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Study of support types for deposits in contact with serpentines: Ait-Ahmane site

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Abstract

Purpose. The purpose of this paper is to study the characteristics of the carbonate serpentines present at the level of the Ait Ahmane site (Bou Azzer Mine, Morocco). Empirical methods are suitable for analyzing their behavior and determining the dimensions of support types.

Methods. The rock mass of different structures mentioned in the study is categorized using empirical methods such RMR, Q-system and AFTES classifications.

Findings. It has been found that the use of the rock mass quality method (Q-system) is extremely effective in mining rock mass, based on simulated statistical results obtained using empirical approaches.

Originality. The equivalent dimensions of the gallery, the stress state in-situ after mining operations, as well as the height of the overburden are all important factors in the gallery stability.

Practical implications. The approach creates a strengthened support structure that is optimal. In addition, this research will be useful as a starting point for geotechnical engineers when designing and planning support systems for tunneling under high in-situ stress conditions for very friable rocks.

Keywords: *empirical methods, serpentine characteristics, carbonate serpentine, underpinning, facies, rock matrix*

1. Introduction

The characterization procedure begins with a structural investigation and a study of the rock mass mechanical behavior. The rock mass regularly experiences stresses, fracturing, discontinuities and weak planes, which deteriorate its mechanical qualities and accelerate its decomposition. None of the existing approaches can guarantee that it will be able to handle all the possible circumstances that a geotechnical engineer may face.

The empirical approach is a widely used approach in the characterization of rock masses, especially during their mining. Thus, several authors have proposed approaches in accordance with mass-specific geotechnical parameters to determine the behavior of rocks based on already field-proven and successful experiments. In this regard, there are several classifications. Each of them has its own characteristics and meets a number of requirements. Due to its simplicity, reliability, and experience, categorization of rock masses has been a popular strategy for over three decades (Goel and Singh 2011). Since Terzaghi and White (1946) developed the initial rock mass classification system, several empirical classifications for distinct geological environments have been proposed.

Thus, there are empirical approaches, such as the Rock Mass Rating (RMR) system [1], which combines the most significant geologic parameters of influence and represents them using one overall complex index of rock mass quality, Rock Mass Iindex (RMi) [2], which reflects the resistance index in relation to the rock mass by combining certain rock mass characteristics. Besides, there is the New Australian Tunneling Method (NATM) [3], also known as the Sprayed Concrete Lining (SCL) tunneling in the United Kingdom, and the Sequential Excavation Method (SEM) in the United States, developed in 1960 and based on an understanding of how rock reacts to tunneling. The Q-system [4] serves as the basis for design and proposals for supporting underground mine workings, and the Geological Strength Index (GSI) [5] is used to assess the strength and the deformation modulus of the rock mass. These are important tools that geotechnical engineers frequently use to assess the properties of rock masses and discontinuities.

However, we have chosen the most widely used approaches, namely: rock mass quality (Q) [4], AFTES classification [6] and rock mass index (RMR) [1], [5] as empirical approaches for the characterization of the serpentine carbonate rock mass at the Ait Ahmane site, located at the extreme east of the BouAzzer mine, Morocco. After the characterization of serpentine rocks, methods of supporting will be proposed to address the instability problems related to mining of this type of rock.

The purpose of this project is to study the characteristics of carbonate serpentines, to determine the fracturing and mechanical characteristics of these rocks in order to better understand their behavior, as well as to determine the dimensions of suitable support types for them.

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1.1. Subsection

Several hypotheses have been put forward to explain the development of the BOUAZZER cobalt mineralization. They generally state that the BOUAZZER cobalt mineralization is a type of hydrothermal vein whose serpentines constitute the cobalt mother rock. Therefore, it is the hydrothermal alteration of these serpentines that allowed the release of Co.

The hydrothermal hypothesis assumes that cobalt is leached from serpentines, while arsenic and gangue elements (SiO_2, Co, Ca) come from a magmatic source.

The genetic model has several stages:

Stage 1. Serpentinization of ultrabasic rocks, accompanied by the concentration of cobalt and arsenic in magnetite or in sulfide-rich levels.

Stage 2. Meteoric alteration of serpentines during the upper PII, which contributes to the concentration of cobalt within the alteration shell (Ambed formation).

Stage 3. Trapping and concentrating with brecciation and recrystallization of sedimentary material in the Late Precambrian and Hercynian tectonic faults.

All structural-geochemical studies confirm the structural control of cobalt mineralization and propose a model for the mixing of hot endogenous fluid, loaded with elements such as As, Mo, Au, reacting during their upwelling with cooler brine-rich exogenous fluids (Ca^{2+}, Na^{+}, SO_4^{2}).

As a result, cobalt arsenide sediments are deposited in old fractures or due to upwelling of magmatic fluid at the level of serpentine contact with PIII lavas or with quartz diorites.

