

Assessment Of Ground Support Ifor Tau Underground (640 Mamsl) Banded Iron Formation Section, (Mupane Gold Mine, Botswana

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Abstract

In Mupane Gold Mine, the conditions of the ground vary from good to moderate. The identification of the appropriate ground support is therefore less challenging. The lithology of Mupane comprises of Quartzite, Schist, Banded Iron Formation and/or Graphitic Iron Formation and Dolerite. The main challenges at great depth are high rock stress levels, seismic events, large-scale deformation, sudden failures, and elevated temperatures that may cause abrupt and unpredictable instability and collapse over a large scale. However, the purpose of this research is to determine the suitable type of rock support for the Banded Iron Formation section. Support design recommendations are based on the Rock-mass rating (RMR) system and rock-quality index (Q) system which derives values that will indicate the quality and condition of the rock mass. Face mapping which involves the measuring of joint orientations, frequency, persistence, and condition relative to the host rock. Ground support is a fundamental requirement for all underground mining operations. Use of two or more classification systems in ground support investigation, will generally lead to better and more accurate results. Use the Q-system because provides a solid quantitative representation of rock mass quality or use the modified Rock Mass Rating System. Further, kinematic analysis can compensate for the shortcomings in the Q system and facilitate the way to develop safe excavation methodology.

Keywords: Mupane Gold Mine, Dolerite Dyke, RQD, RMR, Q-System

INTRODUCTION

GENERAL LOCATION

Mupane gold mine is located in Northeastern Botswana 30km Southeast of Francistown. The Mupane Mining License covers an area of 1 165.5833 Ha and is located on two adjoining farms, designated Farm 75 NQ and Farm 18/77 NQ, in the Northeastern Administrative District, Botswana, southern Africa. The license area is located between Latitudes 21°21'21" and 21°23'44" South and Longitudes 27°41'11" and 27°44'02" East (Figure 1.1.1). The Mupane Mining License is registered as Mining License No. 2003/26L, issued on 5 September 2003. It covers a single contiguous area. It is Galane Golds first major gold producer and since 2005 has produced over 700,000 ounces of Gold (Glanvill, 2011).

Figure. 1: Location of Mupane Gold Mine



REGIONAL GEOLOGY

The Mupane Gold Deposit lies within the Tati Greenstone Belt (TGB) which comprises of Archaean metavolcanic, metasedimentary, and intrusive igneous rocks. The belt is subdivided into the following formations: Eastern Volcanic Succession, Last Hope Formation, Penhalonga Formation and Lady Mary Formation.

Lithology-The Mupane deposits are located in an area known as the Mupanipani Hills. The lithology comprises of Banded Iron Formations (BIF), Graphitic Iron Formation (GIF), Para- amphibolite, Ortho-amphibolite, Conglomerate, Carbonate-conglomerate, Quartz-feldspar-mica- schist and Dolerite dykes.

Mineralization-Mineralization is a “disseminated-style” in well-bedded, silicified quartz-rich parts of the graphitic iron formation (GIF). Deformation is ductile with a very minor brittle component. The highest gold grades are associated with arsenopyrite, pyrrhotite and pyrite. The non-sulfide mineralogy of gold ores comprises of quartz, carbonate, amphibole, graphite, chlorite, and/or biotite.

Metamorphism and Alteration-The Mupane Gold deposits are in rocks at amphibolite facies. Garnet-amphibole is the metamorphic grade of some of the host rocks and the mineralized rocks are biotite-grade (Glanvill, 2011).

