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Hypogene classification system: A proposal to classify rock masses in hypogene environment

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ABSTRACT

Geotechnical classification systems are commonly used in the mining industry to estimate the geotechnical quality of rock masses and have several applications in the geotechnical and mining design. All systems have been conceived for weathered rock masses characterized by open and weathered joints, except for the IRMR system (Laubscher & Jakubec, 2001) that evaluate the geotechnical quality considering the effect of both open joint and cemented microdefects and veins. This first attempt was not followed by others in order to improve the classification systems for hypogene environments. Since last decades, block caving operations are facing the challenge to mine ore deposits at deeper conditions, with higher stress and to characterize, with the traditional systems, a rock mass with cemented veins and microdefects. Recently, has been proposed the IGSI (Russo et al., 2020) as a method to quantify the GSI in hypogene environments and now, as a second step, the Authors are proposing a classification system to characterize rock masses in those environments. The proposed system assigns a rating for the rock block strength and, as for IGSI, assigns ratings for the spacing of weaker cemented veins that are able to open during the mining activity and the hardness of veins mineral infill, including strong veins, as quartz veins, that contribute to the strengthening of the rock mass. The system has been applied to three cases study showing a good difference between the geotechnical units according to the mineral infill strength and their frequency. The implementation of the Hypogene System demonstrates that this method is able to shows more differences than the traditional systems between the same lithology but with different types of alterations.

1 INTRODUCTION

Geotechnical classification systems are used in the mining industry in all engineering stages of a project and have several empirical applications in the geotechnical and mining design, that are mostly used in the Scoping and Pre-Feasibility studies.

Several systems are used in the mining industry such as: RMR (Bieniawski, 1976, 1989) mostly used in open pit operations; MRMR mostly used in block caving operations; Q System (Barton et al., 1974; Grimstad & Barton, 1993) mostly used in tunneling and sub level stoping operations; finally, the GSI (Cai et al., 2004; Hoek et al., 2013; Marinos & Hoek, 2000; Tzamos & Sofianos, 2007) that has been used as classification system in several open pit operations, even if it was conceived as a tool to scale strength properties from sample to rock mass.

All above mentioned classification systems were conceived to assess a jointed rock mass, generally located at surface or at lower depth and characterized by open joints showing different degree of weathering on their surfaces, excepting the Laubscher & Jakubec (2001) system that includes the effect of presence of cemented veins and microdefects with weaker mineral content.

In the last decades, the mining activity has been facing the challenge to mine ore deposits at deeper and higher stresses conditions. In this scenario the challenge has been to assess a primary rock mass, characterized by a stockwork of cemented veins and microdefects, applying the traditional classification systems. It has been observed, in several underground operation, that traditional systems are not able to show differences, in terms of final rating, between geotechnical units that are showing a different behaviour to the mining activity.

Recently, some modifications have been applied to the GSI chart in order to be able to assess both weathered and hypogene rock masses, proposing the Composite Geological Strength Index (Day et al., 2016, 2019). Later, Russo et al. (2020) proposed a new chart to quantify the Intact Geological Strength Index for rock masses in hypogene conditions. The quantification of IGSI is based on the rating assigned to the blockiness of the rock mass, estimated according to the spacing of weak cemented veins (Mohs hardness up to 5) and according to the veins condition estimated according to the weighted average of the Mohs hardness considering all infill types.

The aim of this work is to propose a geotechnical classification system to characterize the rock mass in hypogene conditions that, for this reason, we called Hypogene Classification System (H System).

2 CHARACTERISTICS OF HIPOGENE ROCK MASS

It is well known that porphyry copper deposits were formed at some kilometers in depth, in a hypogene environment where sulfide mineralization developed and that, subsequently, due to erosion and exhumation processes, they were exposed to leaching and oxidation processes generated by meteoric water infiltration.

Meteoric water infiltration processes generate a vertical zonation (Figure 1) with different degrees of weathering, ranging from a leached zone in the shallowest part to the hypogene zone in the deepest part. The greater or lesser development of the gossan will depend on several factors such as the degree of fracturing of the rock mass, morphology, and local climatic conditions. The vertical zoning of the gossan is associated with a vertical zoning of the geotechnical quality of the rock mass, defining different geotechnical zones (Russo & Ramírez, 2023).

