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Finding the Relationship between RQD and Fracture Frequency in the different Ok Tedilithologies

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Abstract

Rock Quality Designation, RQD, is based on core recovery procedure which, in turn, is based indirectly on the number of fractures and amount of softening or alteration in the rock mass as observed in the rock cores. Many researches have been conducted to relate RQD and rock mass fracture. Along with many other parameters, RQD and fractures contribute greatly to the classification of a rock mass, which affect practical engineering practice and design such as pit slopes in mining. Setbacks in accurate judgement of the strength of the different rock types at one of the major open pit mine in Papua New Guinea was observed. Series of practical examinations using RQD data and scan line mapping of fractures has been conducted in four main section of the pit slope. Variation of RQD with scan line mapping of structures was observed to be as high as 24\% in the horizontal bench face. In addition, the range of possible variation of RQD with scan line length was analyzed with four different models including two new models introduced in this case study for the first time. It is shown that at least 4 m of scan line length is required to maintain a reliable value for the RQD in the models.

Keywords:

1. Introduction

1.1. Background

The Ok Tedi porphyry copper-gold deposit lies in the Star Mountains, located in the Western Province of Papua New Guinea, which is 18\,km east of the PNG-Indonesian border, centred on Mt Fubilan (lat.5° 12’S, long.141°8’E). Rainfall in the mine area averages to about 10 – 12m per annum. Before the mine initiated, its altitude was originally 2,053m above sea level, and after 30 years of mining, the current (2011) pit floor lies at 1,408m. The Ok Tedi mine is a large scale open-cut operation in which both ore and waste rock are being removed each day (150 – 180kt) from a pit covering about 2.6 km$^2$. The mine and mill operate 24 hrs/day, 365 days/yr.

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1.2. Geology

The Ok Tedi deposit lies within the Western Fold Belt mineral province (which incorporates New Guinea Fold Belt and the Papuan Fold Belt). The region is characterised by weakly to moderately folded and thrust faulted Mesozoic and Cainozoic continental marine sedimentary units, intruded by stocks of Middle Miocene to Pleistocene age. The deformation occurred as a result of accretionary tectonics and orogenesis during the WSW-trending collision of the Pacific Plate and Indo-Australian Plate in the Late Oligocene – Early Miocene. The oldest exposed sedimentary unit in the region is the Ieru Formation, comprising marine mudstone and glauconitic sandstone. Disconformably overlying the Ieru Formation is the Darai Limestone (Late Oligocene to Early Miocene). At Mt Fubilan, this unit is 300–600m thick, thrust faulted, and hosts many of the skarn bodies. Pnyang Formation overlies Darai Limestone and consists mainly of calcareous mudstone and siltstone with some prominent limestone horizons. The first volcanic activity occurred in the Mid-Miocene with deposition of minor tuffaceous sandstone in the Birim Formation. Overlying the Birim Formation are volcanoclastic sediments, the Awin Formation, which represent an eroding stratovolcano of Late Miocene to Pliocene age.

The main rock types in the Ok Tedi Deposit comprise stratigraphically of both Sedimentary units and Intrusive units, as a result of the Ieru Formation and Darai Limestone that was intruded by the Ok Tedi intrusive complex.

The main rock types at the Ok Tedi Deposit include:

(1) Sedimentary Units (host Cu-Au Mineralization)
- **Ieru Silstone**- country rock surrounding the ore body, overlain unconformably by limestone.
- **Darai Limestone** – main country rock in the area which also host mineralization. Limestone is used to neutralize the acid mine drainage resulting from the mining activities.
- **Pnyang Formation** – youngest sedimentary unit in the area which conformably overlies the Darai Limestone and comprises of siltstones, sandstones and mudstones.