According to the geological study of the Bouazzer mine deposits, all ore bodies at least at one of their extremities are in contact with the serpentine mass. Since mineralization frequently occurs between serpentines and other formations (quartz diorites, Precambrian III Infracambrian volcanic cover or other Precambrian II formations), we believe that most of the Bouazzer Mine contact deposits are dominated by a serpentine mass. We sometimes have to cut out entire galleries in the serpentine. The structure studied at the Ait-Ahman site is shown below. We present below the studied structure of the Ait Ahmane site.

1.2. The Ait Ahmane deposit

The site is part of the Bouazzer El Graara buttonhole, which is mostly Precambrian terrain with an ophiolitic sequence that primarily supports cobalt and chromium mineralization. The Bouazzer buttonhole is of significant importance to mining because of its history, extensive coral mineralization and distinctive geology. It has an Infracambrian layer on top of a Proterozoic-age base. Ait Ahmane is the last site located to the east of the Bou Azzer Mine. In the geological structure of the area, there is a contact of quartz diorites with serpentines, vein-type mineralization occurring in quartz diorites and carbonate serpentines. The ST4 structure of niv-115 (Fig. 1) is the main structure of our study.

1.3. Used support specification

Wooden beam support is very old and has always been appreciated by miners, who can see its work by eye from the gradually formed cracks. The Bou Azzer Mine uses wood as support in its various forms.

In terms of dimensions, the Bou Azzer Mine has circular section wood with a diameter ranging from 8 to 25 cm. It should be noted that wood requires good ventilation; otherwise it tends to rot and thus loses its resistance. This rotting is often accompanied by CO_2 emissions, even CO.

(a) (b)

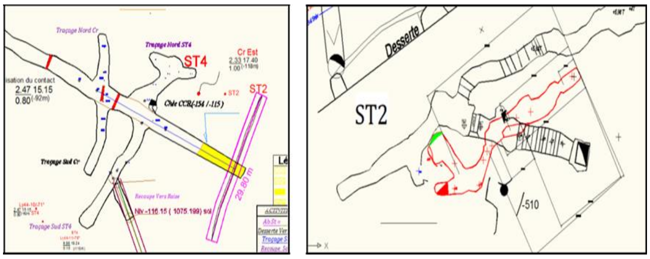

Figure 1. ST4 structure of Ait Ahmane: (a) north and south tracing of the structure; (b) project of the structure development

Push beams are wooden beams that are placed between two faces to ensure stability. When pruning, pushers are placed between the faces in areas with small openings to slow down the convergence of the earth, preventing the pruning from closing up, and/or preventing blocks from falling into the mine workings. Only openings of 1.70 m are suitable for the use of pushers. Figure 2 shows this form of support.

(a) (b)

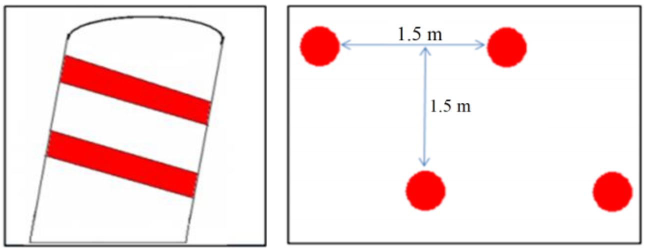

Figure 2. Support by wooden Beams: (a) cross section of size ST4 N-115; (b) longitudinal section

For larger openings, a bolt-on, or more precisely, a split-set bolt is used. This is a friction bolt, consisting of a high-strength steel tube, split along the length of the generatrix. This type of support is installed according to the dimensions shown in Figure 3 [7].

The split-set bolt is sensitive to borehole diameter, so it loses most of its capacity in the case of over-drilling.

(a) (b)

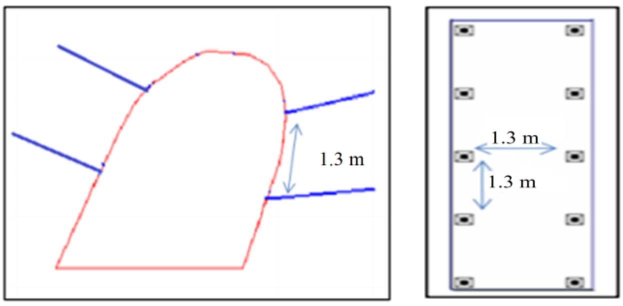

Figure 3. Support by split set bolt: (a) cross section of size ST4 N-115; (b) longitudinal section

In this way, extraction and support systems are assessed using all empirical design approaches of the study. Using in-situ conditions unique to Ait Ahmane for each empirical design approach, the selected extraction and support system are then modeled using the finite element method.