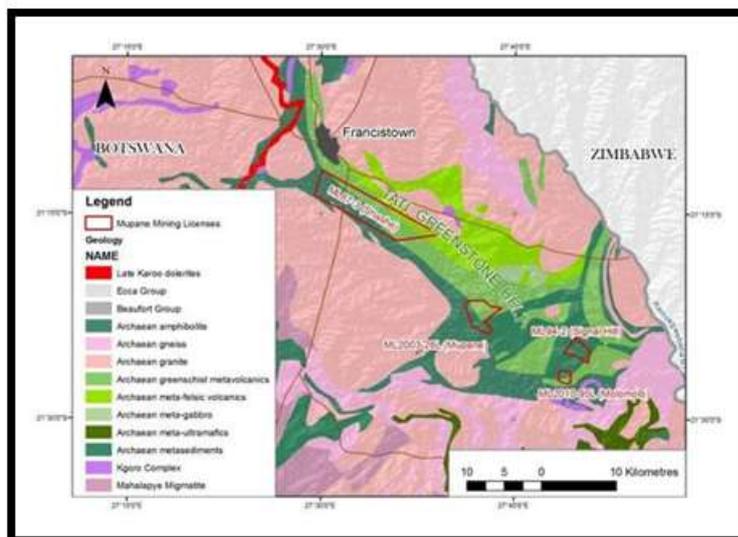


Figure. 2:Regional Geological Map

STATEMENT OF THE PROBLEM

Mupane Gold Mine specifically at Tau Underground does mining at great depth, and therefore this poses some challenges for ground control and maintenance of stability of excavations. The main challenges at great depth are high rock stress levels, seismic events, large-scale deformation, sudden failures, and elevated temperatures that may cause abrupt and unpredictable instability and collapse over a large scale. The strength of rocks increases at great depth due to high confinement and it is removed with underground excavation, resulting in a considerable reduction in rock strength. Rapid change in rock strength, high field stress conditions, sources of static and dynamic loads and defects in geological structures can cause complex ground behaviors from the microscale, such as microcracks in rocks, to the large scale like a sudden failure. Hence that is why a ground support investigation is required at Tau Underground to try and prevent these ground behaviors.

OBJECTIVES OF RESEARCH

- ❖ The purpose of this work is to determine the suitable type of rock support for the Banded Iron Formation section.
- ❖ Face mapping which involves the measuring of joint orientations, frequency, persistence, and condition relative to the host rock.
- ❖ Derive values that will indicate the quality and condition of the rock mass.

REVIEW OF RELEVANT LITERATURE

According to Jacobsson et al., (2013) Ground support investigation based on static loading conditions is used in underground mining projects where the risk of seismic events is low. The typical ground support devices for static loading conditions are fiber-reinforced shotcrete, rock bolts and cable bolts. On the other hand, Kaiser et al., (1996) states that Ground support investigation in a ground with dynamic loading conditions should include an absorbing kinetic energy factor derived from seismic events.

Transferring the load from the surface to reinforcement ground devices is not critical in static conditions, whilst this point is a fundamental requirement in dynamic conditions to ensure the performance of ground support systems.

Ground support investigation according to Rahimi et al., (2014) based on static loading conditions which are the conditions experienced at Mupane and dynamic loading conditions follows the steps below.

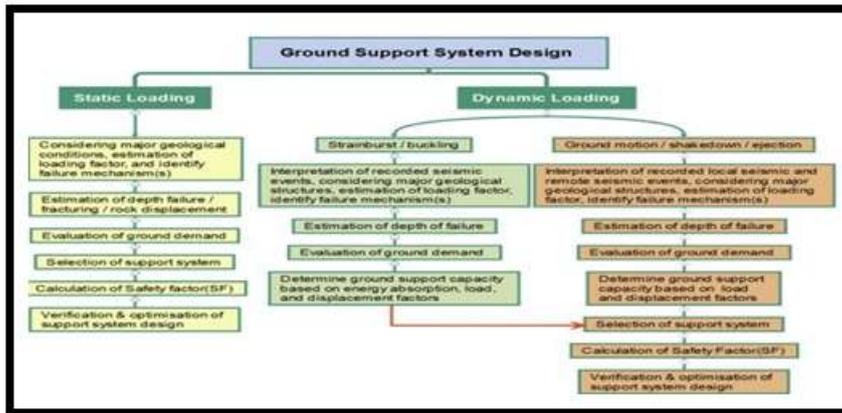


Figure. 3: Ground support design in deep underground mines.
 After Rahimi et al. (2020)

METHODOGY

For the current work, the following methods were used, the details of which is given below:

Face Mapping

Pen-and-paper based face mapping form was used to collect the geotechnical data which were used for RMR and Q system. The geotechnical data collected was the spacing, Persistence, infill, aperture, weathering, span and the dip and dip direction.

Determination of Rock-Mass Rating (RMR) System

Calculated to determine the composition and characteristics of the rock mass so as to be able to estimate the support requirements. The parameters used for classification were the Uniaxial compressive strength of rock material, Rock Quality Designation, Spacing of discontinuities, Conditions of discontinuities, Groundwater conditions and Orientation of discontinuities.

