

Establishing a site specific mining geotechnical logging atlas

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ABSTRACT: In many instances geotechnical training and the generation of geotechnical logging procedures is undertaken using a generic application of accepted rockmass classification systems. These logging procedures regularly neglect to take into account the site specific rockmass characteristics and interpretations that are integral to the undertaking of a quality assured assessment of the rockmass conditions. In addition, the regular practice of fly in and fly out (FIFO) schedules and high personnel turnover leads to numerous quality control aspects related to the inconsistent acquisition of geotechnical data. Discussed is the approach and benefits of establishing a site specific detailed geotechnical logging atlas. This atlas should include aspects such as descriptions and photographic references to specific types of discontinuity characteristics for the various lithologies; rock strength testing and sampling procedures, as well as the reference logging of site representative boxes of core. Three case study examples are included in the paper. Also discussed will be the tailoring of a site-specific geotechnical data acquisition program relative to the level of study being undertaken, from exploration through to the final feasibility.

1 INTRODUCTION

Geotechnical logging programs, as with geology logging programs, can be susceptible to quality control issues within the data set. These quality control issues typically arise from poorly-defined nomenclature and incorrect or inconsistent logging procedures at a site. Errors can be further exacerbated by the FIFO schedules of loggers at remote sites as well as the high turnover of personnel related to the current positive mining market.

The creation of logging procedures manuals for quality control is not a new approach, but existing manuals tend to be generic documents. These documents are often carried without modification from one project to the next. This paper advocates the establishment of a site specific geotechnical logging atlas that achieves the consistent field determination of geotechnical parameters.

This system takes into account the level of the applicable study; the specific characteristics of the mineralization context; the likely mining methods as well as the specific rock mass characteristics that may affect the mining method selection. By considering all these aspects, the “blanket approach” of unfocused detailed geotechnical data acquisition programs could be avoided. In the absence of a site-specific, tailored approach, the logging exercise may be a high cost, time consuming process. Additional-

ly, this would also avoid the case where earlier drill holes should have been logged based on specific geotechnical requirements prior to sampling, but were not.

This paper discusses the process of establishing a site specific atlas. Also included are three case studies where the geotechnical logging program was tailored to focus on specific geotechnical aspects related to future likely mining methods.

2 ASSESSING THE SPECIFIC REQUIREMENTS OF A GEOTECHNICAL CORE EVALUATION PROGRAM

To assess the key elements and tailor the requirements of the geotechnical logging program, the following aspects, need to be considered prior to and in association with, a dedicated site visit (Fig. 1):

- Current level of study
- Mineralization context
- Likely mining methods
- Distinctive orebody/country rock characteristics.

The first three aspects listed above are discussed within this section and the final aspect is considered later in a separate section.

