Mining of Mineral Deposits
Volume 19 (2025), Issue 2, 56-64

https://doi.org/10.33271/mining19.02.056

Geomechanical classification of the downstream section of the Ighrem Aousser Deposit with determination of optimal spacing for mine workings

Khalid Hossayni [1*], Abdelaziz Lahmili [1]

[1] *Mohammadia School of Engineers, Mohammed V University in Rabat, Rabat, Morocco*
**Corresponding author: e-mail* k.hossayni@gmail.com

Abstract

Purpose. The paper seeks to classify the downstream rock mass of the Ighrem Aousser (I/A) mine and examines its fracturing in order to determine the optimal distance between mine workings.

Methods. The study starts with a geo-mechanical classification of the rock mass using widely recognized methods: Rock Quality Designation (RQD), Rock Mass Rating (RMR), Q-Barton, Geological Strength Index (GSI), and Rock Mass Index (RMI). Fracturing surveys were then carried out to identify the primary fracture families using DIPS software. Finally, PHASE 2 software was employed to determine the optimal distance between galleries.

Findings. This study presents a comprehensive geological and geomechanical analysis of the Ighrem Aousser (I/A) mine, including field observations, core drilling, and structural analysis using DIPS software. The rock mass was found to be highly fractured and altered, particularly within the mineralized zones. Laboratory tests show a UCS of 58.79 MPa for flysh, and RQD values are 66.2 for flysh and 48.5 for mineralized zones. The RMR ranges from 28 to 45, and Barton's Q-values vary from 0.8 to 3.7, indicating poor to fair rock quality. Numerical modeling suggests an optimal distance of 16 to 17 meters between vein drifts and main mine workings for improved stability and safety as the mine deepens.

Originality. This study offers a comprehensive classification and structural analysis of the downstream I/A rock mass to propose the optimal distance between the vein drifts (GF) and the main mine workings (VM). This integrated approach not only enhances the understanding of rock mass behavior but also ensures improved safety, stability, and productivity in mining operations, establishing a new benchmark for sustainable mining development.

Practical implications. In the mining industry, classifying rock masses, designing excavation supports, and determining the optimal distance between galleries improve safety, boost site productivity by reducing contamination, and lower mining costs.

Keywords: *empirical classifications, rock mass, fracturing, support, DIPS, UNWEDGE, PHASE 2*

1. Introduction

The Compagnie Minière de Touissit (CMT) is a Moroccan company that exploits deposits located in the polymetallic district of Jbel Aouam, in central Morocco. This district is particularly known for its lead, zinc and silver vein mineralization, but there is currently a growing interest in other types of mineralization, including gold in the skarns developed around some granitic intrusions in the district.

The Signal vein was the first discovered in this region, marking the beginning of the exploitation of other veins such as Ighrem Aousser, Sidi Ahmed and Iguer Oujna.

Currently, Ighrem Aousser is the most active production center and is home to the deepest mine in Tighza and North Africa. To optimize operations, a re-engineering of the mining infrastructure was undertaken, including a project to centralize extraction by a single 1100-metre shaft, supervised by the Canadian group CMAC. This reengineering also takes into account the increased degradation of the hanging wall with depth.

Production activities at the Ighrem Aousser mining site are currently taking place at the 14^{th} level (700 m deep), while development work is underway at the 15^{th} level (750 m deep). The exploitation of this vein-type deposit at such depths presents increasing ground stability issues, including block falls, progressive narrowing of gallery walls along the vein and access routes, as well as collapses. These instabilities significantly complicate operations in terms of personnel safety and worksite productivity, ultimately leading to higher technical production costs. As the mine deepens further to reach 1100 meters, these stability problems are worsening, intensifying both technical and safety-related challenges.

The exploitation of mineral deposits faces many challenges, particularly with regard to the stability of the land. Several researchers, such as S. Wang, CY Li and C. Didier, have highlighted stability problems at mine faces, emphasizing the risks associated with these complex environments [1]-[3]. These stability issues pose a significant threat to the safety of personnel working on the site. Indeed, B. Altindis, SN Ismail

Received: 8 January 2025. Accepted: 17 April 2025. Available online: 30 June 2025

Mining of Mineral Deposits. ISSN 2415-3443 (Online) | ISSN 2415-3435 (Print)

and B. Jiang, in their work, particularly insisted on the importance of ensuring the safety of workers in mines, stressing that unstable conditions can lead to serious accidents [4]-[6].

In addition to safety issues, ground stability also affects the productivity of mining sites, which has the direct consequence of increasing operating costs. That is why a proactive and methodical approach is needed to minimize these risks and optimize the performance of the operating sites.

In this context, our study will focus on determining the optimal distance to be maintained between the vein drifts (GF) and the main mine workings (VM). This analysis will result from an in-depth study of the characterization of the rock mass [7]-[9], an essential aspect to assess the geotechnical quality of the terrain [10], [11]. The aim is to simultaneously improve productivity and safety at the operating site. This approach will involve a detailed study of the rock matrix [12], and its discontinuities [13]-[15], taking into account the factors influencing the mechanical stability of the mass.

To do this, a precise modelling of the rock mass will be implemented [16], [17], in order to simulate the real conditions and determine the ideal distance to be observed between the GF and VM galleries. This optimal distance is of paramount importance, as it guarantees not only the stability of the mining structures, but also that of the deposit as a whole. By optimizing this spacing, we can both improve worker safety and maximize sites yields, while reducing the risk of rock destabilization.

2. Study area

2.1. Geographical setting

The mining center of Tighza is located in the Beni Mellal-Khenifra region, in the province of Khenifra, commune of Elhammam-M'rirt. It is located 100 km south of the city of Meknes, and 7 km north-west of the city of M'rirt, as shown in Figure 1. The majority of the inhabitants of Tighza are miners, former miners or sons and widows of miners. Indeed, the subsoil of Tighza contains mineral wealth exploited by the Compagnie Minière de Touissit (CMT). Aouam, Ighram Aoussar, Sidi Ahmed are the main mining deposits in the region. 500 people work there. Lead, zinc, copper, silver and, more recently, gold are mined here. Agriculture, livestock and trade occupy the rest of the inhabitants of Tighza [18].

