Engineering characterization of Oro Descanso underground gold mine deposit in Placetas, Cuba

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Abstract—This work reports the study on the design subject associated with the incorporation of mineral processing within the underground mining systems with its focus on the rock mass characterization of the underground gold mine, ‘Oro Descanso’ in Placetas town of the Province Villa Clara, Cuba. The assessment of the rock mass is based on the geological features and geomechanical characteristic. The study applies observational and empirical methods using established empirical formulae to characterize the rock mass of the underground gold mine. The results of the discontinuities orientation and dip data; a Schmidt stereographic diagram and the Rosette diagram obtained with the aid of the Roccscience SDipVS-2004. The physical/mechanical properties of the intact rock and the distribution of the rock mass discontinuities are considered in order to suggest measures that will lead to a secure excavation of the mine workings and the drift. For this purpose, is employed. It is observed that the rock mass comprises of zones of good, fair and poor quality rocks. For this reason, the gallery and the drift shall be of 2.5 to 5 m span for a stand-up time of 10 hours to one week respectively. Systematic bolts of 1 m long, fully grouted and without tension with shotcrete of 2.5 to 5 cm thickness, reinforced with mesh is proposed for zone with poor quality rock, systematic bolts of 1 to 1.5 m long, fully grouted and without tension, reinforced with shotcrete of 2.3 cm thickness is proposed for zone of fair quality rock.

Keywords—Rock mass, underground mine, grouted, shotcrete, engineering characterization

1 INTRODUCTION

The conventional metal production life cycle begins from the mineral exploration to mineral processing and smelting while mineral wastes are sent to dumps and ponds. The need to develop and sustain mining and metal recovery often leads to modern technologies with more incorporated metal producing systems. Advanced hydrometallurgy eradicates the smelting and the related environmental problem; lower grade ore is recovered by in-situ heap leaching; pasting skill allows underground waste storage thus reducing the high surface dumping environmental risks (Klein et al., 2003). The scientific and technological development has led to the search for the industrial raw materials while the limited spaces with environmental consequences of surface mining provoke the need for underground exploration of mineral resources. Underground hard rock mining methods are used to excavate hard mineral-containing metals (Au, Ag, Fe, Cu, Zn, Ni, Sn and Pb) or may involve using the same techniques for gems (diamonds).

Mineral extraction is preceded by prospecting to determine the reserves, ore quality, and economic feasibility of exploiting the deposit, the production capacity of a mining enterprise, and the working methods of deposits. A lot is made and reported on the physical properties of mineral rocks, thus easier to get at the most advantageous solutions in the design and building of rock-crushing equipment and tools, as well as in mineral recovery methods. Some minerals occur in long streaks (as veins or in pipes) and underground mining systems are for these minerals.

For the evaluation of rock mass stability, Bieniawski (1989) established the criterion of rock mass rating index which is based on: compressive strength of the intact rock, RQD of Deere et al. (1964), spacing of discontinuities, condition of discontinuities, underground water conditions and the orientation of discontinuities. Also, Barton et al. (1974) established a classification index, Q, product of rock mass observation
of the following parameters: RQD of Deere, number of joint sets, roughness of the most unfavourable discontinuity, degree of alteration or filling along the weakest joint, water inflow and stress condition (Cabrera and Samaniego, 2013).

Dominy (2010) agreed that geologists in some underground gold mines gather grab samples from broken ore piles or trucks as a method of grade control (muck sampling) and that, the goal of grab sampling is to try and reconcile the mined grade at the ore source to the predicted grade and/or predict the mill feed grade. It is believed that mineral ore and waste must be defined well to ensure an economically optimized mill input in all mining operations. Grade control is indispensable for resourceful mine operation with key player indicators. Gold veins repeatedly cause problems during sampling for their erratic grade circulation, which is often complicated by the existence of coarse gold particles as previously reported by Dominy et al., (2000, 2001), Dominy and Petersen (2005) and Petersen and Dominy (2005).

The available report by Fernández et al., (2013) on the Oro, Cuba has the deposit precipitates with high gold content of Cu, Pb and Zn. The chemical analysis of the hasty treaty of the ore was estimated to contain such constituents as Au, Ag, Cu, Pb, Zn, SiO₂, S and CaO at 0,353 ‰ 0,466 ‰ 15,11 ‰, 2,19 ‰, 35,55 ‰, 13,48 ‰, 1,8 ‰, and 2,5 ‰ respectively.

2 METHODOLOGY
2.1 GEOMINERALOGICAL CHARACTERISTICS OF DEPOSIT

The study area (Figure 1) is located in the municipal of Placetas, Villa Clara, Cuba, with coordinates points according to Lambert system: A(274300,628000), B (274300, 628450), C (273850, 628450) and D (273850, 628000). Geologically, it is located in a principal stratiform folds in the central region of Cuba where a complex rock mass is found of the continental nature, oceanic nature type ophiolitic and with different mixture of earth types. The deposit is found within complex ophiolitic rocks located in wild form over the sedimentary sequence of the continental bank and at the same time over run by volcanic cretaceous arc (Orestes et al., 2010). The principal rock mass type is massive serpentine with veins of gabbros. The mineral occurrence is associated with the tectonic zone conserved within massive serpentine wedge, the zone is affected by systems of faults of orientation between 250°-285° and dip within 65°-90°, also there exist transverse fractures with little development along its length, all these provoke displacement generally not more than 0.2 m (Vázquez et al, 2013).