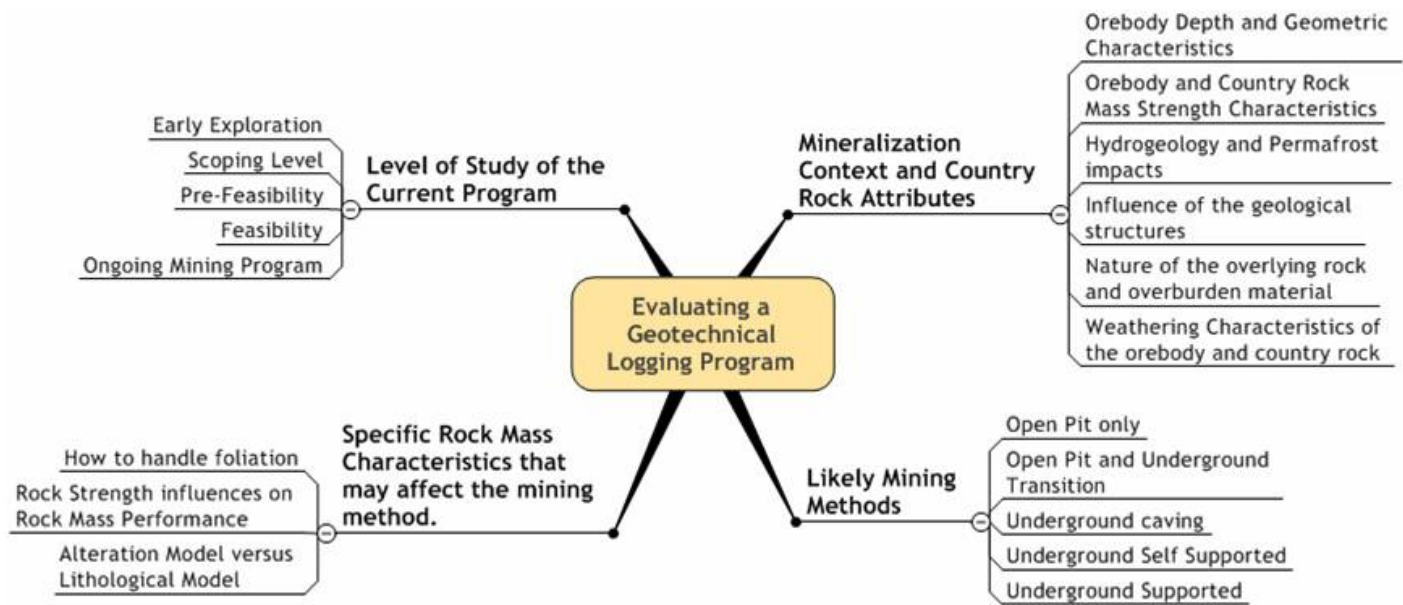


Figure 1. Elements to be considered when evaluating and setting up the guidelines of a site specific geotechnical logging program.

Once these project attributes are well understood it is possible to tailor the exploration program to limit the collection of superfluous data and focus the requirements specific to the context. The implication thereof is discussed in more detail below.

2.1 Level of study of the current program

To customize the level of geotechnical information required, it is important to understand both the study level and short and long term geotechnical objectives. Once these factors are understood, the geotechnical drilling program should be optimized to focus on areas of geotechnical significance. Such areas should target ground to be exploited (e.g. pit perimeter, deeper sections only of drill holes for open stoping). In addition to obtaining relevant, high resolution geotechnical data, this customized approach will potentially save time and money over the duration of the project evaluation.

From the outset of any exploration program it is important to undertake a minimum level of geotechnical data acquisition on all drill holes. This should include the following parameters for each drilling interval: RQD (rock quality designation), TCR (total core recovery), IRS (intact rock strength: strong, weak and % weak) and weathering/alteration type and intensity.

As the project advances through the various levels of study, the coverage and resolution of the representative geotechnical data needs to intensify. Table 1 endeavors to generically quantify the minimum level of required geotechnical data based on the level of study and the type of mining method that may be employed. These requirements can then be fur-

ther tailored to the specific deposit type and context related requirements.

2.2 Mineralization context and country rock attributes

To make a reasonable assessment of the potential range of mining methods and focus the geotechnical logging program, the mineralization context and country rock attributes need to be well understood. Listed below are a number of contextual aspects that need to be considered prior to formulating a geotechnical logging program:

- Orebody depth and geometry
- Orebody and country rock strengths
- Nature of the overlying rock mass and overburden material
- Influence of major geological structures
- Weathering/alteration characteristics of the orebody and country rock
- Hydrogeology and possible permafrost impacts.

Understanding the context of the deposit will facilitate a selection of the range of possible mining methods as well as the specific aspects of the rock-mass that need to be focused on during the geotechnical evaluation.

2.3 Likely mining methods

At an early stage of the project evaluation, an initial engineering judgment should be made on the likely range of mining methods that are being considered. This would be based not only on the context of the mineralization and country rock but also on the po-

tential economic value of the ore and on environmental considerations.

Aspects such as the potential orebody geometry, strength characteristics and depth are initially considered to determine the likely range of mining methods. It is important to consider whether the mining scenario would involve an open pit, underground or a combination of both.

If an underground method is to be used, it is necessary to discern whether a caving, self supported (open stoping/room and pillar) or supported method (backfill) will be employed. Based on the likely mining methods, the geotechnical program can be structured to determine the required, more detailed geotechnical parameters in specific areas, and not just on a 'blanket approach'. This is anticipated to generate time and cost savings throughout the geotechnical evaluation program.