Figure 1. Geographical location of the Tighza mining district [18]

2.2. Geological setting

From a stratigraphic point of view, the Tighza domain encompasses Paleozoic terrains from the Ordovician to the Carboniferous, with allochthonous and autochthonous terrains [19].

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. The deposits attributed to the allochthonous or autochthonous Upper Ordovician are essentially detrital in character, containing a schist series at the base and alternating sandstones and pelites, as well as at the top of the Ordovician, there are bars of quartzite. The Ordovician of the M'rirt region is predominantly clayey or clayey-sandstone with a rhythmic character.

The Silurian is a lithological succession with a fine detrital character. It rests directly on the upper quartzite. It consists of sandstone pelites with a greyish to blackish hue. Silurian schists are rich in organic matter, which facilitates fossiliferous dating. These facies are known in the region of Jbel Aouam under the name of Mokattam schists or cloisonné schists.

Devonian deposits consists of argillites indicating calm sedimentation. The nodules and limestones that enrich the Devonian indicate that the deposition occurred on the outer platform. The sedimentary series of the Devonian is composed of silty argillites intercalated with fine limestones bearing numerous indications of synsedimentary tectonics that indicate bedrock instability.

The sandstone-conglomerate series of the Tournaisian occur unconformably on the previous terrains and are topped by marine platform deposits, formed mainly by bioclastic limestones, sandstone limestones and marls of Middle Target Age. The flysh character series follows these platform deposits.

3. Methods

3.1. Geotechnical study of the Ighrem Aousser rock mass

3.1.1. Identification of rocks

After analyzing the core holes, the facies in question is a flysh with alternating sandstone and shale with a predominance of sandstone banks compared to the schist levels, is the Pb-Ag mineralization.

3.1.2. Empirical classifications of the rock mass

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

3.1.3. Classification de DEERE (Rock Quality Designation)

The Rock Quality Designation (RQD) was developed by Deere et al. (1967) to provide a quantitative estimate of fracturing influencing rock mass behaviour based on the examination of drill cores. RQD is defined as the percentage of intact pieces greater than 10 cm in length over the total length of the borehole [20], [21]. Based on the core drilling analysis, and based on the DEERE classification, the rock mass is classified as good (Table 1).

Table 1. DEERE classification

Rock	RQD	Classification de DEERE
Sandstone	83.6	Good
Flysh	66.2	Average
Mineralization	48.5	Mediocre

3.1.4. Classification de Bieniawski. RMR (Rock Mass Rating)

The Bieniawski classification or CMA is the sum of five scores representing the quantification of five parameters characterizing the rock (simple compressive strength; RQD; discontinuity family spacing; discontinuity roughness and weathering, presence of water; drift orientation relative to critical discontinuity family orientation). The sum of the five notes is adjusted by a note relating to the direction of the deepening in relation to the direction of the dip of the discontinuities. Bieniawski, by this classification, proposes the possible excavation method and the most suitable type of support [22], [23].

According to this classification, the I/A mass is classified as average to good (Table 2), and the adequate support is summarized in Table 3.

3.1.5. Barton classification

Barton's method is an empirical classification of rock masses. The principle of this classification consists of noting the quality of the rock mass through 84 parameters. It is characterized by a Q quality index varying between 0.001 for a very bad mass and 1000 for a very good mass. In practice, this index decreases within 0.005 and 50 [24], [25].

Using this classification, we were able to classify the rock mass from medium to very poor for the flysh (Table 4).

Table 2. RMR result for each facies

Rock	RMR	Class	Bieniawski's classification
Sandstone	62	2	Good
Flysh	53	3	Average
Mineralization	47	3	Average

Table 3. Supports for each facies by RMR

Rock	Support
Sandstone	Given the good resistance of the sandstones, we will opt for bolts spaced 1.5 to 2.0 meters apart and accompanied by a welded mesh or a wire mesh
Flysh	Flysh has an average hold, for this reason we will use bolts spaced from 1.0 to 1.5 meters apart and accompanied by a welded mesh or a wire mesh. In addition, we will install light hangers spaced 0.7 to 1.5 meters apart
Mineralization	Mineralization has a medium hold, for this reason we will use bolts spaced from 1.0 to 1.5 meters apart and accompanied by a welded mesh or a wire mesh. In addition, we will install light hangers spaced 0.7 to 1.5 meters apart

Table 4. Supports for each facies according to Q-Barton

Rock	Q	Classification de Barton	From	Support
Sandstone	3.7	Average	1.87	Barton considered sandstone to be stable, so it was sufficient to adopt light support according to the areas of instability
Flysh	0.98	Poor	1.87	Systematic bolting Lb = 2.20 m / Es = 1 m
Mineralization	0.8	Poor	1	Systematic bolting Lb = 2.20 m / Es = 1m

3.1.6. Hoek and Brown GSI classification

Introduced by Hoek (1995) and Hoek, Kaiser and Bawden (1995), the GSI is a dimensionless, empirically determined number, and their estimation is based on a direct observation of the rock mass structure from an examination of the rock mass quality in situ. This index varies between 5 and 85, by definition, values close to 5 correspond to very poor quality materials, while values close to 85 describe very good quality materials [26]. The modified GSI proposed by Sonmez and Ulusay (1999) [27], is an improvement of the GSI considered too approximate.

The calculation of GSI and modified GSI for the I/A rock mass made it possible to classify the different facies (Table 5).