(2) Intrusive Units
- **Monzodiorite**: Southern intrusive body in the pit and is equigranular in texture, color index is felsic-intermediate, mineral content is plagioclase (andesine), clinopyroxene, orthoclase, hornblende, biotite, (spheine, apatite, magnetite) + quartz, ore minerals include pyrite, chalcopyrite, ± bornite, gold and most is low grade and is blocked as waste.
- **Monzonite Porphyry**: Occupies the northern part of the Fubilan deposit, is porphyritic in texture, mineral content comprise of hornblende, feldspar (plagioclase > orthoclase, quartz, biotite, ± (spheine, apatite, rutile, magnetite), pholophite, ore minerals include pyrite, chalcopyrite, chalcocite, digenite, marcasite > bornite, molybdenite, gold, cristobalite and forms the major ore type for the pit.
- **Skarn (Pyrite skarn, magnetite skarn, oxide skarn, endoskarn)**: Adjacent to the intrusive and sedimentary contacts and holds most of the Cu-Au mineralization of the Fubilan deposit. The Skarn is formed as a result of the replacement of the carbonate-bearing rocks during contact metamorphism and metasomatism.

The Ok Tedi stocks and their deposits occur within the regional scale NW-SE trending Ok Tedi Anticline and are closely associated with two north dipping thrust faults, which cause repetition of parts of the stratigraphy. The thrusts are known as the Taranaki and Parrot’s Beak. The thrust faults comprised of highly fractured and altered fault gouge, pyrite and magnetite skarn lenses, brecciated monzodiorite, and brecciated honfelsed siltstone. Movement along those thrusts occurred during various spasms of igneous activity. Thrusting occurred during and after copper and gold mineralizing events (Baczynski, et al 2008)

2. Field Data Collection

2.1. Scanline Mapping

During the mapping activities, 3 linear scanlines were undertaken for three different lithologies. A total of 90m of scanline were mapped (areas shown in Figure 1) for discontinuity measurements, the rock types and infill information which are shown in Table 1. The discontinuity sets in the mapping area were quite randomly oriented, not following a fixed pattern.
Several downsides were also noted during the course of this study:

- The cores were logged, to obtain the RQD values, in vertical drillholes, whereas scanlines were mapped horizontally.
- Limited amount of data were used for analysis due to time and cost limitations.
- The scanlines were located on bench faces, in which the faces appeared to have some fractures induced by blasting. They were recognized by having lacked orientation, without infills, non-continuous in strike length and were disregarded during the course of counting fractures.
- Other discontinuity parameters were not recorded during the time of mapping.
- The mapping area was located approximately near the coordinates of the drilling location and not exactly.
| Intervals | Fracture Frequency | Faults | General Comments                      |
|-----------|--------------------|--------|---------------------------------------|
| 0 - 1m    | 5                  | 1      | Major fault running across the face   |
| 1 - 2m    | 3                  | 1      |                                       |
| 2 - 3m    | 3                  | 1      |                                       |
| 3 - 4m    | 10                 | 1      |                                       |
| 4 - 5m    | 5                  | 1      |                                       |
| 5 - 6m    | 5                  | 1      |                                       |
| 6 - 7m    | 4                  | 1      |                                       |
| 7 - 8m    | 7                  | 1      |                                       |
| 8 - 9m    | 6                  | 1      |                                       |
| 9 - 10m   | 4                  | 1      |                                       |
| 10 - 11m  | 3                  | 1      |                                       |
| 11 - 12m  | 5                  | 1      |                                       |
| 12 - 13m  | 3                  |        |                                       |
| 13 - 14m  | 4                  |        |                                       |
| 14 - 15m  | 4                  |        |                                       |
| 15 - 16m  | 4                  |        |                                       |
| 16 - 17m  | 3                  |        |                                       |
| 17 - 18m  | 7                  |        |                                       |
| 18 - 19m  | 7                  |        |                                       |
| 19 - 20m  | 5                  |        |                                       |
| 20 - 21m  | 5                  |        |                                       |
| 21 - 22m  | 4                  |        |                                       |
| 22 - 23m  | 4                  |        |                                       |
| 23 - 24m  | 4                  |        |                                       |
| 24 - 25m  | 6                  |        |                                       |
| 25 - 26m  | 9                  |        |                                       |
| 26 - 27m  | 4                  |        |                                       |
| 27 - 28m  | 2                  |        |                                       |
| 28 - 29m  | 2                  |        |                                       |
| 29 - 30m  | 4                  |        |                                       |

Table 1: Fracture counts data collected during mapping

2.2. RQD Data

The RQD information was collected, by the mine geotechnical personnel, from vertical drillholes which were drilled during the early stages of mining. The cores were logged for structures, RMR, RQD and recovery. The RQD data from various drillhole shown below are specific data for around the mapping area.
3. Discontinuity Frequency and RQD

3.1. Background

According to Hudson & Harrison (2000), discontinuity frequency, being the number of fractures per metre, is the reciprocal of the mean spacing. When a sufficiently large sample of these individual spacing values (preferably more than 200 individual measurements) is plotted in histogram form, a negative exponential distribution is often evident. The general trend of this histogram is for there to be many small spacing values and few very large spacing values in the distribution.