3 MINERALIZATION CHARACTERISTICS - INFLUENCES ON THE INTERPRETATION OF GEOTECHNICAL PARAMETERS THROUGH CORE LOGGING

Depending on the deposit type, the interpretation of certain aspects can substantially affect the interpretation of the rockmass classification values. Figure 2 summarizes typical practices during core logging which can adversely affect rockmass parameter determinations. Specifically, the following represent typical geotechnical parameters where a customized approach may be required.

- Alteration/weathering;
- Rock strength;
- Foliation/jointing/bedding/cemented jointing; and
- Micro-defects (e.g. veining, cemented matrix).

Table 1. Typical requirements for geotechnical logging programs based on mining method and level of study.

Likely Mining Method	Core Related - Key Geotechnical Aspects	Exploration Stage Project	Pre-Feasibility/Feasibility Following a Positive Scoping Study
Open Pit	Slope stability - waste and ore Rock mass strength Discontinuity orientation and strength Overburden characteristics and strength Hydrology and hydrogeology Structural Geology and fault strengths		In all drill holes: All basic geotechnical information requirements Point load testing program In all drill holes within potential pit slope areas: Detailed discontinuity information for the full hole length. In representative drill holes: Overburden characteristics including laboratory testing Detailed discontinuity information including full orientation of thereof Laboratory testing intact rock strengths and discontinuity shear strengths Shear strength tests on fill material within the influential major structural features. Detailed hydrogeology information and testing.
Caving Method Block, Panel, Sublevel	Cavability Fragmentation Waste/overburden Characteristics and strength Ore characteristics and strength Hydrogeology Structural Geology and fault strengths Stress Field	Basic Geotechnical Information Recovery, RQD, Rock Strength and alteration/weathering intensity for each drilling interval. <u>Detailed major structural feature information</u> General hydrogeology information during drilling. High resolution dry core photographs Detailed photographs of possible major structure intersections.	In all drill holes: All basic geotechnical information requirements Detailed discontinuity information Cemented joint frequency and strength Micro-defect frequency and strength Point load testing program. In representative drill holes: Detailed overburden logging and laboratory testing Full orientation of discontinuities (orientation tool / televiewer) Laboratory testing of representative orebody and country rock samples Detailed hydrogeology information and testing.
Self Supported Partial Extraction Room and Pillar Backfill Supported Cut and Fill Bench and Fill Overhand Underhand	Orebody strength/pillar strength Detailed understanding of Immediate HW and FW rock mass characteristics Hydrogeology Structural Geology and fault strengths Stress Field		In all drill holes: All basic geotechnical information requirements Detailed discontinuity information (~20m above HW to end)* Cemented joint frequency and strength (~20m above HW to end)* Micro-defect frequency and strength (~20m above HW to end)* Point load testing program. * distance above orebody HW increase if a HW infrastructure is proposed. In representative drill holes: Full orientation of discontinuities (orientation tool / televiewer) Laboratory testing of representative orebody and country rock samples Detailed hydrogeology information and testing.

