological monitoring of drilling campaigns and mining operations has clarified the geometry of mineralization and its deep occurrence, exceeding 1100 m at the Ighrem Aousser (I/A) mine site.

Underground mining faces significant ground stability challenges, which intensify with depth. Extensive geotechnical research over the past two centuries has sought to understand rock mass behavior [2]-[4]. Despite this, stability issues persist, particularly beyond 1000 m, due to the unique characteristics of each rock mass.

A range of factors contribute to stability challenges in underground mining, particularly at depths exceeding 1000 m. Kim et al. [5] emphasize the influence of rock engineering characteristics and hydrogeology factors, with pore-water pressure being a significant factor. Cała et al. [6] underscore the importance of stability in design, while Majcherczyk et al. [7] highlight the impact of large depths on rock mass behavior and support deformation. Singh et al. [8] discuss the complexities of rock mass characteristics and stress conditions at great depths, suggesting that mechanization and automation can improve performance. Zhang et al. and Vo et al. [9], [10] both emphasize the importance of understanding the response of rock masses to mining activities, with Zhang focusing on the self-healing ability of aquicludes and Vo on rock support stability in large underground caverns. Konieczna-Fuławka et al. [11] discuss the potential repurposing of post-mining underground workings, emphasizing the need to address hazards such as seismicity and ground control problems. Waqar et al. [12] provide a comprehensive review of rockburst, a violent phenomenon occurring during hard rock excavation, and the challenges in predicting and controlling it. Taken together, these studies underscore the need for a comprehensive understanding of the unique characteristics of each rock mass and the development of appropriate support systems to ensure stability in underground mining.

Despite these advancements, challenges in ground stability persist, particularly at greater depths. The unique characteristics of each rock mass, such as fracture patterns and material composition, require tailored solutions. Existing research often lacks comprehensive studies that integrate geological, structural, and mechanical analyses to propose and measure effective support systems.

Received: 23 March 2024. Accepted: 18 June 2024. Available online: 30 June 2024

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Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)
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The Ighrem Aousser deposit exploitation is confronted with ground support problems [13], which increase with depth and make exploitation challenging [14] in terms of personnel safety, site productivity (soiling) [15], and subsequently, increase in the cost of exploitation.

Despite significant progress in understanding rock mass behaviour, some critical aspects remain unresolved. Specifically, there is a need for integrated studies that combine empirical classifications, fracturing surveys, and advanced support system design tools. The unique geological and structural characteristics of the Ighrem Aousser rock mass require a detailed analysis to develop effective support strategies that address both safety and productivity concerns.

This study focuses on characterizing I/A rock mass through geo-mechanical mass classification [16], [17], using the most widely-used empirical methods (RQD, RMR, Barton, GSI) in order to propose a support specification [18], [19], the sizing of which are processed using UNWEDGE software.

So, the primary purpose of this research is to classify the rock mass of the Ighrem Aousser mine and analyze its fracture patterns to measure appropriate excavation supports. By integrating geo-mechanical classifications with structural analyses and support system design tools, this study aims to develop a comprehensive understanding of the rock mass behavior and propose tailored support solutions.

The objectives of the study are to perform a geo-mechanical classification of the Ighrem Aousser rock mass using the most widely-used empirical methods: Rock Quality Designation (RQD), Rock Mass Rating (RMR), Q-Barton, and Geological Strength Index (GSI). Additionally, the study aims to conduct fracturing surveys using DIPS software to identify the main fracture families and their characteristics. Based on the classification and fracturing analysis results, a support system specification is proposed. Finally, the proposed support system will be measured using UNWEDGE software to ensure its effectiveness in enhancing safety and productivity. By addressing these objectives, this research aims to contribute to the body of knowledge on rock mass classification and support system design, providing practical solutions to challenges faced in deep underground mining operations.

### 1.1. Geological context

#### *1.1.1. Geographical situation*

The Tighza mining district, known as Jbel Aouam, is located in central Morocco's Middle Atlas Mountains (a portion of the Hercynian chain that has remained undisturbed by Alpine movements), more precisely in the administrative region of Meknes-Tafilalt, 7 km from M'Rirt, 90 km south of Meknes (Fig. 1). The Tighza mining district is part of the Hercynian Orogenic Belt, characterized by a complex geological history. The region's geology is dominated by Paleozoic sedimentary and volcanic rock sequences that have undergone multiple phases of deformation and metamorphism. The area features a variety of rock types, including schists, quartzites, and volcanic tuffs, indicating a dynamic geological environment.