Table 5. GSI Classification and modified GSI

Rock	GSI	Modified GSI	Classification
Sandstone	70	62	Good
Flysh	57	56	Good
Mineralization	30	24	Poor

3.1.7. Rock Mass Index (RMI)

The Rock Mass Index (RMI) is a system for classifying rock masses developed to meet the need to characterize the strength of rock masses, a requirement emphasized by several researchers such as Hoek and Brown (1980), Bieniawski (1984) and Nieto (1983). Unlike building materials commonly used in civil engineering, which are mainly characterized by their strength properties, rock masses did not benefit from such a specific characterization of their strength. Developed between 1986 and 1995, the RMi system is designed to use input parameters that have major significance in the behavior of rock masses [28].

According to this classification, the I/A mass is classified from very high to extremely high (Table 6).

Table 6. RMI result for each facies

Rock	RMI	Classification RMI
Sandstone	107.18	Extremely high
Flysh	61.70	Very high
Mineralization	30.47	Very high

4. Results and discussion

4.1. Study of the fracturing between the 15th level and the 20th level

As part of this study, we carried out a survey of the fractures and discontinuities present in the levels: the 15th, the 16th and the 20th level at the level of the cross bands (TB) – a horizontal gallery connecting the shaft and the mineralized vein – since these are the only structures excavated to date. Figure 2 shows the areas surveyed.

This figure illustrates the various mine workings carried out as part of the Ighrem Aousser new shaft project. Three access points are shown in orange, located around the shaft at the 15th, 16th, and 20th levels, corresponding to altitudes of 750, 800 and 1000 m, respectively. The drifts connecting the shaft to the mineralized vein at each level are marked in green. The vein was intersected at the 16th and 20th levels, at horizontal distances of 128 and 172 m, respectively.

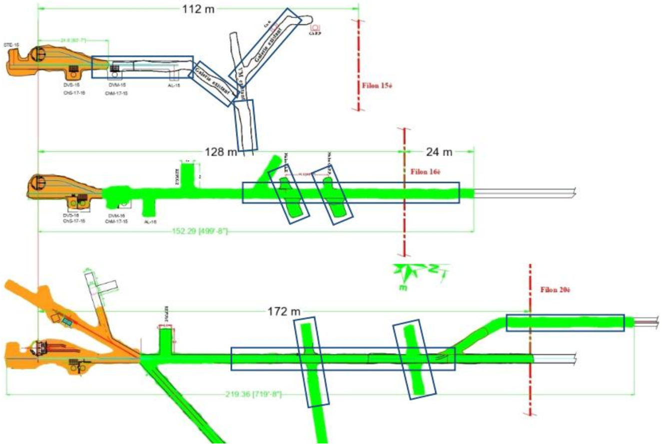

Figure 2. Map of the location of the raised galleries

4.1.1. Survey processing tool

To identify the main fracture families in each orebody, we used the DIPS software (Rocscience, 2006). DIPS is a software specifically designed for the interactive analysis of orientation-based structural geological data, using advanced graphical tools. It focuses on the analysis of fracturing data via stereographic projection, integrating statistical tools for qualitative and quantitative analysis, as well as for the calculation of fracture family characteristics.

4.1.2. Study of fracturing

In this study, we conduct fracture surveys on three downstream mine levels that are in active condition (15th, 16th and 20th levels) to process them using Dips software to characterize fracture families (Fig. 3). The main areas of concentration for the three levels are grouped into families in Table 7.

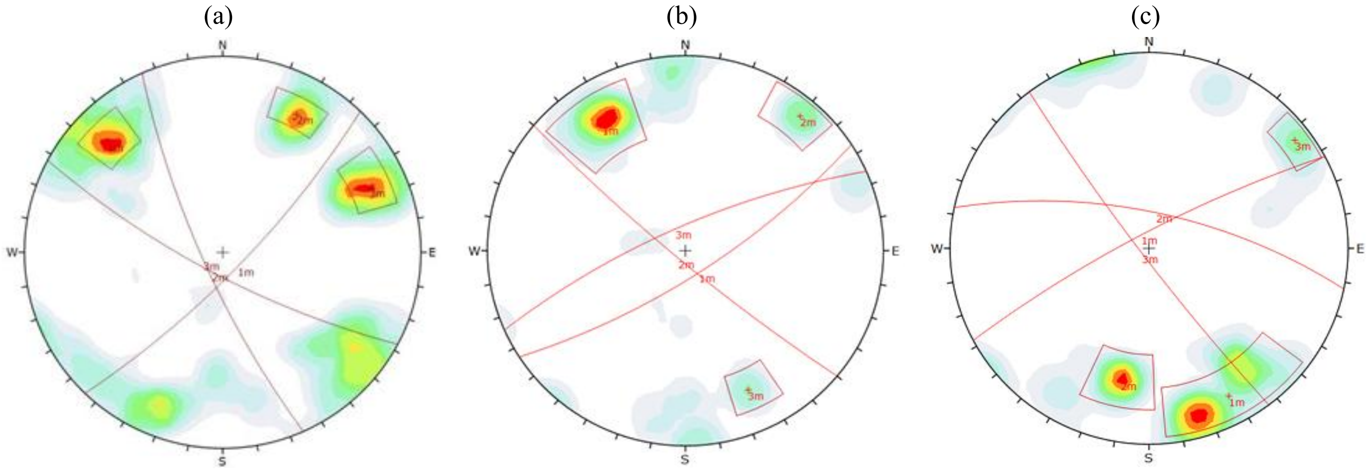

Figure 3. Contours of the concentrations of the poles at the TBs of the three levels: (a) 15th level; (b) 16th level; (c) 20th level

Table 7. Families of discontinuities at the TBs of the three levels 15th, 16th and 20th

Areas	Discontinuity ID	Dip	Dip direction	Description
Families of discontinuities at the TB of the 15th level	1 m	75	147	Main family
	2 m	84	220	Main family
	3 m	76	336	Main family
Families of discontinuities at the TB of the 16th level	1 m	78	134	Main family
	2 m	77	208	Main family
	3 m	78	246	Main family
Families of discontinuities at the TB of the 20th level	1 m	81	332	Main family
	2 m	69	12	Main family
	3 m	85	233	Main family

The objective of the fracturing surveys carried out at three different levels (15th, 16th and 20th levels) is twofold: on the one hand, it is a question of identifying the different families of fractures present in the rock mass, and on the other hand, it is about verifying the continuity of these fractures at different depths. The results obtained showed that each area studied contains three distinct families of fractures, whose dip varies between 69° and 85°. These fractures extend continuously at depth, thus confirming their persistence and structure within the rock mass.