Determination of Rock Quality Designation(RQD) & Q- System

These were calculated to estimate the type of support required. The following parameters were used; Rock quality designation (RQD), Number of joint sets (Jn), Roughness of the most unfavorable joint or discontinuity (Jr), Degree of alteration or filling along the weakest joint (Ja), Water inflow (Jw) and lastly Stress condition given as the stress reduction factor (SRF). Rock mass classification systems continue to constitute an integral part of empirical mine- design. There are several classification systems used in underground support investigation. In the mining industry the Q and RMR classification system form the basis of many empirical design methods, as well as the basis of failure criteria used in many numerical modelling programs hence that is why they are of interest. The Q-system and the RMR are used together with RQD estimation and Face Mapping below to determine the suitable type of support for the 640 Banded Iron Formation section in Mupane.

Face Mapping

Pen-and-paper based face mapping form was used to collect the geotechnical data which were used for RMR and Q system. The geotechnical data collected was the spacing, Persistence, infill, aperture, weathering, tunnel height, tunnel width and the dip and dip direction. This data was used to determine the rock mass rating and in the selection of support.

Rock Quality Designation Index (RQD) estimation & Support selection

Since there was no core available but only discontinuity traces, the RQD was be estimated from the number of discontinuities per unit volume. The RQD was estimated using the formula:

$$RQD = 115 - 3.3J_v$$

Where J_v is the volumetric joint count

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \dots + \frac{1}{S_n}$$

where S_1, S_2 and S_3 are the average spacings for the joint sets.

RQD is a directionally dependent parameter and its value may change significantly, depending upon the borehole orientation. Therefore, the use of the volumetric joint count is said to be quite useful in reducing this directional dependence.

Geomechanics Classification or the Rock Mass Rating (RMR) system & Support Selection

The RMR classification was applied by determining the six classification parameters which are- uniaxial compressive strength of rock material, rock quality designation index, spacing of discontinuities, condition of discontinuities, groundwater conditions and orientation of discontinuities by taking measurements in the field. Once the classification parameters were determined, the ratings are assigned to each parameter according to Table 6. In this respect the typical, rather than the worst conditions, are evaluated. Lastly, the support was then selected with the help of the rock mass rating, the rock mass class, and the table in Appendix B.

Determination of the stand-up time of the excavation

Stand-up time is defined as the amount of time a tunnel will support itself without any added support structures, which means also the time that the rock mass around the tunnel begin to collapse. Knowing this time allows the engineers to determine how much can be excavated before support is needed. The span and the Rock Mass Rating were used to determine the stand-up time by means of a schematic chart.

Selection of the ground support using the Q-System

Six rock mass parameters (RQD = Degree of jointing (Rock Quality Designation), J_n = Joint set number, J_r = Joint roughness number, J_a = Joint alteration number, J_w = Joint water reduction factor, SRF = Stress Reduction Factor) were used to calculate the Q-value for the Banded Iron Formation. This value was used to give a description of the rock mass quality. Furthermore, the Q-value was used to determine the permanent support required by means of a schematic support chart. The Q-system is useful in the sense that calculation of the Q-value makes it possible to find the type and quantity of support that has been applied previously in rock masses of the similar qualities.

RESULT AND DISCUSSION

Data Collected During Face Mapping

The tunnel at which the data was collected has a span of 4.1m and is located at 640mamsl. The facet on which the data was collected was filled with smooth, Unweathered joints, with no aperture. Most of the joints had a dip of less than 90°. Lastly, the facet was dry with no water.

Table.1: Data Collected from Mupane Gold Mine at Tau Underground 640mamsl BIF section

Set 1	Set 2	Set 3
Spacing: 0.2m	Spacing: 0.3m	Spacing: 0.28m
Persistence: <1m	Persistence: <1m	Persistence: <1m
Smooth, undulating	Smooth, undulating	Smooth, planar
Infill: None	Infill: None	Infill: None
Aperture: None	Aperture: None	Aperture: None
Unweathered	Unweathered	Unweathered
Perpendicular to the tunnel	Parallel to the tunnel	Parallel to the tunnel
Dip: 45°	Dip: 65°	Dip: 45°