The mining activities in the Tighza district have had both positive and negative impacts on the local environment and communities. On the one hand, mining has contributed to economic growth and job creation in the region. On the other hand, it has led to environmental degradation, including soil erosion, water pollution, and habitat destruction. Efforts are being made to mitigate these impacts through sustainable mining practices and environmental rehabilitation programs.

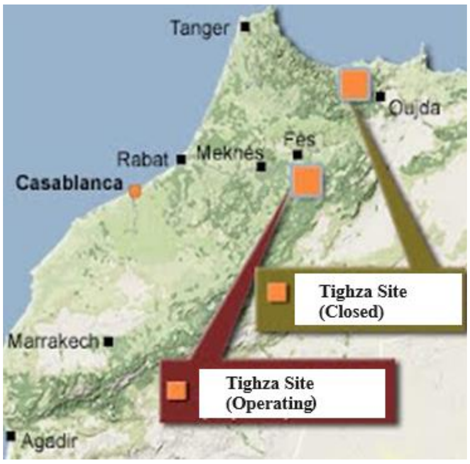


*Figure 1. Geographical location of the Tighza mining district [20]*

#### *1.1.2. Regional geology*

Geologically, the Tighza area belongs to central Morocco, subdivided into five parts from west to east, of which the fifth unit of the Kasbattadla-Azrou anticlinorium contains the Tighza district (Fig. 2). This district illustrates the Hercynian phenomena affecting Paleozoic terrains from Ordovician to Carboniferous age [21].

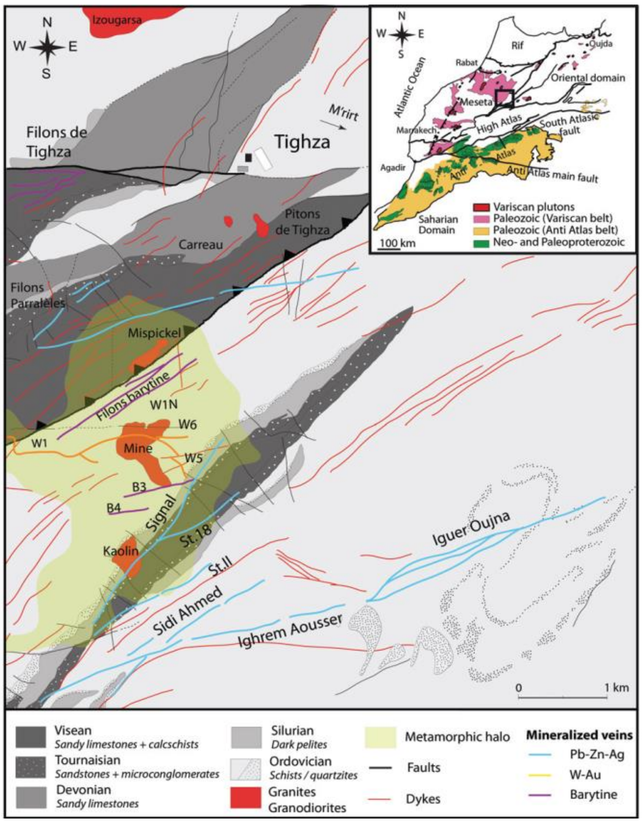


*Figure 2. Geological map of Tighza mining district [21]*

The Ordovician is the most dominant stratigraphic stage, constituting the Aouam, Anajdam and Iguer Oujana massifs, which correspond to the allochthonous part of the Ordovician. Deposits, attributed to the allochthonous or autochthonous Upper Ordovician, are essentially detrital in character, containing a schistose series and alternating gres and pelites at the base, as well as quartzite bars at the top of the Ordovician. The Ordovician of the M'RIRT region is dominated by clay or clay-limestone with a rhythmic character.

Silurian is a lithological succession with a fine detrital character. It rests directly on the upper quartzites. It consists of greyish to blackish pelites. Silurian schists are rich in organic matter, which facilitates fossil dating. These facies are known in the Jbel Aouam region as Mokattam schists or loisonné schists. Devonian deposits consist of argillites, indicating calm sedimentation. The nodules and limestones enriching the Devonian indicate that deposition occurred in the outer platform. The Devonian sedimentary series is composed of silty argillites intercalated with fine limestone-bearing numerous signs of synsedimentary tectonics indicating bedrock instability.

The Tournaisian greso-conglomatitic series rests unconformably on the preceding terrain and is overlain by marine platform deposits composed mainly of bioclastic limestones, sandy limestones and marls of Middle Venetian age. The flysch series follows these platform deposits.