4.2. Simulation of the interaction between GFs and VMs

The aim of this study is to find the minimum, or even optimal, distance between the VM and the GF to ensure the stability of the ground. To find this distance, we will work with the PHASE2 software. Before starting the study, it should be mentioned that this distance plays a very important role in ensuring the stability of the environment that contains the chimneys (backfill, jet, personnel).

The study consists of two phases:

– the study of the behaviour of the ground after digging;

– the process of finding this minimum distance.

The input data include the average values from established mechanical tests, the passivity factor of the ground, which is $K = 0.2$, the data of the embankment and the depth which is of the order of 800 m.

The termination criteria adopted are set out in Table 8.

4.2.1. For the main routes

Figure 4 represents the force factor distribution around the walls of the main track, and Figure 5 represents the deformations and displacements around the VM with the main deformation of the opening from the simulation by the Plaxis software.

Table 8. Breakup criteria

Mineralization	Sterile	Mechanical backfill
Generalized Hoek Brown	Generalized Hoek Brown	Mohr-Coulomb

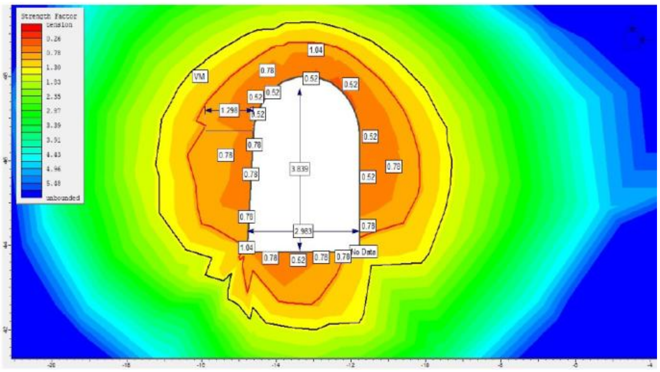

Figure 4. The distribution of the force factor around the VM

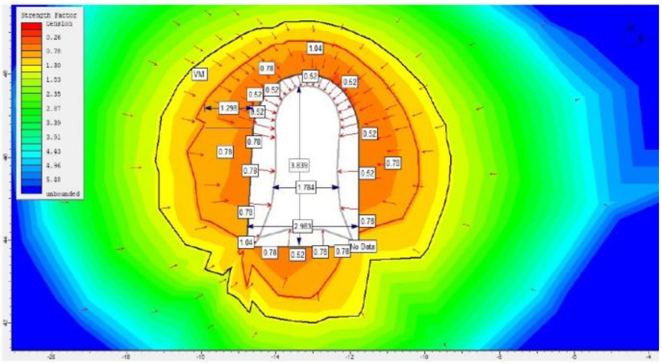

Figure 5. Movements around the VM

The SFR behaves as an alternative to FS (safety factor), for the structure to be stable, the SFR should be in the range of 1 and 1.5; the red and black outlines present the areas limited by the SFR < 1.5 condition, respectively.

For VMs, the SFR is mediocre for a hanging wall and crown, with deformations and displacements converging towards the size limitation, which justifies the existence of serious problems such as uplift of the environment and convergence of the facings, which requires the installation of adequate support and, as soon as possible, the restriction of ground movement.

4.2.2. For the vein galleries

Figure 6 represents the force factor distribution around the walls of the main track, Figure 7 represents the deformations and displacements around the VM with the main deformation of the opening and Figure 8 represents the distribution of the SFRs of a 50 m Panel with a hollowed slice from the simulation by the Plaxis software.

The safety factor is very low (0.52 and 0.78) around the excavation, which justifies the instability around the excavation, especially on the roof, which requires the installation of adequate support as soon as possible to limit the movement of the ground. We also note the concentration of stresses and the maximum displacements, as well as the low safety coefficients around the backfilled units due to the geomechanical parameters of the backfill, which can create significant movements over time, and this has a very important role in the creation of bells.

Around the VM and GF excavations, the zone that exceeds the elastic part (SFR < 1) converges towards the plastic state. This zone is located within a radius of 1.28 m from the facings, the modelling of the exploited panel (in the case of Torpedoing or in the process of operation) shows that the panel remains unstable on the boundaries of the trenches, the head and base GF tracks.

4.2.3. The simulation of the panel operated by the Plaxis software

The simulations of the panel operated by the backfilled rising slice method are carried out by taking into account the alternation of the facies (the location of the phases resulting from the observations made during the establishment of the structural lift).

– the distances between the chimneys in the I/A site is 7 m;

– dm = 7 + 7 + 7 + 3 = 24 m is the distance at 45° in the I/A site, so the perpendicular distance is of the order of 17 m, but we have to check the stability.

It is noticeable that at this distance (16.642 m) and the radius area of 3.371 m from the facing, the safety factor or SFR seems acceptable of the order of 2. For the unit in operation, the decompressed height is estimated at 0.895 m (Fig. 9).

4.3. Supporting of mining structures (UNWEDGE software)

UNWEDGE is a software developed by Rocscience that aims to study the stability of the facings of an excavation based on the block fracturing. Designed to be a fast, interactive and simple tool, it allows the analysis of the geometry of the blocks (delimited by 3 planes of discontinuities) surrounding an underground excavation and allows us to assess their behavior [29].