2.2 RESEARCH PROCEDURE

The local and regional geological data of the mine was obtained from the mine geological department, according to the observational study carried out, the area of study was divided into 3 lithological zones of the rock type: massive serpentine, sheared serpentine and gabbros, according to each zone, 2 to 3 joint sets was observed and their orientations and dips were measured in areas accessible from level 2 to 4 of the mine. Figure 2 shows (a-c) sections of various minerals in Oro ore deposit and (d-f) sections of the mineralized zones of gold-arseno-sulphite with serpentine-carbonatic rock minerals in the deposit. The acimut and the dip of 300 discontinuities were measured in all the accessible galleries of the mine with the aid of compass, and the values were plotted in the Schmidt Diagrams to obtain a mean curve of the great circles shown in Figure 3 (i-ii).

Also the measurement of joint spacing of each set was taken and average value was obtained using Student’s statistical method. Based on the data from the field, the size of the rock block is obtained by the following expression:

\[ V_b = \beta \left( \frac{1}{\text{sen} \beta_1 \cdot \text{sen} \beta_2 \cdot \text{sen} \beta_3} \right)^{\frac{1}{3}} \]  

where: \( \beta \) - angle between joint sets, in degree  
\[ \beta = \frac{(a_2 + (a_2 - a_3) + a_3)^2}{(a_2 - a_3)^2} \]  

\[ a_2 = \frac{S_1}{S_1} \]  

\[ a_3 = \frac{S_2}{S_1} \]  

The joint volumetric (Jv) number (m⁻³) is determined from equation (5)

\[ J_v = \frac{1}{S_1} + S_2 + \frac{1}{S_3} \]  

where: \( S_i \), \( S_2 \), \( S_3 \) are the average joint set spacing (m). The RQD is determined by the equation (6)

\[ RQD = 100\% \sum_{i=1}^{n} \frac{S_i}{L} \]  

where: \( L \) is length of core sample greater than 100 mm, and \( n \) is the number of spaces intercepted by the measuring tape (Deere, 1989).

The index RMR is determined using the geomechanical classification table by Bieniawski (1989) based on data from the field. And finally, the index Q of Barton et al., 1966 is determined by using equation (7):

\[ Q = \left( \frac{RQD}{J_n} \right) \left( \frac{J_r}{J_a} \right) \left( \frac{J_a}{SRF} \right) \]  

where, \( J_n \) – joint set number  
\( J_r \) – joint roughness number  
\( J_a \) – joint alteration number
Jw – joint water reduction number
SRF – Stress reduction number.

The values of volume blocks are presented in Table 1; the column of interpretations (Table 2); summary of % mineral content in the rock mass of a well log, and type of blocks (Table 4) were obtained from the tables of Palmstrom (1982), (Orestes et al., 2010) and the Noa (2003) diagram.

3 RESULTS
3.1 MINERAL CONTENT OF ORE FROM THE DEPOSIT ZONE
Macroscopically, the mineral zone is composed of ultramafic rock serpentinized with macro and micro brecha and at times milonitized and highly carbonatized in which appears metallic minerals especially arsenopirite in a disseminated manner and vein form. The content of gold is somehow high within the limit of 5 g/t to 400 g/t. In some intervals there are occurrences as high as 1863.2 g/t. From the core samples it has registered gold content values from 223.4 g/t to 181.0 g/t with macroscopic traces of native gold. By calculation the average law of gold is 53.56 g/t. The silver content oscillates between the first g/t and 416 g/t with an average content of 19.65 g/t. The other elements content are approximately 0.9 % with exception of arsenic that reaches 3.9 %.

3.2 DISCONTINUITIES ORIENTATION AND DIP DATA
The results of the discontinuities orientation and dip data; a Schmidt stereographic diagram and the Rosette diagram obtained with the aid of the Rocscience DipV5-2004 are presented in Figures 3-4. The colours denote the pole points. Figure 5 is used in the determination of the type of rock block (Noa, 2003).

It was observed generally that the joints are continuous and smooth, sometimes as a fault model, the walls of the joints are altered by a slippery film material, the water inflow is below 5 litres per minutes, only drops of water is observed and at the wall of the joints moisture.