The optimal approach for mining the gallery is selected based on the specific peculiarities and design methodology of the site that creates the most controlled deformations in contrast to other alternatives.

2. Methods

The purpose of this project is to propose a suitable support method using a set of design and analysis methods to solve the instability problems that occur in carbonate serpentine. Serpentine instability can be exacerbated or controlled by parameters other than its mechanical characteristics. Thus, three empirical methods have been developed, resulting in different support solutions.

2.1. AFTES classification method

The Association Française des Travaux en Souterrain (AFTES) [6] was created in January 1972 in response to the recommendations of the International Conference on Underground Works held in Washington in 1970. This Conference called for the creation in each country of an organization bringing together various actors involved in underground mining.

Instead of giving mass a general "score" that determines the conditions for excavating a structure, AFTES prefers to clearly specify the different factors required to design an underground structure in a rock mass, namely:
– the state of the rock mass weathering;
– hydrogeological conditions;
– the rock mass discontinuities;
– the terrain mechanical characteristics;
– natural constraints and the structure coverage height;
– the rock mass deformability.

2.2. The Q-system method

The Tunnelling Quality Index (NGI rock mass classification), or Q [8], was introduced by Barton, Lien and Lunde in 1974. Based on the analysis of a large number of underground mine workings, this index allows the surface quality of discontinuities to be reported in order to infer the rock mass mechanical behavior. The numerical values of the Q index change in logarithmic order from 0.001 to 1000 according to the following Formula:

$$Q = \frac{RQD}{Jn} \cdot \frac{Jr}{Ja} \cdot \frac{Jw}{SRF}, \tag{1}$$

where:
RQD – is Deere's rock quality designation;
Jn – a number characterizing the set of joint families;
Ja – characterizes the weathering of joints;
Jr – characterizes the roughness of the joints;
SRF – the stress reduction factor;
Jw – the hydraulic seal reduction factor.

2.3. Rock mass index method RMR

Bieniawski [9] published in 1976 the details of a rock mass classification called the Geomechanics Classification or Rock Mass Rating (RMR) system. Some changes have been made compared to the original version. Today, several variants of the Bieniawski classification are available. The 1976 and 1989 versions are the most commonly used.

The Bieniawski classification provides for the evaluation of different parameters, each of which is assigned a numerical coefficient. The sum of these coefficients determines the RMR value, which can range from 0 to 100. The following six parameters are required to evaluate the rock mass compressive strength using the RMR system:
– the uniaxial compressive strength of the rock;
– the RQD value for the rock mass;
– the spacing of discontinuities;
– the state of discontinuities;
– hydraulic conditions;
– orientation of discontinuities.

3. Results

This chapter presents the rock mass classification results using three empirical methods calculate the required support for a studied structure.

3.1. The AFTES method

The AFTES method proposes the most suitable support for the mechanical and hydrological conditions of the different sites. The type of support obtained using the AFTES classification is summarized in Table 1 below.

Table 1. Support obtained by using AFTES for carbonate diorites and serpentines

Rock	Chloritized and altered diorite (Ait Ahmane)
For diorites	
Support provided by AFTES	– shotcrete with drainage; – heavy hangers with wooden or metal shielding; – sliding light stands with wooden or metal supports.
For carbonate serpentines	
Support provided by AFTES	– shotcrete with drainage; – heavy supports with wooden or metal shoring; – sliding light stands with wooden or metal frame.

3.2. The Q-system method

Using core sampling and field observations, the rock mass in the studied area can be classified according to the Barton's classification by calculating Q for the identified rock types. Table 2 shows the results obtained.

Table 2. Support specifications for each facies given by the Q-system method (Ait Ahmane)

Rock	Q	Barton classification	From	Support
Carbonate serpentine	0.75	Very low	2	bolting Lb = 1.60 m, Es = 1.30 m
Chloritized diorite altered	2.53	Poor	2	Bolting Lb = 1.60 m, Es = 1.30 m
Mineralized body	0.30	Very low	2	Mesh + shotcrete 50-90 mm with bolts Lb = 1.60 m

For De (equivalent mine working size), a maximum opening is equal to 6 m (case of operation size), while ESR is equal to 3 (temporary mine workings). Therefore, De = 2.

3.3. Correlation between the two classifications RMR and Q-system:

The correlation between the two classifications RMR and Q-system [10] has been developed by studying and analyzing several cases. There are 68 cases from Scandinavia, 28 cases from South Africa, and 21 cases from the USA, Canada, Australia and Europe.

There is an almost linear correlation between the two classifications, given by Equation 2:

$$RMR = 9\ln(Q) + 44. \tag{2}$$

3.4. Correlated RMR results

The numerical application of this formula (Equation 2) allows us to classify facies into five decreasing classes. Table 3 summarizes the results.