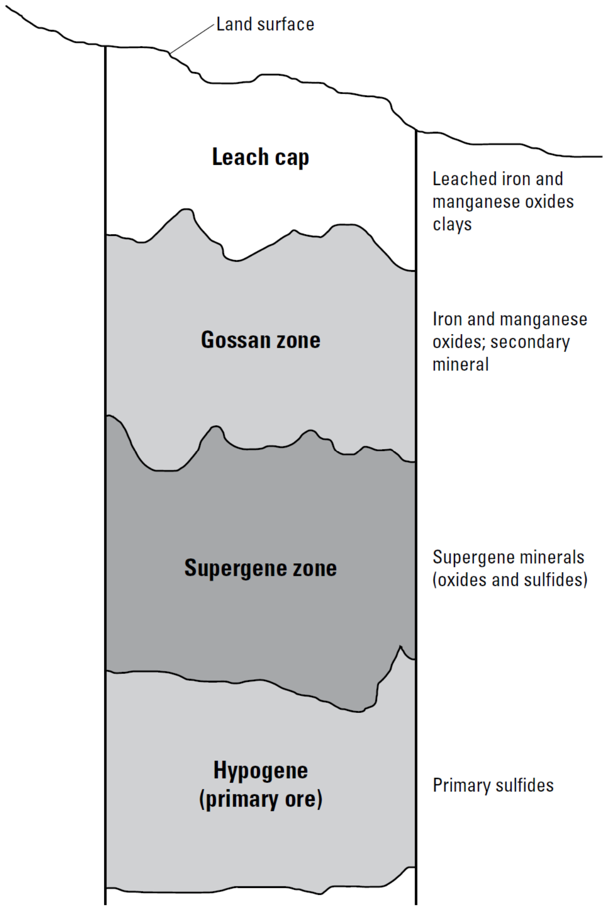

Figure 1 Profile view of a mature gossan (John et al., 2010).

The boundary between the supergene and hypogene zone is characterized by being the lower limit to which the action of meteoric waters leach and oxidize the discontinuities or indicates the maximum paleo depth to which meteoric waters could penetrate, showing the passage from a rock mass with leached and open veins to a mass with cemented veins (Figure 2).

Figure 2 Example of hypogene rock mass.

The hypogene rock mass is characterized by having a fresh and unaltered aspect, it is impermeable and is characterized by a stockwork of veins cemented by minerals such as anhydrite, quartz, sulfides, carbonates, etc. that block infiltration water from seeping in and circulating. A few open cemented veins and microdefects are observed at the drill core (Figure 3), with relatively weaker infill, which split with the drilling, an event that shall occur during the mining activity, creating the formation of unstable wedges or allowing the rock mass to cave and fragment.

Figure 3 Examples of open and cemented veins in drill cores.

In several projects was debated how these open veins have to be assessed, if have to be considered as mechanical breaks due to the drilling or as open joints. It has been observed that if the open veins are considered as mechanical breaks, the entire hypogene rock mass is assessed with a FF/m = 0 or very low, consequently giving very high ratings, even for a highly fractured rock mass (Figure 4).

In other projects, it has been observed that, to avoid this problem, it was used the spacing of the cemented veins but was considered all type of mineral infill, including hard mineral such as quartz veins that never breaks, overestimating the fracture frequency.

The aim of this work is to propose a methodology that could be helpful to characterize hypogene rock masses based on the assessment of weaker veins, regardless if they are open or sealed in drill cores.

Figure 4 Example of geotechnical interval where all fractures were assumed as mechanical. The estimated Bieniawski RMR = 72.

3 THE HYPOGENE CLASSIFICATION SYSTEM

The H System has been conceived to assess the typical hypogene rock mass in porphyry copper deposits.

According to the experience in several deep block cave operations, the failure mechanism of the rock mass is mostly structural and being influenced, firstly, by the vein density, secondly, by the quality of the mineral infill and a minor failure is due to the rock block strength. The H System has been developed following these criteria. The final rating will range from 0 up to 100, classifying the rock mass in 5 Classes and 10 Sub-Classes, as proposed by Laubscher (1990).

It is recommended that geotechnical assessment should be performed on interval lengths that are representative of the rock mass, according to that the recommended interval length should ranges between 3m and 10m both for core logging and face mapping, unless the rock mass to characterize would be, i.e, a dyke with a thickness less than 3m. It has been observed that, in some mining project, the core logging is performed even on very short intervals as 10cm or 20cm; this practice it is not recommended because is producing skewed ratings that could affect the estimation of the average or representative values of the rock mass.