#### *1.1.3. Geology of the Ighrem Aousser (A/I) site*

In I/A vein area, two units outcrop essentially with the corresponding ages of Upper Ordovician and Silurian. The Upper Ordovician age terrains are formed by bluish-grey micaceous pelites with intercalations of centimetric sandstone bars, while the Silurian is represented by light-gray silicified mudstones, surmounted by dark-gray mudstones that break up into fine graptolite-rich platelets. The bedrock is of Primary age, Paleozoic: between Visean and Ordovician. Essentially alternates with sandstones and shales, with a difference in dominance affecting the strength (sandstone dominance: good strength, shale dominance: average strength).

The purpose of this research is to conduct a geotechnical characterization of the rock mass, starting with a geo-mechanical study, namely structural characterization and fracture density, followed by a geo-mechanical classification of the rock mass by the most used methods (RMR, Q-Barton, GSI), with the intention of proposing a support system with dimensions to be processed by the UNWEDGE software.

## 2. Methods

### 2.1. Geotechnical study of the Ighrem Aousser rock mass

#### *2.1.1. Rock identification*

After analyzing the core drillings, the facies in question are: Flysch with alternating sandstones and shales with a predominance of sandstone benches over shaly levels.

#### *2.1.2. Empirical rock massif classifications*

In this section, we will characterize the rock mass of the Ighrem Aousser mine using several empirical methods, namely the RQD, Barton, RMR and Geologic Strength Index (GSI).

Rock Quality Designation (RQD) was developed by Deere et al. (1967) to quantify the fracturing influencing the rock mass behavior based on the study of drill core samples [22]. The RQD is defined as the percentage of intact pieces longer than 10 cm along the total length of the drilling.

Barton's method is an empirical rock mass classification [23], [24]. The principle of this classification is to assess the rock mass quality by 84 parameters. It is characterized by a quality index Q ranging from 0.001 for a very poor mass and 1000 for a very rich mass. In practice, this index is reduced to values from 0.005 to 50.

The Bieniawski classification or RMR is the sum of five scores representing the quantification of five parameters characterizing the rock (simple compressive strength; RQD; distance between fracture families; roughness and weathering of fractures; presence of water; gallery orientation compared to orientation of the critical fracture family) [25], [26]. The sum of the five scores is adjusted by a score for the direction of excavation in relation to the direction of dip of fractures. With this classification, Bieniawski suggests the possible excavation method and the type of support that is best suited.

Introduced by Hoek (1995) and Hoek, Kaiser and Bawden (1995), the GSI is an empirically determined, dimensionless number, and its estimation is based on direct observation of the rock mass structure by examining the quality of the rock mass in situ [27]. This index varies between 5 and 85, with values close to 5 correspond to materials of very poor quality, while values close to 85 describe materials of very good quality. The modified GSI proposed by Sonmez and Ulusay (1999) [28], is a further development of the GSI, which is considered too approximate.

#### *2.1.3. Results of empirical rock mass classifications*

Based on the analysis of core drills and the use of the DEERE classification, the rock mass is classified as good (Table 1).

***Table 1. DEERE classification***

| Rock | RQD | DEERE classification |
|---|---|---|
| Sandstone | 90 | Very good |
| Flyshs | 70 | Average |

Using Barton's classification, we were able to classify the rock mass from average to very poor for Flyshs (Table 2).

***Table 2. Corresponding support for each facies by Q-Barton***

| Rock | Q | Barton classification | ED | Support |
|---|---|---|---|---|
| Sandstone | 4.22 | Average | 1.75 | Barton considers sandstone to be stable, so it is sufficient to accept light support according to the areas of instability. |
| Flyshs | 0.58 | Very poor | 1.75 | Bolting $BL$ = 2.20 m / $S_p$ = 1 m |

According to Bieniawski classification, I/A mass is classified as fair to good (Table 3), and the most suitable support is summarized in Table 4.

***Table 3. RMR results for each facies***

| Rock | RMR | Class | Bieniawski classification |
|---|---|---|---|
| Grès | 74 | 2 | Good |
| Flyshs | 58 | 3 | Average |

***Table 4. Corresponding support for each facies by the RMRzs***

| Rock | Support |
|---|---|
| Sandstone | Given the good resistance of the sandstones, we will opt for bolts spaced 1.5-2 m apart and accompanied by a welded mesh or a wire mesh. |
| Flyshs | The Flyshs have a medium hold, for this reason we will use bolts spaced 1-1.5 m apart and accompanied by a welded mesh or a wire mesh. In addition, we will install light hangers spaced 0.7-1.5 m apart. |

The calculation of GSI and modified GSI for I/A rock mass allowed us to classify different facies (Table 5).