Table 3. Calculation of correlated RMR from the Q-system

Facies	Q-system	Correlated CMA	Class
Carbonate serpentine (Ait-Ahmane)	0.75	41.41	3
Chloritized diorite altered (Ait-Ahmane)	2.53	52.35	3

It is noted that east of Bou Azzer, the carbonate serpentine is class 3 mass in terms of correlated CMA and is therefore fractured and requires surface support.

4. Discussion

It should be noted that the AFTES classification method recommends shotcrete and arches as surface supports for the Ait Ahmane carbonate serpentine [7].

The results obtained by the Q-system method indicate that the first two facies (carbonate-serpentine and chlorite-altered diorite) are weak. In this case, a tight mesh bolted support without the use of surface support is highly recommended.

The RMR method confirms the incompatibility of free-form serpentine bolting. Its use in carbonate serpentines requires reinforcement by welded mesh.

Thus, an application of empirical methods on different facies of the Ait Ahmane site is given as a method for supporting:

– diorites: Bolting (Lb = 1.60 m, Es = 1.30 m).

– carbonate serpentine: 40 to 100 mm shotcrete with bolting (Lb = 1.60 m, Es = 1.30 m).

– mineralization: Mesh + shotcrete 50-90 mm with bolting (Lb = 1.60 m, Es = 1.30 m).

The use of these means of support in the field shows satisfactory results for the Q-system method compared to other methods [7]. This method is expedient, because it takes into account the equivalent dimensions of the gallery when determining the support system. Furthermore, the Q-system method efficiency increases, since the method takes into account the existing in-situ stresses, as well as the height of the additional stresses during mining. This is the same case obtained to determine the rock mass behavior when mining under conditions of high in-situ stress [11].

Thus, in order to characterize a rock mass located in a zone with severe restrictions, it is first necessary to use the Q-system method, which will provide us with the elements and parameters of stability necessary for the mass. Then, based on the support data obtained by the method, numerical and analytical analysis will determine these last support parameters that need to be selected and set up.

5. Conclusion

Calculations show that the quality of diorites is medium to good, while the quality of carbonate serpentines is poor. Mechanical characterization of intact rock has revealed that rock properties (strength and deformability) deteriorate as mineralization approaches. These parameters will be influenced by hydrogeological conditions, depth and state of fracturing around the mine working.

A support mode has been found by traditional empirical methods after determining the Hoek-Brow parameters, namely: RMR, AFTES and Q-system. The application of these methods on different facies has led to the following support modes: Bolting (Lb = 1.60 m, Es = 1.30 m) for diorites, 40-100 mm shotcrete with bolting (Lb = 1.60 m, Es = 1.30 m) for carbonate serpentines.

This makes it possible to take into account the application of the Q-system method for any classification of rock masses from friable to very friable, such as serpentine. This allows geotechnicians to take the Q-system parameters more seriously in order to better manage friable masses.

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Дослідження типів кріплення для відкладень, що контактують із серпентинами: ділянка Айт-Ахмане

І. Закі, М. Суіссі, А. Ларабі

Мета. Вивчення характеристик карбонатних серпентинів, присутніх на рівні ділянки Айт-Ахмане (шахта Бу-Аззер, Марокко) та визначення раціональних розмірів типів кріплення штолень на основі емпіричних підходів.

Методика. Гірнича маса різних структур, що згадується у дослідженні, класифікується за допомогою емпіричних методів, таких як класифікація RMR, Q-система та AFTES.

Результати. Розрахунки показують, що якість діоритів змінюється від середнього до високого, а якість карбонатних серпентинів низька. Механічна характеристика непошкодженої породи показала, що властивості породи (міцність та деформованість) погіршуються з наближенням мінералізації. Встановлено, що використання методу якості гірничої маси (Q-system), який базується на змодельованих статистичних результатах, отриманих за допомогою емпіричних підходів, є надзвичайно ефективним при видобутку гірничої маси. Застосування цих методів на різних фаціях призвело до наступних режимів рекомендованого кріплення: анкерне (Lb = 1.60 м, Es = 1.30 м) для діоритів, набризк-бетон завтовшки 40-100 мм з анкерним кріпленням (Lb = 1.60 м, Es = 1.30 м) для карбонатних серпантинів.

Наукова новизна. Виявлено, що еквівалентні розміри штольні, напружений стан на ділянці після проведення гірничих робіт, а також висота розкриву є важливими факторами стійкості штольні.

Практична значимість. Розроблений підхід дозволяє створити оптимально посилену конструкцію кріплення. Результати будуть корисними для інженерів-геотехніків як відправна точка при проєктуванні та плануванні систем кріплення для проходки тунелів в умовах високого напруженого стану на ділянці дуже крихких порід.

Ключові слова: *емпіричні методи, діорит, карбонатний серпентин, кріплення, фації, матриця гірських порід*