3.1 Rock Block Strength Assessment

The rock mass behaviour is controlled by the vein frequency, vein condition and the strength of the rock blocks delimited by the open veins. The intact rock strength (IRS) or the unconfined compressive strength (UCS), estimated on very small volumes, are not representative of the larger volumes of the blocks generated by the failure of the rock mass.

The rock block strength should be calculated following the methodology proposed by Laubscher & Jakubec (2001) but taking in account the following considerations.

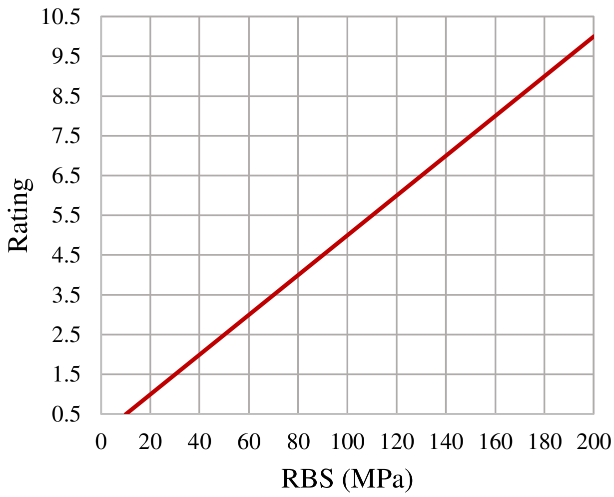

Figure 5 Rock block strength ratings.

If the rock block strength is calculated using the empirical IRS method, just follow the methodology described in Laubscher & Jakubec (2001), reducing the IRS by 80% and applying the adjustment for the presence of microdefects.

If the rock block strength is calculated using the UCS values, just apply the reduction of 80% and disregard the adjustment for microdefects to avoid a double penalty to the final rock block strength. Because valid results are considered from rock failure, combined and multiple veins failure (Bewick et al., 2015; Marambio et al., 2000; Russo & Hormazabal, 2016), the estimated UCS strength is already including the lowering effect for the presence of microdefects.

The H System will be assigning rating from 0 to 10 according to Figure 5.

3.2 Vein Condition Assessment

The vein condition is controlled by the strength of the mineral infills. Mineral infills like molybdenite, gypsum, bornite, anhydrite, chalcopyrite etc. that breaks due to the mining activity like blasting or induced stresses, will be producing a weakening of the rock mass, whereas infills like magnetite, tourmaline, quartz etc. will be producing a strengthening effect on the rock mass.

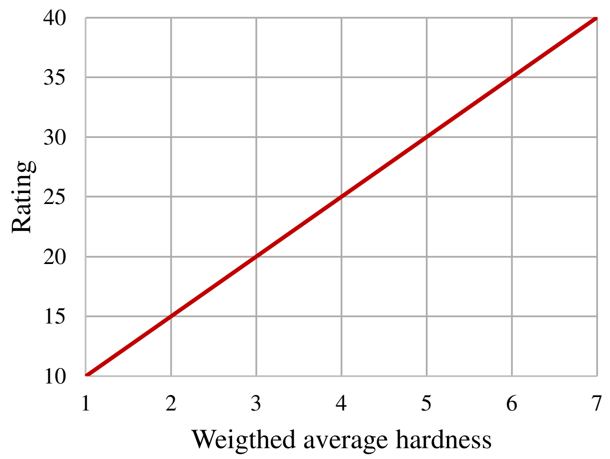

Figure 6 Vein condition ratings.

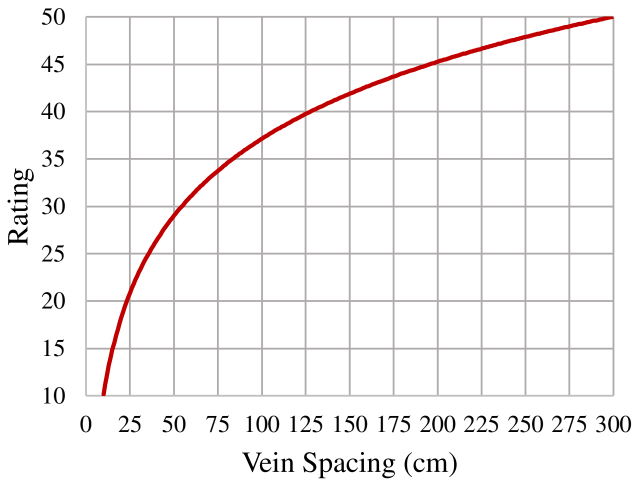

Figure 7 Vein frequency ratings.