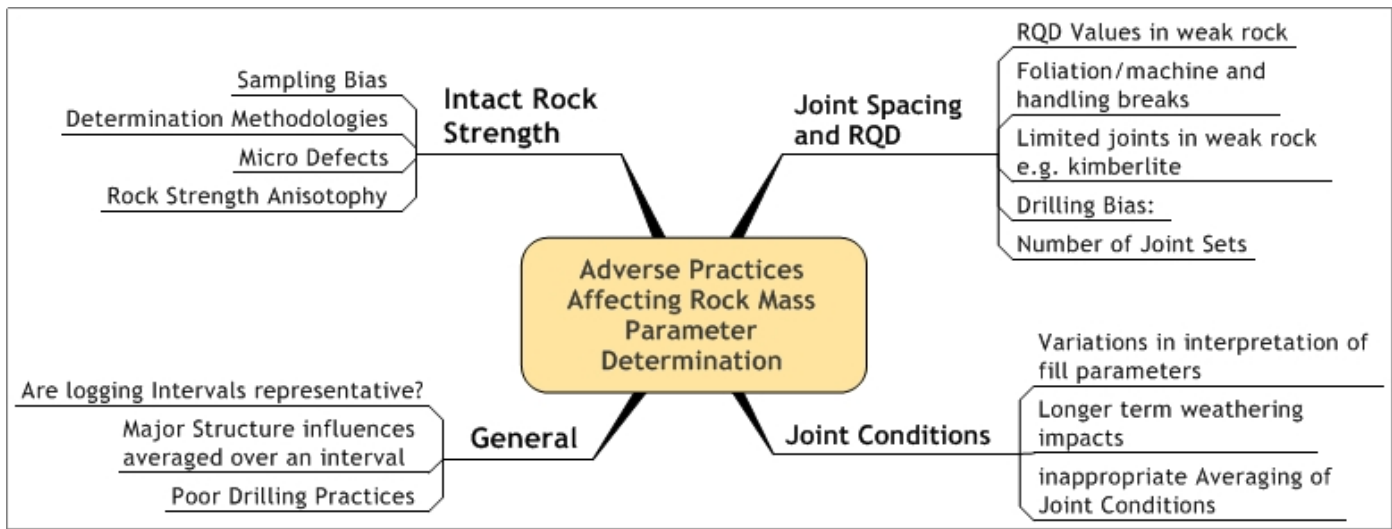


Figure 2. Practices during core logging that can affect rock mass parameter determinations.

Although the themes presented above are often captured using traditional rock mass classification systems, complications typically arise from technical misapplication and user error (lack of training, etc).

We plan to illustrate that with proper parameter evaluation, field staff can collect extremely valuable information required for future evaluation studies.

3.1 Intact Rock Strength (IRS)

3.1.1 Sampling bias

This can occur where strong and weak sections exist within the same interval. The tendency is to sample the stronger material thus leaving the weaker unrecorded thereby overestimating the strength. This bias has been addressed by Laubscher (1990) where the percentage of both strong and weak rock is recorded.

3.1.2 Rock strength anisotropy

The rock strength can be substantially different parallel and perpendicular to features such as foliation, schistosity and micro-defects. It is therefore important to collect strength data in multiple orientations.

3.1.3 IRS determination methodologies

IRS can be determined from empirical measurements, Schmidt Hammer and point load estimations and laboratory testing. As the level of study advances the methodology of estimating the IRS requires improvement and calibration.

3.1.4 Soft rock/soil strength determination

Commonly, field-staff classify weak rocks or soils as an R0 rating without applying the weaker S1 – S6 empirical strength evaluation. With weaker materials, the S1 – S6 evaluation should be applied otherwise a substantial level of detail will be lost.

3.2 Rock Quality Designation (RQD) and joint spacing

3.2.1 Machine and handling breaks

The logging guidelines should ensure that the impact of drilling and handling breaks are removed from the estimation of discontinuity counts.

3.2.2 Drilling direction bias

The impact of drilling bias on the determination of the number of joint sets, joint spacing and the RQD needs to be well understood. Evaluation programs should include a number of drill holes drilled in multiple orientations to ensure that all joint sets are intersected. If available, the geotechnical drill program must be evaluated against surface mapping at an early stage to estimate the potential impact of drilling orientation bias.

3.2.3 Weaker rock RQD estimations

High RQD measurements and low joint counts in weaker rock masses such as kimberlite lead to unrepresentative high rock mass classification rating values. The impact of the rock strength on rockmass strength determinations should be understood early on and the geotechnical evaluation program tailored to evaluate potential variations in this strength at a higher resolution. This may contribute significantly to the excavation designs and the related extraction levels within the mining method stage of the evaluation.

3.2.4 Joints and cemented joints

Cemented joints have a higher tensile strength than open joints, but the type and nature of the cementing material influences just how much stronger these are. Often when undertaking core logging, it is difficult to discern whether a discontinuity in the ground represents an open joint or a cemented joint. A reasonable approach is that if a cemented joint is open in the core, then it is reasonably weak and the

joint be counted as an open joint feature. This approach may be reconsidered for certain underground mass mining techniques (e.g. caving) where the relative amount of cemented joints and open joints may significantly affect the design layout. The above aspects are addressed in detail by Jakubec & Laubscher (2000).

