Serra Grande, owned by AngloGold Ashanti, is located in central Brazil in the state of Goiás, about 5km from the city of Crixás. Serra Grande comprises three mechanised underground mines: Mina III (and an open pit on the outcrop of the Mina III orebody), Mina Nova (which includes the Pequizão orebody) and Palmeiras. One dedicated metallurgical plant treats all of the ore that is mined.

This paper aims to show how the rockmass classification of the mine known as Orebody V was performed, as well as different ways of interpreting a 3D geotechnical model.

PRE-FEASIBILITY OF OPEN PIT MINING

The study serves as the initial step of the pre-feasibility of open pit mining. Due to the lack of fresh rocks, this classification was performed only on the basis of drillcores. Most of the drillholes analysed were drilled at the end of the 1990s, when the Serra Grande Mine adopted the procedure of discarding the most weathered drillcores. Significant non-recovered intervals occur due to the existence of "cavities" developed in karst, as well as in saprolite. The structural data required for the development of the study comes from underground ore-drives.

Once the drillcores were logged, a database was created that shows the numeric values assigned to each of the individualised intervals, and also the classes to which these intervals were applied. Four classes of rockmass were identified. These four classes enabled two interpretations of different 3D models. The first interpretation considers the data in a qualitative way, with the direct association of the rockmass classes and the Down-Dip of the main foliation. The second interpretation also considers Down-Dip, but considers the data in a quantitative way, so the boundaries between the classes are delimited by a geostatistical method which influences the numerical data of the neighbouring intervals.

Due to the geological environment where the Orebody V mine is located, it can’t be considered as certain that the geotechnical parameters have significant spatial continuity in a specific direction. For this reason, the model that was interpreted in a qualitative way, with correlated classes, was considered the best option.
1 INTRODUCTION

1.1 Regional geological context

According to Pimentel et al. 2000, the Crixás Green Stone Belt is an elongated feature that has a north to south orientation and is approximately 45 km long and 6 km wide. It has a thin appendage that branches to the northeast. The belt’s northwest region borders the Anta Complex to the west; to the east and south it borders the Caiamar Complex; to the north it borders metavolcanosedimentary rocks (Mina Inglesa Sequence) as well as metasediments that are attributed to the Neoproterozoic of the Santa Terezinha Sequence (Jost et al., 2001, Dantas et al, 2001).

The Orebody V Mine is found within the Crixás “Green Stone Belt” region of thrust faults, and is positioned in a corridor where reptile deformations are prevalent. This corridor follows the regional direction, and, within it, hydrothermal fluids percolate through the rock, creating distinct hydrothermalised zones. Orebody V is found among these hydrothermalised zones. This deformation corridor is referred to as Structure IV and has a dip of 32/245°.

It is positioned above a group of rocks of the Córrego Alagadinho Formation (Jost & Oliveira, 1991), which is comprised of metakomatiites, metabasalts and intercalations of banded iron formations. Carbonaceous schists, meta-graywakes and dolomites of the Ribeirão das Antas Formation (Figure 1) also occur.

1.2 Local geological context

The Orebody V mineralisation occurs within quartz venulations in a band that is approximately 100 metres thick, where centimetric intercalations of metasediments (META_SED) occur as graphite schists and meta-graywakes. Above the mineralised horizon, within the hanging wall, a distinct horizon of dolomites (DOL) occurs, as well as a solid band of metabasalts (MBA), which are intercalated with carbonate-chlorite schists (CBCX) (Figure 2).

Numerous duplications of lenses of metasediments, metabasalts, carbonate-chlorite schists and dolomites occur within the footwall. The voids (fissures) occur preferentially in the dolomites; however, they are also observed within the weathering profile (SOIL). The preferential direction of the foliation, which was measured on structures underground, was 38/250°.

2 MATERIALS AND METHODOLOGY

2.1 Materials

Tables containing the existing geological descriptions and the fields to be filled in with the geotechnical descriptions were used to develop the geotechnical descriptions of the drill cores of the eleven drillholes and the classification of the rocks according to the RMR system.

A geologist’s field hammer and a tungsten tip were also used. The data was interpreted with Leapfrog Geo software.
2.2 The RMR (Rock Mass Rating System) Classification Method

The RMR classification system is also known as the Geomechanical Classification System (Bieniawski, 1989). The system was developed to better understand the importance of various parameters, and also to provide a design tool, for the construction of tunnels. The range of RMR values varies between zero and 100 points in accordance with five classifications; moreover, this system of classification via points may be penalized as a result of the orientations of unfavourable discontinuities that are applied to underground excavations. The main advantage of the RMR system is its ease of use; however, minute variations in the quality of the rockmass are difficult to detect.