To assess the vein condition, it is required to count the number of veins by Mohs hardness, including up to strong quartz veins, and then calculate the weighted average hardness representative of the geotechnical interval.

The vein condition ratings range from 10 to 40 and will be assigned according to Figure 6.

3.3 Vein Frequency Assessment

The frequency of weaker veins is the geotechnical parameter that most influence the rock mass behaviour. As mentioned before, weak veins are able to break due to blasting or the abutment stress, the size of the unstable wedges or the caveability and the fragmentation will depend on the spacing of these weaker veins.

The veins frequency is determined by the spacing of the weaker veins (Mohs hardness ≤5) in each geotechnical interval. The rating of vein frequency ranges from 0 up to 50 and is assigned according to the Figure 7.

The final rating to assess the H System will be obtained from the sum of the three individual ratings, summarized in Table 1.

Table 1 Ratings to assess the H System

Vein Condition		Rock Block Strength		Vein Frequency	
Mohs hardness	Rating	RBS (MPa)	Rating	Weak veins spacing (cm)	Rating
1	10	20	1	10	10
2	15	40	2	25	21
3	20	60	3	50	29
4	25	80	4	75	34
5	30	100	5	100	37
6	35	120	6	150	42
7	40	140	7	200	45
		160	8	250	48
		180	9	300	50
		≥200	10		

4 IMPLEMENTATION OF THE HS

The Hypogene System has been implemented to assess some geotechnical units from an underground mining project characterized by a primary rock mass with a stockwork of cemented veins and intact rock strengths ranging from 120 MPa up to 180 MPa. The results as been compared to the traditional classification systems in order to verify if the HS is able to better differentiate the geotechnical quality of the analyzed geotechnical units.

Table 2 Rock mass assessment using HS and traditional systems.

Geotechnical Unit	HS	IRMR	MRMR	RMR
Andesite	52	57	54	73
Potassic Igneous Breccia	56	60	58	76
Sericitic Igneous Breccia	54	60	57	75
Potassic Porphyry	66	67	62	79
Sericitic Porphyry	62	67	62	78
Post Mineral Dyke	47	56	60	75

The total amount of drill cores that have been used to calculate the different classification systems is about 20,000m. For each geotechnical interval logged were calculated the Hypogene System (HS), the IRMR (Laubscher & Jakubec, 2001), the MRMR (Laubscher, 1990) and the RMR (Bieniawski, 1989), then the average value for each geotechnical unit was calculated.

The results are summarized in Table 2, where can be observed how the HS allows to better differentiate among the Potassic Porphyry and the Sericitic Porphyry, 66 and 62 respectively, instead of the traditional systems. Particularly, is remarkable the assessment of the Post Mineral Dyke, a 2m thick dyke characterized mostly by open post mineral veins filled by gypsum and obtaining a rating of 47 with HS, instead of the ratings 50, 60 and 75 obtained using the IRMR, MRMR and RMR respectively.

It is important to note that this Post Mineral Dike is similar to the post mineral Lamprophyre Dike (Gomez, 2001), a 0.5-2m thick dyke characterized by open post mineral veins filled by gypsum and responsible of important overbreaks during the tunnel developments at El Teniente Mine.

5 CONCLUSIONS

The deepening of the mining activity of the last decades generates a challenge to the geotechnical characterization using the traditional classification systems.

Recently, some attempts have been proposed in order to assess the GSI of rock masses in hypogene environment but was still missing the implementation of a classification system conceived to characterize these types of rock masses.

The Hypogene Classification System proposed in this work represent a proposal to characterize the rock mass based on the rock block strength, the weighted average hardness of the mineral filling the veins and the spacing of the weak veins that are able to break due to the mining activity.

The implementation of the H System demonstrates that this method is able to shows more differences than the traditional systems between the same lithology but with different types of alterations. The difference is remarkable when the H System is applied to a post mineral dyke characterized by veins filled by gypsum, in this case the traditional systems assign high ratings that are not reflecting the geotechnical behaviour observed for this unit during the mining activity, whereas the HS estimate much lower rating that better reflect the poorer geotechnical quality of this unit.

The proposed system is recommended to characterize primary rock masses. The future step will be the implementation of this system in operating underground mine in order to validate and calibrate it through numerical modelling.

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