***Table 5. Classification of GSI and modified GSI***

| Rock | GSI | Modified GSI | Classification |
|---|---|---|---|
| Sandstone | 75 | 74 | Good |
| Flyshs | 60 | 61 | Good |

## 3. Results and discussion

### 3.1. Study of fracturing

The rock mass supporting the construction of underground mining structures always contains discontinuities of different nature with different hydrogeological and geomorphology of the mineralized structure.

In this study, we conduct fracture surveys on two downstream mine levels that are in active condition (14$^{th}$ and 15$^{th}$ levels) to process them using Dips software (a stereographic representation program using spherical projection on the Wolf-Smith canvas) to characterize fracture families and calculate fracture density.

To get a good rock mass representation, fracture surveys are conducted from the travers band (TB), then in the master roads (MR), which are close to and parallel to the mineralized vein, and then in the link galleries between the MR and the vein.

#### *3.1.1. At the 14$^{th}$ level (750 m of depth)*

*Travers band.* At this site, we note a smaller number of poles concentrated in the E-W direction (Fig. 3). The main concentration areas are grouped into families in Table 6.

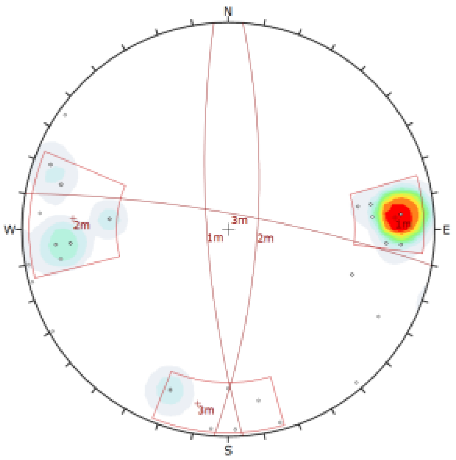


***Figure 3. Contours of pole concentrations at the TB***

***Table 6. TB discontinuity families***

| Discontinuity ID | Dip | Dip direction | Description |
|---|---|---|---|
| 1 m | 72 | 274 | Primary family |
| 2 m | 76 | 59 | Primary family |
| 3 m | 78 | 101 | Primary family |

For this structure, we only have a concentration zone in the east of the canvas with a maximum concentration of 36.50%.

*Link gallery 539.* The number of poles on this site is lower (51 poles), mainly concentrated in the East and NW directions (Fig. 4). The main concentration areas are grouped into families in Table 7.

For this project, we have two concentration zones to the east of the canvas with a maximum concentration of 23.02%.

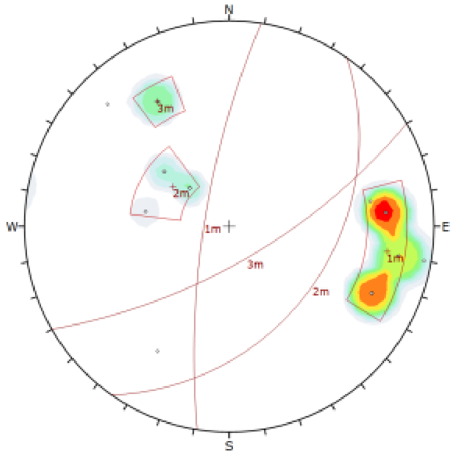


***Figure 4. Contours of pole concentrations at the link gallery 539***

***Table 7. Discontinuity families at the link gallery 539***

| Discontinuity ID | Dip | Dip direction | Description |
|---|---|---|---|
| 1 m | 75 | 279 | Primary family |
| 2 m | 37 | 125 | Primary family |
| 3 m | 70 | 150 | Primary family |

*East master road.* At this site, the number of poles is minimal, and their distribution is dispersed (Fig. 5). The main concentration areas are grouped into families in Table 8.