The discontinuity spacing parameter is often used in rock mass classification schemes such as the rock mass rating system (Wines & Lilly, 2002).

Discontinuity spacing measurements can be separated into the following three forms:

- Total spacing is the distance between two adjacent discontinuities, measured along a line of general, but specified, location and orientation.
- Set spacing is the spacing between two adjacent discontinuities from a particular discontinuity set, measured along a line of general, but specified, location and orientation.
- Normal set spacing is the set spacing measured along a line that is normal to the mean orientation of a particular set.

Priest and Hudson reported that discontinuities are never similarly distributed in all directions and, as a consequence, frequency values will depend on the direction of the mapping line. They provide formulae that allow the estimation of discontinuity frequency along any orientation for a given discontinuity set of known orientation and spacing. The formulae allow detailed analysis of frequency variation and can be used to estimate the directions and magnitudes of the maximum and minimum frequency values for a given rock mass.

The Rock Quality Designation (RQD) measures the percentage of “good” rock within a borehole. It was developed by Deere as a means of qualitatively describing whether a rock mass provided favourable tunnelling conditions. It is now used as a standard parameter in drill core logging and forms a basic element of several rock mass classification systems. It is an index related to the degree of fracturing of the core. RQD is a modified core recovery percentage in which all the pieces of sound core over 100 mm (4 in.) long are summed and divided by the length of the core run (Kirkdale, 1988).

Priest and Hudson proposed the following relationship between a theoretical RQD* and the mean discontinuity frequency per metre ($\lambda$):

$$RQD^* = 100 \left(0.1\lambda + 1\right)e^{-0.1\lambda} \quad (1)$$

Priest and Hudson (1976) also proposed that the use of this equation in conjunction with scanline surveys on freshly exposed faces is more appropriate than the determination of RQD from diamond core.

| DDH 960 (Easting: 315339.76; Northing: 429940.18; RL: 1510.897) |
|------------------------|-----------------|-----------------|-----------------|-----------------|-----------------|
| RUN | RECOVERED | LITHOLOGY | CORE LOSS | RQD |
| From (M) | To (M) | length (M) | [M] | [%] | Length (M) | (M) | % |
| 78.90 | 80.50 | 1.60 | 1.60 | 100.00 | MP | 0.10 | 1.40 | 87.50 |
| 80.50 | 81.90 | 1.40 | 1.40 | 100.00 | MP | 0.00 | 1.34 | 95.71 |
| 81.90 | 83.50 | 1.60 | 1.60 | 100.00 | MP | 0.10 | 0.57 | 35.63 |
| 83.50 | 84.90 | 1.40 | 1.40 | 100.00 | MP | 0.10 | 0.95 | 67.86 |
| 84.90 | 86.40 | 1.50 | 1.50 | 100.00 | MP | 0.00 | 1.35 | 90.00 |
| 86.40 | 87.90 | 1.50 | 1.50 | 100.00 | MP | 0.10 | 0.86 | 57.33 |
| 87.90 | 88.40 | 0.50 | 0.50 | 100.00 | MP | 0.00 | 0.4 | 80.00 |

Table 2: DDH 960 Core log data
This is because core logging may tend to underestimate RQD values due to the formation of induced fractures during the drilling process. Priest and Hudson suggested that a plot of $\lambda$ versus RQD* shows a good linear approximation within ranges of $6<\lambda<16$ is provided by the tangent at the inflection point of the curve. The equation of the tangent is given by:

$$RQD^* = 110.4 - 3.68\lambda$$  \hspace{1cm} (2)