Tunnel Height: 4.1m Tunnel Width: 4m

Rock Quality Designation Index (RQD) Estimation and Support Selection

The Rock Quality Designation index (RQD) was developed by Deere & Deere, (1986) to provide a quantitative estimate of rock mass quality from drill core logs. RQD is defined as the percentage of intact core pieces longer than 100 mm (4 inches) in the total length of core. The procedure for measurement and calculation of RQD when using drill core logs is shown in Appendix A. However, Palmstrom and Broch (2006) suggested that, when no core is available, but discontinuity traces are visible in surface exposures or exploration adits, the RQD may be estimated from the number of discontinuities per unit volume. The suggested relationship for clay-free rock masses is:

$$RQD = 115 - 3.3J_v$$

Where J_v is the volumetric joint count

$$J_v = \frac{1}{S_1} + \frac{1}{S_2} + \frac{1}{S_3} + \dots + \frac{1}{S_n}$$

where S_1, S_2 and S_3 are the average spacings for the joint sets.

Therefore, since there was no core available for the Banded Iron Formation at Mupane the RQD was estimated using the formula and calculated as shown below:

$$J_v = \frac{1}{0.2} + \frac{1}{0.3} + \frac{1}{0.28} = 11.9047619$$

$$RQD = 115 - (3.3 \times 11.9047619) = 76\%$$

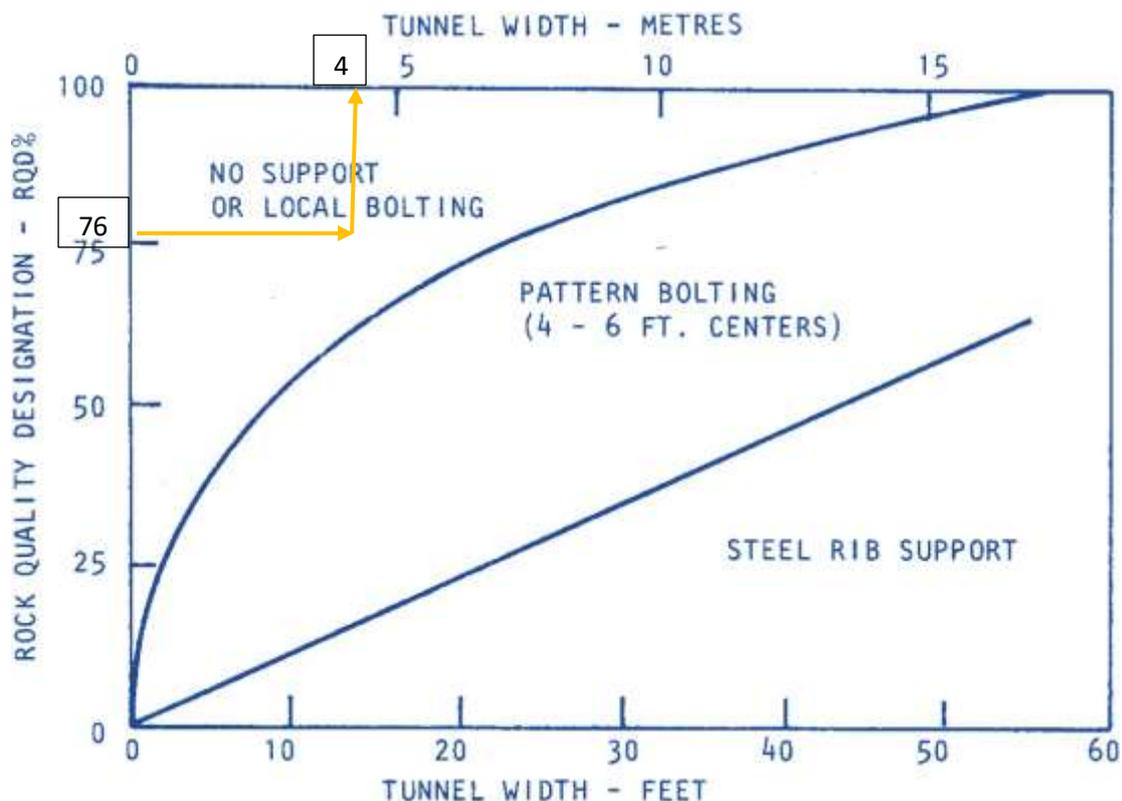


Figure. 4: RQD support design chart

According to the Rock Quality Designation (RQD) support design graph above for the Mopane's Banded Iron Formation that has an RQD of 76% and a tunnel width of 4m, no support is required, or local bolting can be carried out.