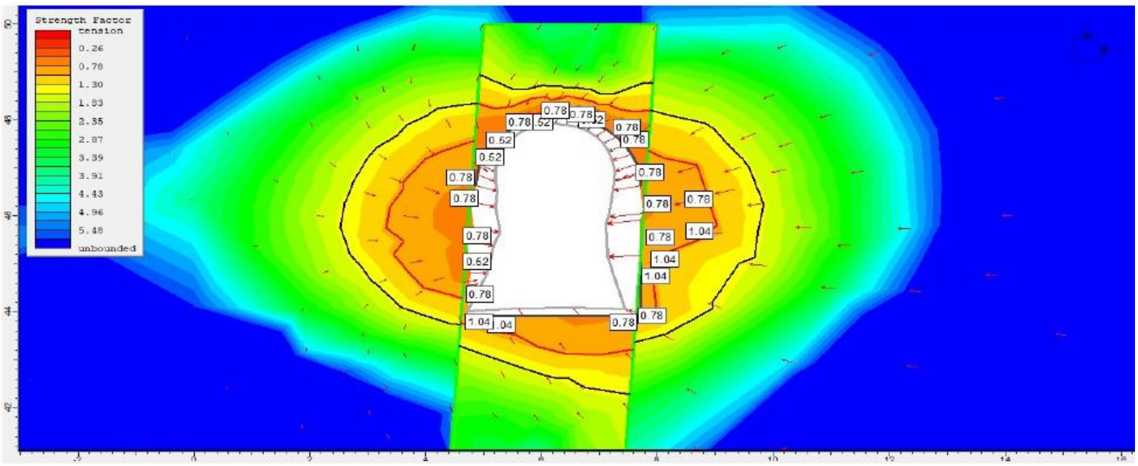

Figure 6. The distribution of the force factor around the GF

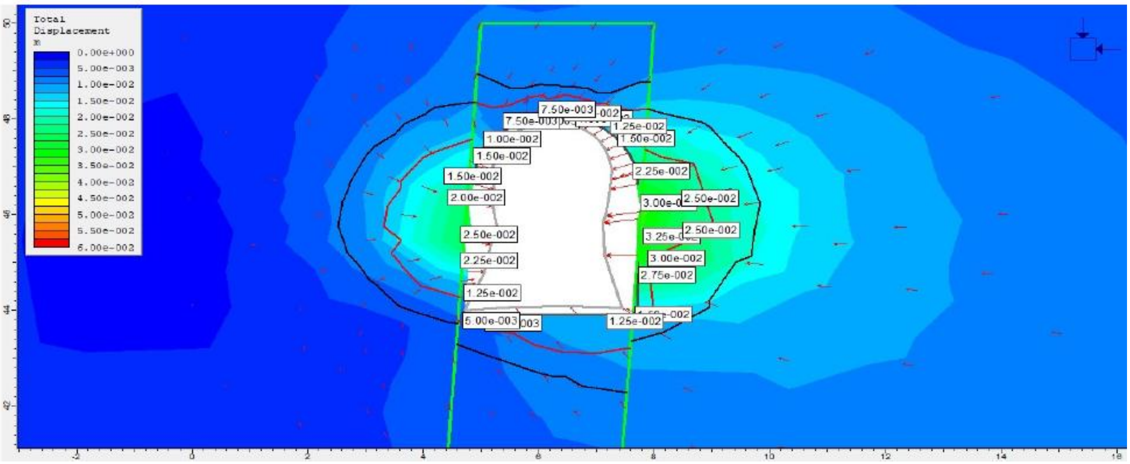

Figure 7. Movements around the GF

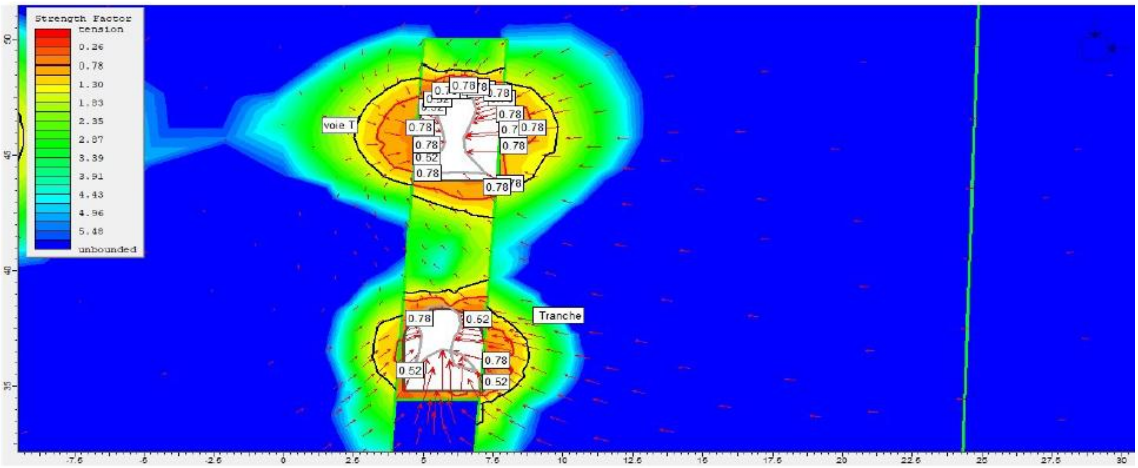

Figure 8. The distribution of the SFRs of a 50 m panel with a hollowed edge

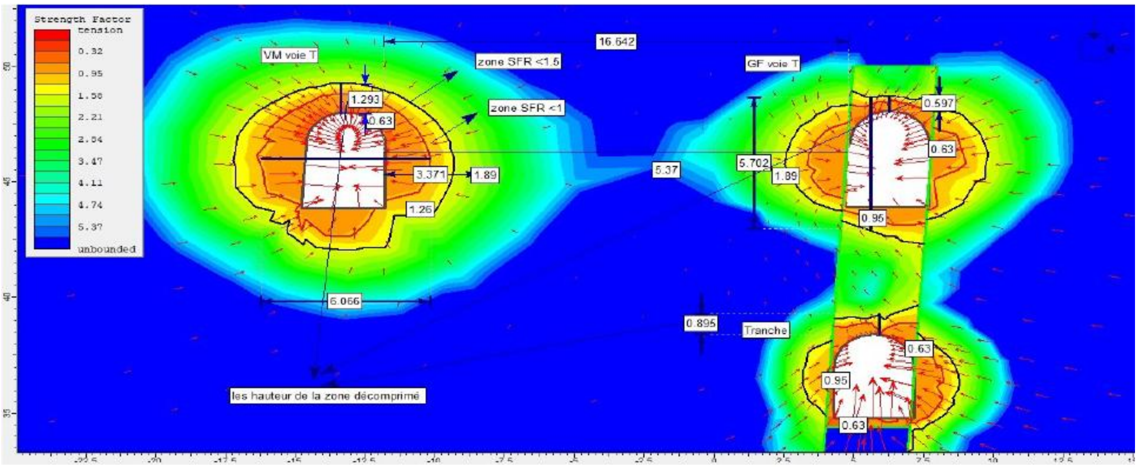

Figure 9. The solution found with the determination of the decompressed zone heights (optimal distance 16.642 m)

UNWEDGE also makes it possible to set up, or rather to size, a retaining system either by bolting or by shotcrete, and even to combine several types of supports, with the possibility to determine their characteristics.

After having processed all the galleries on the UNWEDGE software, we will represent the results obtained by determining the blocks likely to fall, then we will put a bolting on them to determine the behavior of the ground. After estimating the height of the decompressed zone, it is now possible to calculate the load applied to the supports placed in the section.

The results of the support are grouped in Table 9 for the vein drifts and in Table 10 for the main mine workings.

4.4. Simulation of the interaction between the GFs and the VMs after insertion of the supports