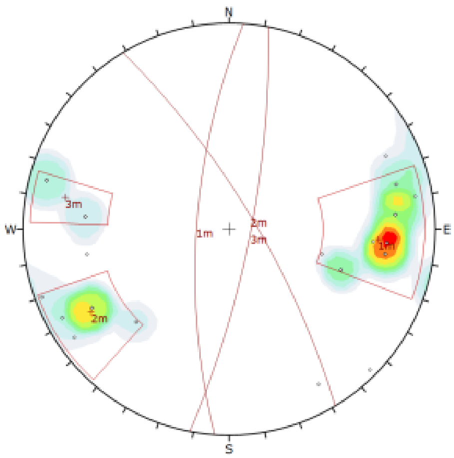


***Figure 5. Contours of pole concentrations at the EAST master road***

***Table 8. Discontinuity families at MR***

| Discontinuity ID | Dip | Dip direction | Description |
|---|---|---|---|
| 1 m | 78 | 266 | Primary family |
| 2 m | 74 | 94 | Primary family |
| 3 m | 81 | 10 | Primary family |

For this construction site, we have two areas of concentration of the E-W steering poles with a maximum concentration of 21.99%.

#### *3.1.2. At the 15$^{th}$ level (800 m of depth)*

Start with the west master road of the 800 m level, working on the 2 sections between columns (45-47) and (47-49).

*Master road 45-47.* Based on this wide distribution, the fracture state of the terrain can be described as significant, since the gallery consists of a total of 196 poles located mainly in the NW and SE zones (Fig. 6). The main concentration areas are grouped into families in Table 9.

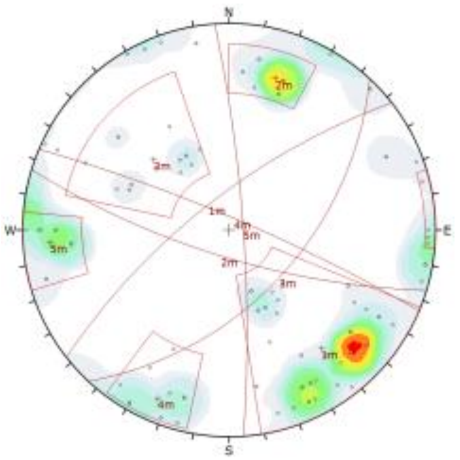


***Figure 6. Contours of pole concentrations at the master road 45-47***

***Table 9. Discontinuity families at MR 45-47***

| Discontinuity ID | Dip | Dip direction | Description |
|---|---|---|---|
| 1 m | 72 | 322 | Primary family |
| 2 m | 75 | 197 | Primary family |
| 3 m | 53 | 133 | Primary family |
| 4 m | 83 | 23 | Minor joints |
| 5 m | 82 | 86 | Minor joints |

Based on this wide distribution, the fracture state of the terrain can be described as important, since the gallery consists of a total of 196 poles located mainly in the NW and SE zones.

*Master road 47-49.* In the same way, for this second part of the western MR of the 15th level, we conclude that the fracture state of the terrain is important, since we have a wide distribution consisting of a total of 206 poles located mainly in the NW and SE zones (Fig. 7). The main concentration areas are grouped into families in Table 10.

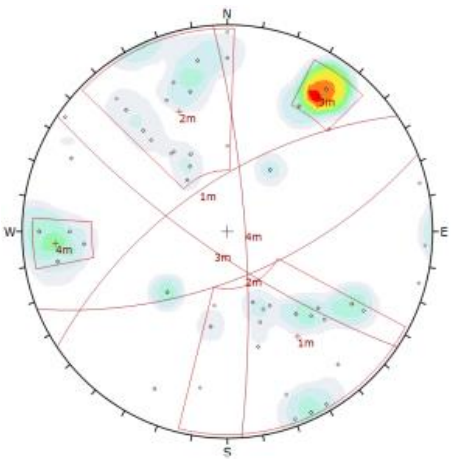


***Figure 7. Contours of pole concentrations at the master road 47-49***

***Table 10. Discontinuity families at MR 47-49***

| Discontinuity ID | Dip | Dip direction | Description |
|---|---|---|---|
| 1 m | 63 | 326 | Primary family |
| 2 m | 64 | 158 | Primary family |
| 3 m | 77 | 214 | Primary family |
| 4 m | 80 | 86 | Minor joints |

We conclude that the fracture state of the terrain is important, since we have a wide distribution consisting of a total of 206 poles located mainly in the NW and SE zones. It should be noted that the families shown in MR 47-49 are similar to those in MR 45-47, hence the continuity is evident in both galleries.

*Link gallery 645.* The distribution of poles shows a NE-SW concentration of discontinuity poles, with 57 poles in total (Fig. 8). The main concentration areas are grouped into families in Table 11.