Table. 2: Classification Based on the Parameters

PARAMETER	SET 1	SET 2	SET 3
	Rating		
UCS (>250MPa)	15	15	15
RQD (75-90%)	17	17	17
Condition of discontinuities	25	25	25
Groundwater (Completely dry)	15	15	15
Spacing (200-600mm)	10	10	10
Adjustment for Discontinuity Orientation	10	12	5
Total	72	70	77

Rock Mass Class: -The total ratings fall between 80-61 and according to table 2 above the rock mass class of banded iron formation determined by the ratings is class II, which further describes the rock as a good rock.

SUPPORT SELECTION

The values of RMR of 72, 70 and 77 indicate that Banded Iron Formation rock is a good rock. Table 4 above suggests that the tunnel could be excavated full face with an advance of 1.0-1.5m and support should be installed at a maximum distance of 20m from the face. Recommendations of locally bolts in crown, 3m long, spaced 2.5m with occasional wire mesh. Furthermore, shotcrete 50mm in crown is required.

DETERMINATION OF THE STAND-UP TIME OF THE EXCAVATION

Stand-up time is defined as the amount of time a tunnel will support itself without any added support structures, which means also the time that the rock mass around the tunnel begin to collapse. Knowing this time allows the engineers to determine how much can be excavated before support is needed. Having a span of 4.1m and an RMR rating of 70 the stand-up time chart below was used to clearly determine the stand-up time of the excavation.

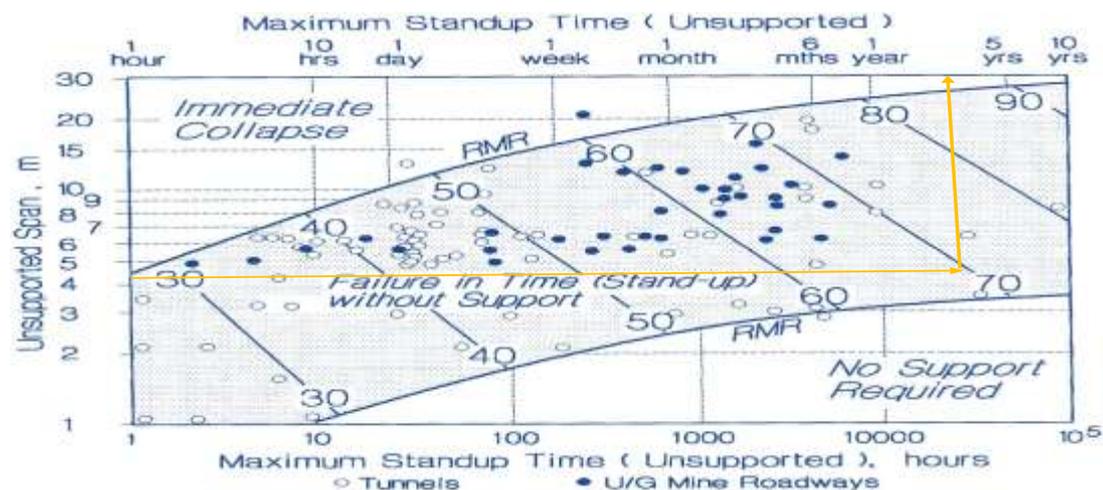


Figure. 5: Stand-up time Chart (Bieniawski, 1973)

According to the stand-up time chart above the amount of time the 640 tunnel in Mupane can take to support itself is approximately 3 years without any added support structures.

SELECTION OF GROUND SUPPORT USING THE Q-SYSTEM

Ground support is selected using the Q-system. This is a quantitative classification system for estimates of tunnel support, based on a numerical assessment of the rock mass quality using the following six parameters:

- ❖ Rock quality designation (RQD).
- ❖ Number of joint sets (J_n).
- ❖ Roughness of the most unfavorable joint or discontinuity (J_r).
- ❖ Degree of alteration or filling along the weakest joint (J_a).
- ❖ Water inflow (J_w).
- ❖ Stress condition given as the stress reduction factor (SRF); composed of
 - ✓ Loosening load in the case of shear zones and clay bearing rock
 - ✓ Rock stress in competent rock, and
 - ✓ Squeezing and swelling loads in plastic, incompetent rock

The Q System classification is based on three aspects:

- ❖ Rock Block Size (RQD/J_n)
- ❖ Joint Shear Strength (J_r/J_a)
- ❖ Confining Stress (J_w/SRF)

The data collected at Mupane was used together with the information in table 5 to acquire the information below which was then used to calculate Q.