After the design of the gallery supports (split set bolts), it is necessary to study the interaction between the main mine workings and the vein galleries after the bolts have been inserted. Figure 10 shows the location of bolts in vein drifts, Figure 11 shows the interaction between the main tracks and vein drifts after bolt insertion while taking into account the optimal distance.

Table 9. Characteristics of bolts in vein drifts

Bolt No.	Length, m	Spacing, m	Orientation
1	2	1	Normal to the opening section
2	2	1	Normal to the opening section
3	1.5	1	Normal to the opening section
4	1.5	1	Normal to the opening section

Table 10. Main track bolt characteristics

Bolt No.	Length, m	Spacing, m	Orientation
1	2.5	1	Normal to the opening section
2	1.5	1	Normal to the opening section
3	1.5	1	Normal to the opening section

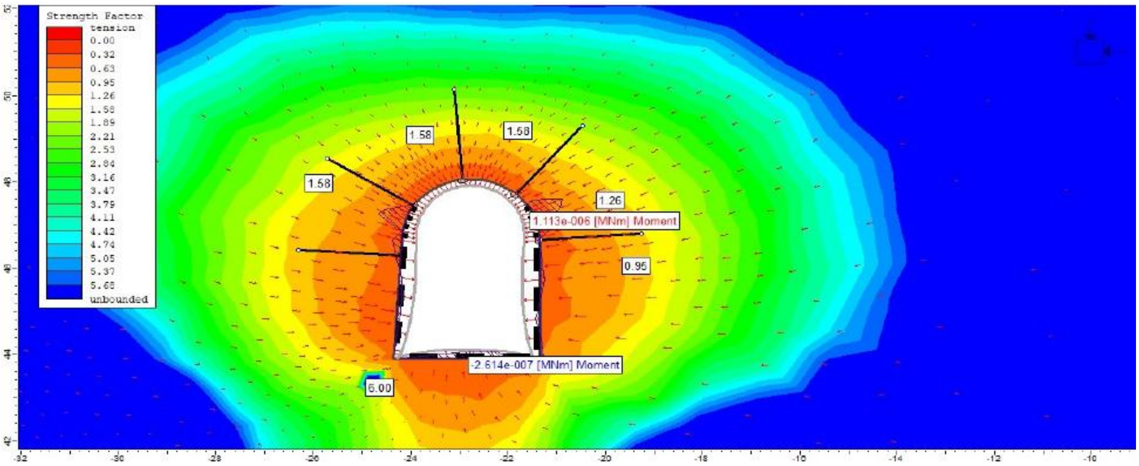

Figure 10. Bolt layout around the vein drifts

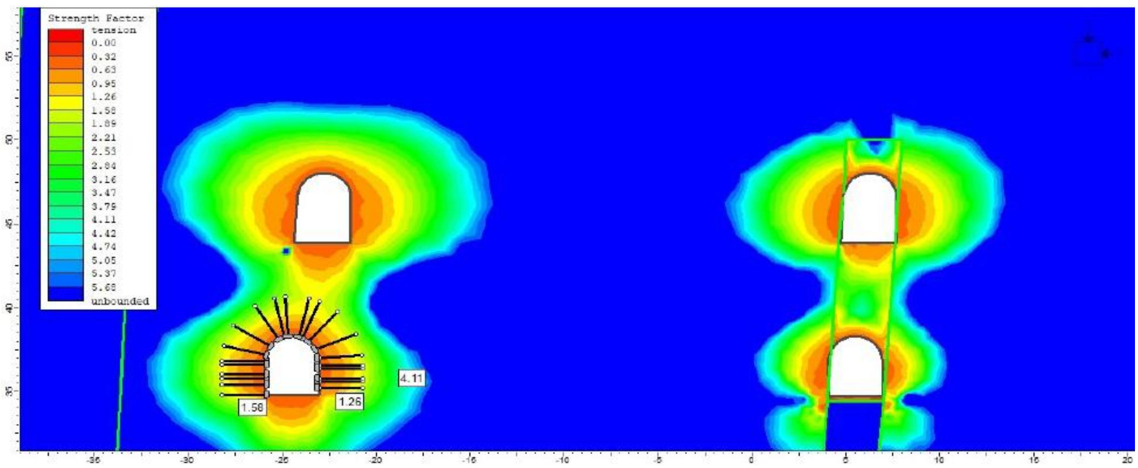

Figure 11. Effect of the optimal distance to the bolt insertion

Despite the remarkable increase in the safety factor after the bolting location (FS > 2), and taking into account the optimal distance (16.642 m), some blocks are still susceptible to falling (FS < 1.5) which implies the need for additional support such as wire mesh.