The six parameters and the formula that is used to classify the rockmass are defined in accordance with the relationship (1) below:

\[ \text{RMR} = A_1 + A_2 + A_3 + A_4 + A_5 + B \quad (1) \]

The RMR must be applied by separating the rockmass into uniform units that display similar structural and geological characteristics. Although the rockmass is discontinuous by nature, one should try to separate it into regions where the spacing between discontinuities (or frequency) is uniform, such regions being separated from each other by fault zones, dykes and/or fractures, among other features.

The RMR is defined by the above mentioned parameters, and the criteria and values for each parameter are presented in Table 1:

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Factor</th>
<th>Weight</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uniaxial resistance solid rock</td>
<td>A-1</td>
<td>0 - 15</td>
</tr>
<tr>
<td>RQD quality of the drill core</td>
<td>A-2</td>
<td>3 - 20</td>
</tr>
<tr>
<td>Spacing of the discontinuities</td>
<td>A-3</td>
<td>5 - 20</td>
</tr>
<tr>
<td>Condition of the discontinuities</td>
<td>A-4</td>
<td>0 - 30</td>
</tr>
<tr>
<td>Groundwater conditions</td>
<td>A-5</td>
<td>0 - 15</td>
</tr>
<tr>
<td>Discontinuity orientation adjustment</td>
<td>B</td>
<td>(-12) - 0</td>
</tr>
</tbody>
</table>

Table 1:
RMR CLASSIFICATION SYSTEM PARAMETERS.

In section A, each parameter is grouped into five intervals of decreasing value that reflect a reduction in the quality of the rockmass. Of the five parameters used within the classification system, three refer to the discontinuities that are present in the rockmass, especially the average spacing that is taken into account twice in the RMR classification - primarily with respect to the value of the spacing in and of itself and, second, through the RQD. Because of this, obtaining a correct estimate of the average spacing of the discontinuities is very important. Regarding this case study, the RQD was obtained via equation (2), where “A-3” represents fracturing (Hoek, 1998).

\[ \text{RQD} = 115 - 3.3(A-3) \quad (2) \]

Table 2 follows below, in which the classes of rockmass are specified in accordance with the RMR system:

<table>
<thead>
<tr>
<th>Class of the Rockmass</th>
<th>Description of the Rockmass</th>
<th>RMR</th>
</tr>
</thead>
<tbody>
<tr>
<td>I</td>
<td>Very Good Rock</td>
<td>81 - 100</td>
</tr>
<tr>
<td>II</td>
<td>Good Rock</td>
<td>61 - 80</td>
</tr>
<tr>
<td>III</td>
<td>Fair Rock</td>
<td>41 - 60</td>
</tr>
<tr>
<td>IV</td>
<td>Poor Rock</td>
<td>21 - 40</td>
</tr>
<tr>
<td>V</td>
<td>Very Poor Rock</td>
<td>0 - 21</td>
</tr>
</tbody>
</table>

Table 2:
CLASSIFICATION OF THE ROCKMASS ACCORDING TO THE RMR SYSTEM

2.3 Results

By means of the geotechnical description of 11 drillholes (Figure 3), two distinct interpretations of the rockmass were developed.
The first interpretation that was developed was quantitative, and it was reached through the simple linear interpolation of the RMR values that were obtained via the summation of the weights of the parameters that were outlined above (1). The simple linear interpolation is used to establish the impact that an individual interval within the RMR classification has on its neighbouring intervals. To execute the interpolation, standard Leapfrog Geo software was used, which adopted as its orientation the Down-Dip of the principal foliation.

The second interpretation was qualitative in nature, and also adopted the principal foliation as its orientation. However, in contrast, a direct correlation was made between the classes of rockmass that were developed for the geotechnical description (Table 2).

### 2.3.1 Interpretation developed via the interpolation of the RMR values

The spatial arrangement of the drillholes that were logged is shown in Figure 4:

Figure 4. Oblique view of the conceptual pit and RMR data.

Figure 5 shows that the RMR values have the tendency of accumulating on the SW slope of the conceptual pit.

Figure 5. SW-NE cross-section of the centre of the conceptual pit. Azimuth 350°. A colour scale represents the sum of the RMR values.