$$RQD = 76\% = 0.76$$

$$J_n \text{ (Joint Set Number)} = 9 \text{ (Three Joint Sets)}$$

$$J_r \text{ (Joint Roughness Number)} = 2 \text{ (Smooth, Undulating)} \quad J_a \text{ (Joint Alteration Number)} = 1 \text{ (Fresh Joint Walls)}$$

$$J_w \text{ (Joint Water Reduction Factor)} = 1 \text{ (Dry excavations)} \quad SRF \text{ (Stress Reduction Factor)} = 5$$

$$Q = \frac{RQD}{J_n} \times \frac{J_r}{J_a} \times \frac{J_w}{SRF} = \mathbf{0.0338}$$

The Q-value is related to tunnel support requirement by defining the equivalent dimensions of the underground opening. This equivalent dimension, which is a function of the size and type of the excavation, is obtained by dividing the span, diameter, or wall height of the excavation (Dt) by a quantity called the excavation support ratio (ESR), given as

$$De = \frac{Dt}{ESR}$$

ESR values are given in Table 3 below:

Table 3: Ratings of the excavation support ratio (ESR) (Barton et. al., 1974)

	Type of Excavation	ESR
A	Temporary mine openings	3.5
B	Vertical shafts*: i) circular sections ii) rectangular/square section	2.0-2.5
C	Permanent mine openings, water tunnels, adits, drifts	1.6
D	Minor road and railway tunnels, surge chambers, access tunnels etc.	1.3
E	Power stations, storage rooms, road and railway tunnels with heavy traffic, civil defense chambers, etc.	1.0
F	Nuclear power plants, railroad stations, sport arenas, etc.	0.8

The type of underground opening is permanent mine openings which have an ESR of 1.6.

However, it is recommended to use ESR = 1.0 when $Q \leq 0.1$ for the types of excavation B, C and D. The reason for that is that the stability problems may be severe with such low Q-values, perhaps with risk for cave-in.