5. Conclusions

In order to determine the optimal distance between the mine working structures and to know their mutual interactions, we started our study with a characterization of the downstream rock mass surrounding the Ighrem Aousser mine, composed mainly of sandstone and flysh. This study began with the application of various geotechnical classifications such as the Borehole Quality Index (RQD), the Rock Mass Rating (RMR) classification system, the Q-Barton method and the GSI (Geological Strength Index) geological system. These classifications were combined with the results of the mechanical tests carried out in the laboratory of the Mohammadia School of Engineering, thus allowing an in-depth evaluation of the mechanical properties of the rock mass.

In a second phase, a structural study of the mass was carried out. This study involved a detailed survey of the majority of the fractures observable, specifically at the 15th, 16th and 20th levels of the mine. Thanks to the use of the Dips software, these fractures were analyzed and grouped into different families of fractures. The objective was to identify areas that are particularly vulnerable to instability, which could pose risks to the stability of the mass.

Based on the results of the empirical classifications and the analysis of fracturing, several support proposals have been developed to ensure the stability of the rock mass. These support solutions will then be dimensioned and validated using the UNWEDGE software, to ensure their effectiveness and compliance with the safety standards required for mining.

Finally, several simulations were carried out using the PHASE2 software, integrating the data obtained during previous studies. These simulations made it possible to determine the optimal distance to be maintained between the GF and VM mine structures. This distance plays a crucial role in ensuring not only the stability of the mining workings themselves, but also the overall stability of the deposit.

The objective was to establish a configuration that would guarantee safe working conditions for personnel, while reducing the risk of instability in the rock mass. In addition, this parameter helps to improve the quality of mine production by minimizing the bypass ratio. The latter, if it is too high, can hinder the extraction of the ore, thus reducing yields and increasing costs. Thanks to these simulations, it became possible to optimize the design of the mine working structures, ensuring that they were both safe and efficient, while promoting the exploitation of the deposit in the best possible conditions.

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 in Rabat.

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.

References

[1] Wang, S., Li, X.L., & Qin, Q.Z. (2022). Study on the control of the surrounding rocks and the stability of the support of a very high mine face. *Energies*, *15*(18), 6811. https://doi.org/10.3390/en15186811

[2] Li, C.Y., Hou, S.K., Liu, Y.R., Qin, P.X., Jin, F., & Yang, Q. (2020). Surrounding rock crown convergence deformation analysis for the TBM double shield tunnel based on advanced borehole monitoring and inversion analysis. *Tunnelling and Underground Space Technology*, *103*, 103513. https://doi.org/10.1016/j.tust.2020.103513

[3] Didier, C. (n.d.). *Feedback analysis of two mine collapses in coal mines: The case of the Coalbrook mines (South Africa) and the Gardanne mines (France)*.

[4] Altindis, B. (2023). *Investigation of industrial accidents in the Amasra coal company*. Master's Thesis. Afyonkarahisar, Turkey: Afyon Kocatepe University.

[5] Ismail, S.N., Ramli, A., & Aziz, H.A. (2021). Research trends in the study of mining accidents: A systematic review of the literature. *Safety Science*, *143*, 105402. https://doi.org/10.1016/j.ssci.2021.105402

[6] Ismail, S.N., Ramli, A., & Aziz, H.A. (2007). Mining safety data mining. *Proceedings of the 2007 International Conference on Data Mining*, 678-682.

[7] Hemaidia, A.E.W. (2023). *Stability analysis and characterization of a rock mass-case of the Ain Mimoun mine*.

[8] Aidjouli, T.O., & Horri, A.A.H.E. (2020). *Qualitative and quantitative characterization of discontinuities in rock massifs*.

[9] He, M.M., Li, N., Zhang, Z.Q., Yao, X.C., Chen, Y.S., & Zhu, C.H. (2019). An empirical method for determining the mechanical properties of articulated rock masses using drilling energy. *International Journal of Rock Mechanics and Mining Sciences*, *116*, 27-37. https://doi.org/10.1016/j.ijrmms.2019.02.002

[10] Yuan, H.P., Chen, C.H., Wang, Y.X., Bian, H.B., & Liu, Y. (2020). Joint survey and 3D visual assessment of the quality of the rock mass. *Advances in Civil Engineering*, 8834567. https://doi.org/10.1155/2020/8834567

[11] Hasan, M., Shang, Y.J., Shao, P., Yi, X.T., & Meng, H. (2022). Evaluation of the quality of technical rock masses by integrating the geophysical and mechanical parameters of the rocks. *Rock Mechanics and Rock Engineering*, *55*(4), 2183-2203. https://doi.org/10.1007/s00603-021-02766-8

[12] Castro, L.A.M. (2023). Determination of the strength of rock masses from ruptures in tunnels and boreholes. *Proceedings of the 2023 International Conference on Rock Mechanics*, 112-118.