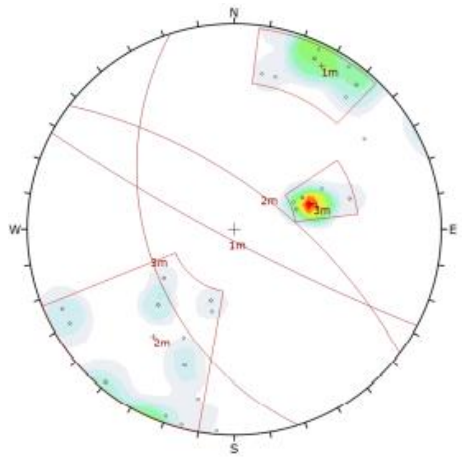


***Figure 8. Contours of pole concentrations at the link gallery 645***

***Table 11. Discontinuity families at the link gallery 645***

| Discontinuity ID | Dip | Dip direction | Description |
|---|---|---|---|
| 1 m | 84 | 208 | Primary family |
| 2 m | 66 | 37 | Primary family |
| 3 m | 44 | 252 | Primary family |

In this zone, we have three concentration zones towards the NE with a maximum concentration of 24.69%.

*Link gallery 649.* We have two concentration zones, one to the north and the other to the NE-SW (Fig. 9). The main concentration areas are grouped into families in Table 12.

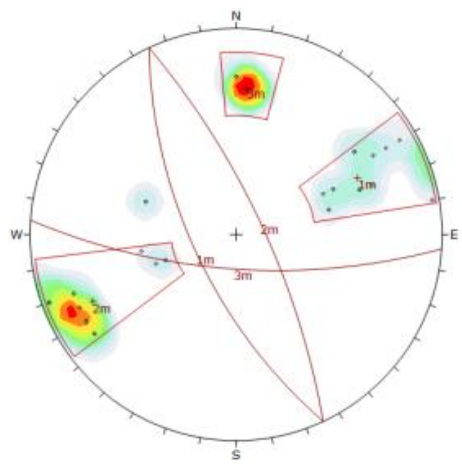


***Figure 9. Contours of pole concentrations at the link gallery 649***

***Table 12. Discontinuity families at the link gallery 649***

| Discontinuity ID | Dip | Dip direction | Description |
|---|---|---|---|
| 1 m | 66 | 245 | Primary family |
| 2 m | 75 | 65 | Primary family |
| 3 m | 71 | 184 | Primary family |

We have two concentration zones, one to the north and the other to the NE-SW, with a maximum concentration of 22.32%. Both cuttings are similar, with the distribution always concentrated at the poles of the NE-SW discontinuities. In other words, the same families cross both cuttings, hence the continuity of these families is evident throughout this zone.

Summarizing the main results obtained by the Dips software for the six surveys conducted at two levels (14th and 15th), we conclude that the highly fractured rock mass and the extension of these fractures conducted in the presence of shale. These results also show that each zone of the terrain is characterized by at least three families of discontinuities which, given their dip and dip direction, can delimit blocks capable of falling.

### 3.2. Supporting mining structures (UNWEDGE software)

UNWEDGE is a software package developed by Rocscience to study the stability of excavation faces based on the mass fracturing. It is designed as a fast, interactive and easy-to-use tool. It enables the geometry of blocks (delimited by 3 discontinuity planes) surrounding an underground excavation to be analyzed and their behavior to be assessed.

UNWEDGE can also be used to design, or rather dimension, a support system using either bolted or shotcrete methods, or even a combination of these two types of support, with the option of determining their characteristics.

After processing all the galleries using UNWEDGE, the results obtained by determining which blocks are likely to fall will be represented, and then the blocks will be bolted to determine the terrain behavior.

#### *3.2.1. On the travers band*

Block instability necessitates the insertion of bolts to increase the safety factor (Fig. 10). Bolt characteristics are listed in Table 13.

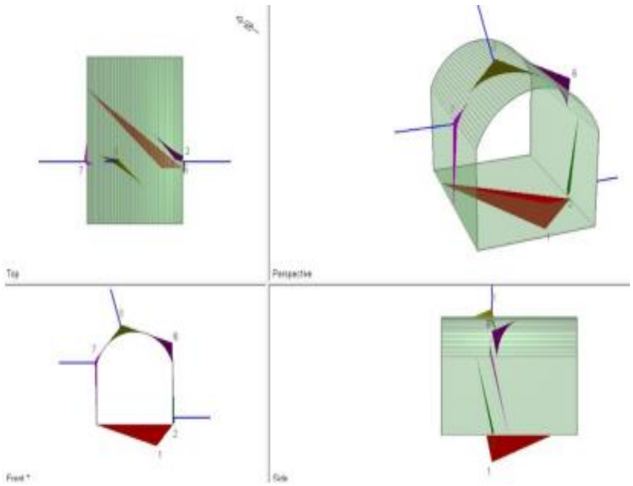


***Figure 10. Bolt distribution at TB level***

***Table 13. Characteristics of TB bolts***

| Bolt N° | Length, m | Spacing, m | Orientation |
|---|---|---|---|
| 1 | 1.5 | 1 | Normal to aperture section |
| 2 | | | |
| 3 | | | |

At the TB level, we will add three 1.5 m long bolts spaced 1 m apart. After inserting the bolts, we see that the safety factor increases.