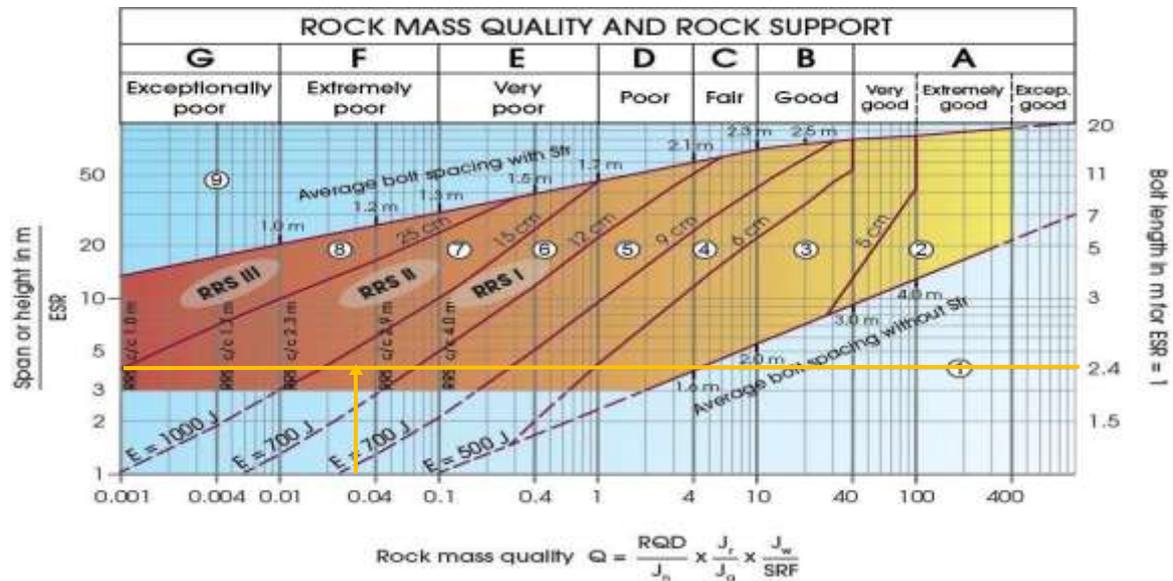


Fig.6: Rock Mass Quality and Rock Support

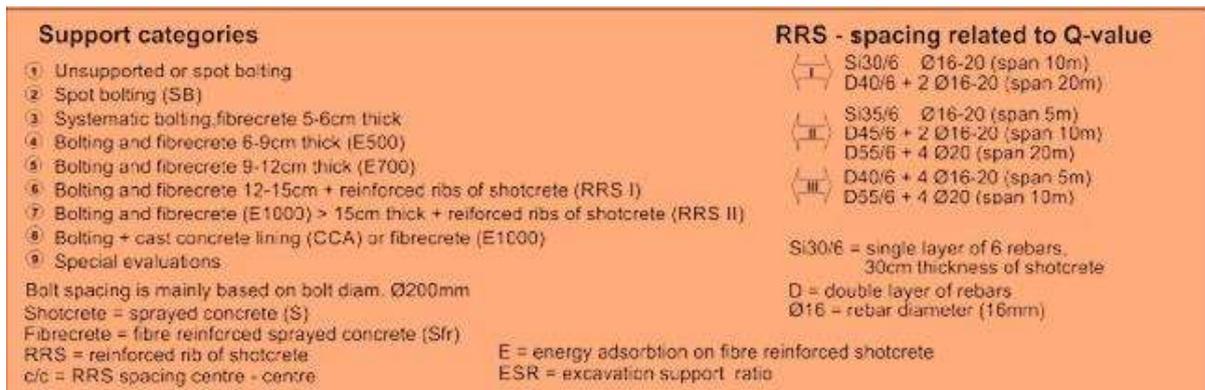


Figure 7: The Q system chart for rock support estimate, developed by the Norwegian Geotechnical Institute (NGI), (based on www.ngi.no, 2022)

According to the Q-system chart above the type of support suitable for the 640 Banded Iron Formation section in Mupane is Bolting and fibrecrete 12-15cm thick and reinforced ribs of shotcrete (RRS I) because it falls in category 6.

DISCUSSION

As observed from the results analysis both the RMR and the Q-system have numerous common parameters, however, there are a few differences which are:

- ❖ RMR uses addition of ratings to combine input values so as to calculate the ground quality whereas, Q-system uses multiplication and division in the calculation of ground quality.
- ❖ RMR uses a table in determining the support required. On the other hand, the Q-system uses a chart where the Q value (ground quality) and the tunnel dimensions (span or wall height) is used. It should be noted that however, the RMR table used to determine the support has been said to have not had a major revision since 1973. An indication is that in many mining and civil engineering applications nowadays, steel fiber reinforced shotcrete is sometimes considered in place of wire mesh and shotcrete. The table is shown in Appendix B.

Furthermore, RMR unlike the Q-system does not account for in situ and induced stresses, stress changes and the effects of blasting and weathering. With regards to the Q-system equation in Appendix C. The ratio (RQD/Jn) in the Q equation clearly shows the effect of block size on the instability of rock masses. Other ratios include (Jr/Ja) and (Jw/SRF), which are related to shear strength and stress conditions, respectively, and play critical roles in the behavior of rock masses. Shear strength of discontinuities and joint surfaces, which is determined by block size and discontinuity roughness, is one of the most important challenges in the stability of rock slopes. Weathering of discontinuity surfaces will also have an adverse influence on the shear strength of rock masses. Another element that reduces rock mass shear strength is the presence of water on discontinuities, which increases pore pressure and reduces shear strength. These factors will cause rock masses to become unstable, and they all contribute to the Q classification. As a result, one can argue that the contributing parameters in the Q equation demonstrate that, when compared to the RMR method, this classification system has a lot of promise for evaluating rock mass quality. Hence, ending up with the conclusion that the Q system provides a solid quantitative representation of rock mass quality.

CONCLUSION

Ground support is a fundamental requirement for all underground mining operations. There is no and never will be a universal support that will be effective in all conditions. Therefore, the use of two or more classification systems in ground support investigation, will generally lead to better and more accurate results.

RECOMMENDATIONS

- When carrying out ground support investigation, use more than one rock classification system to get more accurate results.
- In cases where it is practically impossible to use more than one rock classification system use the Q-system because provides a solid quantitative representation of rock mass quality or use the modified Rock Mass Rating System.
- Use of kinematic analysis as it will compensate for the shortcomings in the Q system to ensure that all aspects of the tunnel are analyzed thoroughly, as this will be an excavation that must remain safe for the life of the mine.

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This manuscript has been neither published nor submitted for publication, in whole or in part, either in a serial, professional journal or as a part in a book which is formally published and made available to the public.

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