[13] Niu, Y., & Chen, Z. (2024). Evolution of cracking and fracture mechanism of brittle rocks containing pre-existing defects under dominant compressive stresses: Contribution of the numerical approach. *Theoretical and Applied Fracture Mechanics*, *134*, 104719. https://doi.org/10.1016/j.tafmec.2024.104719

[14] Xiong, T., Liu, X., Zhou, X., Lin, G., Liu, D., Han, Y., Xu, B., He, C., & Wang, Z. (2022). Deep excavation-induced fractures of hard rock: Methodology and applications. *Journal of Rock Mechanics and Geotechnical Engineering*, *14*(2), 460-476. https://doi.org/10.1016/j.jrmge.2021.09.008

[15] Jin, C.Y., Liang, J.Y., Cui, J.X., & Wang, Q. (2023). Development of a method for classifying rock masses based on a precise description of the joints. *Applied Earth Science*, *82*(21), 567-578. https://doi.org/10.1080/03717453.2023.1894567

[16] Nothnagel, R. (2003). *Modelling of instabilities in rock mechanics: Application to the operation of the Drouville concession*. Doctoral Dissertation. Paris, France: Mines Paris, 255 p.

[17] Durham, V. (2023). *Contribution to structural stability analyses of underground mine excavations of complex geometries by DFN modeling*. Doctoral Dissertation. Quebec, Canada: Université Laval.

[18] Wikipedia contributors. (n.d.). *Wikipedia, the free encyclopedia*. Retrieved from: https://fr.wikipedia.org/wiki/Tighza

[19] Errahmi, M., & Toubri, Y. (2014). *Structural study of the Sidi Ahmed sector*.

[20] Deere, D.U., & Deere, D.W. (1988). The rock quality designation (RQD) index in practice. *Rock Classification Systems for Engineering Purposes*, *984*, 91-101. https://doi.org/10.1520/STP48465S

[21] Su, R., Zhao, Q.H., Zheng, T., Han, G., Jiang, J.F., & Hu, J.B. (2023). A framework for calculating the RQD based on deep learning. *Mining, Metallurgy & Exploration*, *40*(5), 1567-1581. https://doi.org/10.1007/s42461-023-00611-9

[22] Bieniawski, Z.T. (1984). *Rock mechanics design in mining and tunnelling*. London, United Kingdom: CRC Press.

[23] Bieniawski, Z.T. (1993). Classification of rock masses for engineering: The RMR system and future trends. *Comprehensive Rock Engineering: Principles, Practice, and Projects*, 553-573. https://doi.org/10.1016/B978-0-08-042066-0.50028-8

[24] Barton, N., Lien, R., & Lunde, J. (1974). Engineering classification of rock masses for the design of tunnel support. *Rock Mechanics*, *6*(4), 189-236. https://doi.org/10.1007/BF01239496

[25] Barton, N. (2002). Some new Q-value correlations to assist with site characterisation and tunnel design. *International Journal of Rock Mechanics and Mining Sciences*, *39*(2), 185-216. https://doi.org/10.1016/S1365-1609(02)00011-4

[26] Hoek, E., Kaiser, P.K., & Bawden, W.F. (1995). *Support of underground excavations in hard rock*. London, United Kingdom: CRC Press.

[27] Sonmez, H., & Ulusay, R. (1999). Modification to the geological strength index (GSI) and their applicability to stability of slopes. *International Journal of Rock Mechanics and Mining Sciences*, *36*(6), 743-760. https://doi.org/10.1016/S0148-9062(99)00043-1

[28] Rockmass.net. (n.d.). *Introduction to the RMI system*. Retrieved from: https://rockmass.net/files/intro_rmi_system.pdf

[29] Khalid, H., & Abdelaziz, L. (2024). Geo-mechanical classification of the Ighrem Aousser rock mass mining site of the Touissit Mining Company. *Mining of Mineral Deposits*, *18*(2), 132-139. https://doi.org/10.33271/mining18.02.132

Геомеханічна класифікація нижньої частини родовища Іґрем Ауссер з визначенням оптимальної відстані між гірничими виробками

Х. Хоссайні, А. Лахмілі

Мета. Розробка геомеханічної класифікації масиву гірських порід за стійкістю і вивчення її тріщинуватості з метою визначення оптимальної відстані між гірничими виробками в умовах рудника Іґрем Ауссер.

Методика. Дослідження складається з геомеханічної класифікації породної маси із використанням широко визнаних методів: оцінки якості гірських порід (RQD); рейтингу маси гірських порід (RMR); Q-Barton; індексу геологічної міцності (GSI) та індексу маси гірських порід (RMI). Були проведені дослідження тріщинуватості для виявлення первинних сімей переломів за допомогою програмного забезпечення DIPS. Для визначення оптимальної відстані між галереями було використано програмне забезпечення PHASE 2.

Результати. Виявлено, що масиви гірських порід сильно тріщинуваті та змінені, особливо в межах мінералізованих зон. Лабораторні дослідження показують, що одноосьова міцність на стиск становить 58.79 МПа для флішу, а значення RQD – 66.2 для флішу і 48.5 для мінералізованих зон. Рейтинг маси гірських порід коливається від 28 до 45, а значення *Q* за Бартоном – від 0.8 до 3.7, що вказує на задовільну якість масиву гірських порід. Чисельним моделюванням встановлено, що оптимальна відстань між жильними штреками та основними гірничими виробками складає від 16 до 17 метрів, що є достатнім для підвищення стабільності та безпеки в умовах поглиблення гірничих робіт.

Наукова новизна. Розроблено комплексну класифікацію та здійснено структурний аналіз нижньої частини породного масиву досліджуваного родовища для встановлення оптимальної відстані між жильними штреками та основними гірничими виробками.

Практична значимість. У гірничодобувній промисловості класифікація гірських порід, проєктування кріплень виїмкових виробок і визначення оптимальної відстані між галереями підвищують безпеку, збільшують продуктивність ділянки за рахунок зменшення показника збіднення та знижують витрати на видобуток корисних копалин.

Ключові слова: *емпіричні класифікації, породний масив, гідророзрив, кріплення, програмне забезпечення DIPS, UNWEDGE та PHASE 2*

Publisher's note

All claims expressed in this manuscript are solely those of the authors and do not necessarily represent those of their affiliated organizations, or those of the publisher, the editors and the reviewers.