#### *3.2.2. On the master roads*

The intersection of planes from different families forms unstable blocks, hence there is a need to insert bolts (Fig. 11). Bolt characteristics are listed in Table 14.

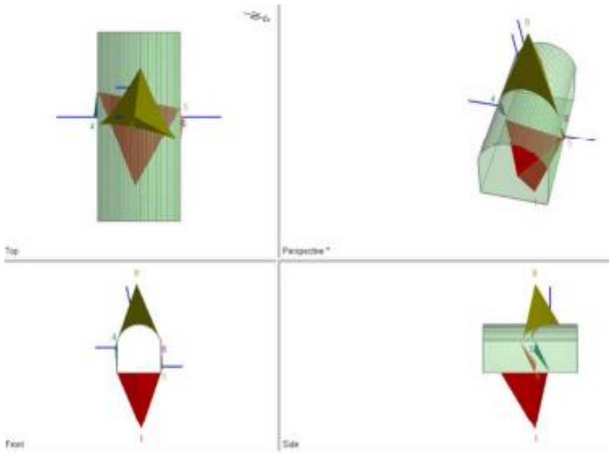


***Figure 11. Bolt distribution at MR level***

***Table 14. haracteristics of MR bolts***

| Bolt N° | Length, m | Spacing, m | Orientation |
|---|---|---|---|
| 1 | 2.5 | 1 | Normal to aperture section |
| 2 | 1.5 | | |
| 3 | 1.5 | | |

Unstable blocks will be secured with three bolts: one 2.5 m bolt and two other 1.5 m bolts spaced 1m apart, which increases the safety factor as shown in Figure 11.

#### *3.2.3. On the link galleries*

Unstable blocks are secured with bolts, thus increasing the safety factor (Fig. 12). Bolt characteristics are listed in Table 15.

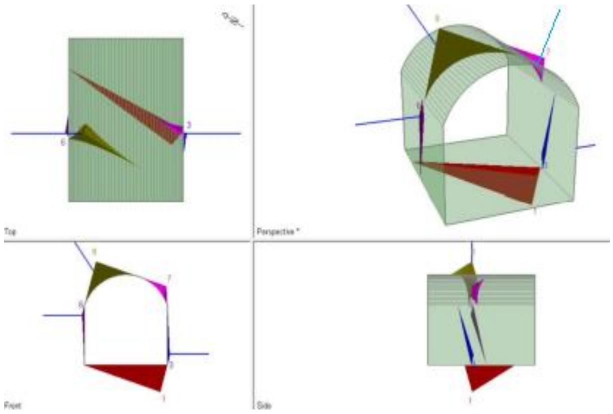


***Figure 12. Bolt distribution at the link gallery level***

***Table 15. Characteristics of link gallery bolts***

| Bolt N° | Length, m | Spacing, m | Orientation |
|---|---|---|---|
| 1 | 2 | 1 | Normal to aperture section |
| 2 | 2 | | |
| 3 | 1.5 | | |
| 4 | 1.5 | | |

The unstable blocks will be secured with four bolts, two 2 m bolts and two other 1.5 m bolts spaced 1m apart, which increases the safety factor as shown in Figure 12.

The Ighrem Aousser mine site is starting to deepen, with the mineralization depth exceeding1100 m according to the latest drilling, and the rock mass is very fractured and degraded. The objective of this research is to conduct a geotechnical study to understand the behavior of the site rock mass based on the most well-known empirical classifications, as well as to conduct a global study of the mass fracturing, to determine the families of main faults delineating blocks that may fall. The results confirm this degradation, leading to the design of the ground supports adapted to each type of gallery to suspend unstable blocks. The objective to be achieved in future research is to determine the optimal distance between the drifts dug at the vein and the haulage drifts dug at the vein wall, which are parallel to the latter, while maintaining their stability due to the ground supports calculated on the screen. This makes it possible to implement a global geotechnical model of the Ighrem Aousser site to determine the mining sequences of the deposit. Thus, it is necessary to propose a mining method that adapts to the new geotechnical conditions in order to maintain personnel safety and reducing the ore dilution rate, and hence operating costs.