Figure 6 shows an interpretation of the various classes of rockmass. The rockmass of the worst quality, represented by classes IV and V, is prevalent within the southwestern slope, whereas the northeastern slope primarily contains class III rockmass, which is considered to be of fair quality.

Figure 6. SW-NE cross-section of the centre of the conceptual pit. Azimuth 350°. Note the four distinct rockmass classes that were obtained through the simple linear interpolation.

### 2.3.2 Interpretation through the direct correlation of classes

The values that were converted into rockmass classes are shown in Figure 7:

Figure 7. SW-NE cross-section of the centre of the conceptual pit. Azimuth 350°. Note the four rockmass classes, which are represented qualitatively.

The interpretation undertaken through the direct interpretation of the four rockmass classes is shown in Figure 8.

Figure 8. SW-NE cross-section of the centre of the conceptual pit. Azimuth 350°. Note the four rockmass classes, which are represented qualitatively.

The southwestern slope is notable for containing mostly very low quality rock, whereas the northeastern slope contains rockmasses that are mostly fair to poor in quality.
2.4 Analysis of the results

The interpretation and correlation between the different classes of rockmass follow specific geological criteria, such as, for example, foliations and faults. However, certain minutiae, such as the degree of rounding of the lines, the point of separation between the classes or the geological contacts, are personal and can vary between the professionals that interpret them.

In light of the possibility of disregarding interpretations that are very "personal" by employing technical methods such as geostatistics, the geotechnical model was developed by using the simple linear interpolation technique. This procedure aimed to produce a more precise geotechnical model.

Generally speaking, the two models show a certain consistency with respect to the spatial arrangement of the four rockmasses that were identified within the region of Orebody V.

A section of class III rockmass occurs which extends from the deepest portion of the conceptual pit for at least 400 metres along the Down-Dip. The class II rockmass is prevalent at depth towards the southwest and the northeast. For both interpretations, the class IV rockmass only corresponds to a small volume of rock that is concentrated in the surroundings of the pit and outcrops within the northeastern portions of the models. The class V rockmass is most prevalent at the southwestern slope.

In comparing the two interpretations, it should be noted that the direct correlation between the classes of rockmass results in a greater volume of the class V rockmass, which reveals a significant drop in the quality of the rockmass for both of the slopes within the pit with respect to the interpolant model.

The interpolation tends to force the interpretation of the different classes of rockmass, elongating them in the Down-Dip direction. Because of this, in situations such as that of the northeastern slope, between drillholes IV-38 and III-79 (Figure 9), the interpretation of class III is exaggerated (Figure 10).

The larger amount of data for classes II and III generates a greater influence of these classes on the total volume of rock depicted in the model that was constructed with the simple linear interpolation technique. This provokes unnecessary impacts on the spatial continuity of class V (Figure 12), such as that which occurs at the southwestern slope of the pit between drillholes IV-13 and IV-23 (Figure 11).
3 CONCLUSIONS

The geotechnical parameters that were taken into account by the RMR classification can show spatial continuity in one direction, as it occurs with various mineralisations. But this is extremely restricted to a geological environment that is propitious for this to occur.

Upon analysing the data that was obtained from the description of the 11 drillholes that were executed within Orebody V, one can note a spatial continuity of the RMR values. However, upon analysing the details of the model that was generated via the simple linear interpolation technique, one can conclude that the spacing between the drillholes is quite large, and an insufficient amount of data exists to generate a reliable geotechnical model by means of geostatistical methods. A misrepresentation of the spatial continuity of the classes of rockmass arises as a result of the small database.

These issues regarding the use of geostatistics can only be eliminated or quarantined through the logging of more drillholes and the resulting increase not only in the size of the database but also in the detail that the region is expressed in.

Despite having knowledge of this continuity in the RMR values within the database that was used, one cannot take for granted that the geotechnical parameters that were used in the classification are spatially continuous within a geological environment such as the Crixás “Green Stone Belt” thrust fault duplex.

The model that was developed via the simple qualitative correlation of classes method, presented within this case study, is considered valid for the purposes of continuing the pre-feasibility studies regarding the Orebody V Open Pit Mine.

The prevalence of the class V rockmass within the southwestern slope of the conceptual pit is associated with a thickening of the weathering layer, which extends along the strike of the principal foliation and is identified in the geological model as reaching a maximum depth of 120 metres.

REFERENCES