3.2. Analysis

Hence, using this equation, data analysis was carried out to find the relationship between RQD and fracture frequency in Monzonite Porphyry. The graph and equation derived from this is shown next page.
| Intervals | Joints | Faults | General Comments | Spacing | Frequency of Occurrence | RQD  |
|-----------|--------|--------|------------------|---------|-------------------------|------|
| 27 - 28m  | 2      |        |                  | 0.5     | 0.74                    | 98.25|
| 28 - 29m  | 2      |        |                  | 0.5     | 0.74                    | 98.25|
| 1 - 2m    | 3      | 1      |                  | 0.33    | 1.10                    | 96.31|
| 2 - 3m    | 3      | 1      |                  | 0.33    | 1.10                    | 96.31|
| 10 - 11m  | 3      | 1      |                  | 0.33    | 1.10                    | 96.31|
| 12 - 13m  | 3      |        |                  | 0.33    | 1.10                    | 96.31|
| 16 - 17m  | 3      |        |                  | 0.33    | 1.10                    | 96.31|
| 6 - 7m    | 4      | 1      |                  | 0.25    | 1.47                    | 93.84|
| 9 - 10m   | 4      | 1      |                  | 0.25    | 1.47                    | 93.84|
| 13 - 14m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 14 - 15m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 15 - 16m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 21 - 22m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 22 - 23m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 23 - 24m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 26 - 27m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 29 - 30m  | 4      |        |                  | 0.25    | 1.47                    | 93.84|
| 0 - 1m    | 5      | 1      | Major fault running across the face | 0.2     | 1.84                    | 90.98|
| 4 - 5m    | 5      | 1      |                  | 0.2     | 1.84                    | 90.98|
| 5 - 6m    | 5      | 1      |                  | 0.2     | 1.84                    | 90.98|
| 11 - 12m  | 5      | 1      |                  | 0.2     | 1.84                    | 90.98|
| 19 - 20m  | 5      |        |                  | 0.2     | 1.84                    | 90.98|
| 20 - 21m  | 5      |        |                  | 0.2     | 1.84                    | 90.98|
| 8 - 9m    | 6      | 1      |                  | 0.17    | 2.21                    | 87.81|
| 24 - 25m  | 6      |        |                  | 0.17    | 2.21                    | 87.81|
| 7 - 8m    | 7      | 1      |                  | 0.14    | 2.58                    | 84.42|
| 17 - 18m  | 7      |        |                  | 0.14    | 2.58                    | 84.42|
| 18 - 19m  | 7      |        |                  | 0.14    | 2.58                    | 84.42|
| 25 - 26m  | 9      |        |                  | 0.11    | 3.31                    | 77.25|
| 3 - 4m    | 10     | 1      |                  | 0.1     | 3.68                    | 73.58|

Table 6: Spacing, Frequency and RQD

Figure 3: Graph showing RQD vs Fracture Frequency in Monzonite Porphyry
3.3. Discussion

The diamond drill holes were drilled across the strike of the predominant structural orientations, whereas the mapping was done approximately parallel to the predominant geological structures. The effects of orientation bias will have caused the diamond holes to intersect the predominant geological orientations more regularly than the scanlines hence showing in the difference between the RQD values obtained from the drill holes and the values obtained using the equation. When comparing the RQD values, they are slightly different and this is explained by RQD being a directional parameter. It is more sensitive in the direction it is obtained.

The main reason for this was that mapping was carried out in the horizontal direction while the RQD parameters were obtained through vertical drill holes.

But the general trend of the relationship between RQD and fracture frequency still tend to follow the one suggested by Priest and Hudson.

4. Conclusion

For the case of Monzonite Porphyry in Ok Tedi, the relationship is similar to that of Priest and Hudson’s and the linear approximation occurs within $2<\lambda<10$, which is given by the equation:

$$RQD^* = 105.9 - 3.0845\lambda$$  \hspace{1cm} (3)

The general concept of the decrease in RQD values as fracture frequency increases is confirmed from the analysis carried out. Where diamond core data is not readily available, the method suggested by Priest and Hudson is a valuable tool to be used for geotechnical investigations.

There is, however, a need for further detailed research required into this area to help improve rock mass classification systems when diamond core data is not available.

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