## 4. Conclusions

To accurately characterize the bedrock of the Ighrem Aousser mine, primarily composed of sandstone and flysch, we have conducted a comprehensive study using various geo-mechanical classification methods including RQD, RMR, Q-Barton, and GSI. These classifications were supplemented by mechanical tests performed in the laboratory of the Mohammadia School of Engineering.

After the initial classification, we conducted a detailed structural study of the rock mass, focusing on the majority of apparent fractures at the $14^{th}$ and $15^{th}$ levels. Using DIPS software, these fractures were classified into families, identifying critical unstable zones within the rock mass. Based on empirical classifications and structural fracture studies, we have developed several support proposals. These proposals were then calculated and validated using UNWEDGE software to ensure that they are effective in stabilizing the rock mass.

The study is an important contribution to the new shaft project, as its results will be used in the planning of preparatory and mining operations for the new shaft, strategically located between the Ighrem Aousser and Sidi Ahmed mines. The results provide important conclusions about the sustainability of development and mining operations, ensuring enhanced safety, stability, and productivity (tonnage) of the exploitation sites.

Overall, the integration of empirical classifications, structural analysis and advanced support design tools represents a key element for the sustainable development and efficient mining of the Ighrem Aousser mine, addressing both current and future challenges related to ground stabi-lity and site productivity.

## Author contributions

Conceptualization: KH; Investigation: KH, AL; Methodology: KH, AL; Project administration: KH; Supervision: AL; Validation: AL; Writing – original draft: KH; Writing – review & editing: KH. All authors have read and agreed to the published version of the manuscript.

## Funding

This research received no external funding.

## Acknowledgements

This research was partially supported by Laboratory of Applied Geophysics, Geotechnics, Engineering Geology and Environment at Mohammadia School of Engineers, Mohammed V University.

## Conflicts of interests

The authors declare no conflict of interest.

## Data availability statement

The original contributions presented in the study are included in the article, further inquiries can be directed to the corresponding author.

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## Геомеханічна класифікація породної маси на гірничодобувній ділянці Ігхрем Ауссер гірничодобувної компанії Туісіт

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**Мета.** Розробка класифікація породної маси шахти Ігхрем Ауссер (I/A) та аналіз її тріщинуватості для визначення відповідних кріплень виїмкових гірничих виробок.

**Методика.** Дослідження передбачає комплексне геологічне дослідження, включаючи польові спостереження, аналіз колонкового буріння та структурний аналіз за допомогою програмного забезпечення DIPS. Методологія починається з геомеханічної класифікації маси із використанням широко використовуваних методів: позначення якості гірничої породи (RQD), оцінка породної маси (RMR), Q-Бартону та індексу геологічної міцності (GSI). Потім з використанням програмного забезпечення DIPS були проведені дослідження тріщинуватості для визначення основних сімейств тріщин. Нарешті програмне забезпечення UNWEDGE було використане для визначення розмірів систем кріплень.

**Результати.** Встановлено, що породна маса шахти Ігхрем Ауссер сильно тріщинувата та мінлива й інтенсивно розвивається при наявності сланців, що підтверджується механічними випробуваннями в лабораторії Інженерної школи Мохаммадії та емпіричними класифікаціями. На підставі цих результатів із використанням програмного забезпечення UNWEDGE було визначено у нестійких зонах масиву відповідні раціональні системи кріплення гірничих виробок з використанням анкерного кріплення.

**Наукова новизна.** Запропоновано класифікацію та здійснено структурний аналіз породної маси шахти Ігхрем Ауссер, щоб запропонувати та визначити розміри кріплень для виймання. Комплексний підхід не лише покращує розуміння поведінки породної маси, але також і забезпечує оптимальну безпеку, стабільність та продуктивність гірничих робіт, встановлюючи новий стандарт у сталому розвитку гірничодобувної промисловості.

**Практична значимість.** У гірничодобувній промисловості класифікація масивів гірських порід і проєктування виїмкових кріплень підвищують безпеку, підвищують продуктивність на ділянці за рахунок зменшення забруднення та зниження витрат на видобування корисних копалин.

***Ключові слова:*** *емпіричні класифікації, масив гірських порід, тріщинуватість, кріплення, DIPS, UNWEDGE*

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