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**Figure 2:** Showing the (a-c) sections of various minerals and (d-f) sections of the mineralized zones of gold-arseno-sulphite with serpentine-carbonatic rock minerals in the deposit

**Figure 3:** Schmidt Diagrams

**Figure 4:** Rosette Diagrams

**Table 1:** Values of volume’s block, Oro Descanso’s mine

| Types of Block | RQD | Joint Spacing (m) | Block Volume (m³) | Interpretation | Type of Blocks |
|----------------|-----|-------------------|-------------------|----------------|----------------|
| Massive        | 0.24| 73.33             | 13.51             | Average        | Elongated & Tabular |
| Sheared        | 0.25| 56.76             | 13.13             | Small          | Cubic          |
| Serpentine     | 0.21| 81.01             | 11.31             | Small          | Elongated & Prismatic |
Figure 5: Determination of the type of rock block (Noa, 2003)

Table 2: Values of RQD, RMR, Q and interpretations

| Types of Rock          | RQD | RMR | Q        | Interpretation |
|------------------------|-----|-----|----------|----------------|
| Massive Serpentine     | 73.83 | 53.1 | 18.84    | Average | Class III Average | Good |
| Sheared Serpentine     | 35.76 | 37.6 | 8.44     | Average | Class IV Poor | Average |
| Gabros                | 61.01 | 55.8 | 11.58    | Good    | Class III Average | Good |

Table 3: Mineral content in the well log of rock mass (Orestes et al., 2010)

| Name of mineral rock | Percentage Content (%) | Colour |
|----------------------|------------------------|--------|
| Serpentine Plagioclastic | 10-30                  | Ash    |
| Massive Serpentine     | 5-20                   | Dark green with crystal |
| Plagioclastic         |                        |        |
| Plagioclase Labradoric | 40-50                  | Ash    |
| Serpentine Apoperidolite | 10-15                | Black with fracture plane |
| Feldspat              | 5-10                   | White  |
| Plagioclase Gabros     | 20                     | Ash    |

Table 4: Range of block volume (Palmstrom, 1982)

| Range of block volume | V<sub>a</sub> (m<sup>3</sup>) |
|-----------------------|-------------------------------|
| Extremely small       | Less than 0.00001             |
| Very small            | 0.00001 – 0.0002             |
| Small                 | 0.0002 – 0.01                |
| Average               | 0.01 – 0.2                   |
| Large                 | 0.2 – 10                     |
| Very large            | 10 – 200                     |
| Extremely large       | Greater than 200             |

4 DISCUSSIONS

The deposit is composed of serpentine-carbonatized rocks that are highly different from the rock mass of serpentinized ultramafic and the serpentine rocks that housed the deposit. There are about 20 metalliferous minerals and 10 non-metallic minerals that constituted the mineral deposit. Native gold is the principal mineral with association of arsenopyrite which is the most abundant, about 90 % more than every other metallic mineral present in the deposit, its average content ranges from 0.5 to 8.5 %. Electrum analysis shows a rare mixture of galena with the native gold. There are small quantities of other metallic minerals like cuproaruite, galenite, altaite, calaverite and petzite, calcopirite, troilite, pentlandite, pirrotite, cobaltite, esfalteritz, calcosine, coveline, cinabrio, etc. The magnetite appears in form of fine secretions disseminated in lizardite and crysolite. The ilmenite occurs in the aggregate of altered rocks in form of very fine skeletal constituents. The mineralized zone of gold-arseno-sulphite coincides with serpentine-carbonatic rock type by the concepts of listvenites carbonătics reservoir of gold.

The principal planes of average discontinuities and fault are shown in the left side of Figure 3 with orientation from 057º to 314º and dip from 04º to 80º which denote stress zone of the mine which must be noted while designing mine excavations and method of exploitation. The Rosette’s diagram shows the orientations and density of the intersection of planes with horizontal surface of the circle which generally run from North to South. The mine is found located in a region which had experienced high tectonic activity, demonstrated by the size of the blocks which ranges from small to average according to Palmstrom classification of 1974 and the shape which varies so much (Table 1). This characteristic of the rock mass is a pointer to instability which might make the mine prone to unexpected fall of small pieces of rock. Also from Table 2, according to rock mass quality index of RQD, RMR and Q, the rock mass of Oro Descanso is of average quality which means that any excavation located within this type of rock mass need support to increase its factor of safety. So, according to the criteria of Bieniawski (1989) and Barton et al., (1966), the gallery should be excavated with top heading and bench, 1.5-3 m advance in top heading, commence support after each blast and complete support 10m from face. The type of support can either be systematic bolts 4m long, spaced 1.5-2.0 m in crown and walls with wire mesh in crown or support with shotcrete 50-100 mm in crown and 30 mm in sides.

5 CONCLUSIONS

From the results obtained from this study, the following conclusions can be drawn: The Oro Descanso mine rock mass is composed of small block sizes connected by fractures and joints. The feature of the rock mass shows its instability, which may make the mine liable to unanticipated fall of small rock fragments.

Also from the rock mass quality indices results, (RQD, RMR and Q), the rock mass of Oro Descanso is of average quality. The gallery should be excavated with top heading and bench, advance in top heading, commence support after each blast and complete support from face. Therefore, there is need for a proper support design and monitoring whenever a gallery is constructed in it. The type of support can either be systematic bolts, spaced in crown and walls with wire mesh in crown or support with shotcrete in crown and sides.

ACKNOWLEDGEMENT

The first author, A.O. Oluwaseyi appreciates TETFUND
for the sponsorship of the programme

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