3.2.5 *Fabric*

At the data collection stage it is essential that the impact of fabric on rock mass strength is well understood. For this reason, the number of fabric parallel breaks need to be separated from the total joint count. Depending on the orientation of the fabric and the prevailing stress field, excavation performance can be substantially better than that determined from a rock mass classification based on empirical design that included fabric counts in the total joint count. This approach can be executed not only in oriented core, but in unoriented core as a relative indicator.

3.3 *Joint conditions*

3.3.1 *Joint fill type and strength*

Unless strict, site specific guidelines are established, the fill type and joint strength determination is subjective and large variations in these parameters will be generated by various loggers. Additionally, field staff must understand the influence of weathering on joint strengths once the rockmass has been exposed. If the effect is recorded, the geotechnical evaluation programs should include further evaluation of this aspect.

3.3.2 *Joint roughness and aperture*

As is the case with fill strength, site specific examples and guidelines need to be established to avoid large variations in the estimation of these parameters and the subsequent impacts on the rock mass strength determination.

3.3.3 *Joint condition averaging over a domain/interval*

A serious flaw in many geotechnical logging programs is the averaging or estimation of the joint parameters. Inappropriate weighting of the weakest or strongest parameters over a domain/interval may also be problematic. Depending on the joint set orientation, it may or may not play an important role in defining the stability of an excavation. It is thus important that the joint conditions of the individual sets be assessed separately. This will allow the use of the appropriate parameters for the most influential joint set, based on an excavation orientation.

3.4 *General aspects*

3.4.1 *Logging intervals*

Decisions need to be made whether the logging is undertaken on a run by run (drilling interval) or domain (section of core with the same geotechnical characteristics) basis. An important aspect to keep in mind is that domain logging must be undertaken by experienced geotechnical personnel.

Typically, the preference is to log the basic general geotechnical parameters (RQD, core recovery and IRS) on a run by run basis and then to determine the more detailed geotechnical parameters over a user-defined domain basis. The length of these domains should be limited to a maximum of 9 – 15 m. Otherwise, severe over-averaging can be incurred and the resolution and accuracy of the data set may be dramatically reduced.

If triple split tube logging is undertaken at the drill rig, then all parameters should be logged on a run by run basis, within the split-tube, prior to placing the core in the core box. Additional logging, such as geology, may be completed at an alternate location.

3.4.2 *Major structures*

From the outset of any geological or geotechnical program, the logging of major structures needs to be undertaken diligently as these measurements will play a significant role in the later structural interpretation of the deposit. Elements such as intersection length, orientation, brittle/ductile characteristics, shear sense indicators, fluid flow and fault zone characteristics (gouge, fracture frequency, nature) should be evaluated. The nature of any gouge material within the fault zones should be documented as cohesive or non-cohesive and a level of soil logging classification applied.

3.4.3 *Poor drilling practices*

Tight controls and documentation of the drilling practices should be maintained throughout all drill programs. This is especially relevant in weaker rock masses where penetration rates, core recovery and core quality should be evaluated and consistently recorded within the database.

4 ELEMENTS OF GOOD SITE SPECIFIC GEOTECHNICAL LOGGING ATLAS

Generally, a detailed geotechnical site specific logging atlas would be established once a project has successfully moved through a positive scoping study. Generation of the atlas should be completed by three to four days of site review by an experienced geotechnical practitioner. The content and structure of the logging atlases have continually evolved though internal experience generated from

previous and ongoing drilling programs (J. Jakubec, pers. comm.).

An important aspect to keep in mind when establishing a list of geotechnical parameters is to consider type of classification system to be used for the initial empirical designs. Depending on the type and range of excavations being considered, the methodologies could include the use of multiple classification systems (e.g. Bieniawski 1976, 1989) RMR for slope stability, Laubscher (1990), RMR and Laubscher (2000) IRMR/MRMR for caving, Barton's Q (1974) for slope, caving and tunnel excavation design). Although there are multiple correlation formulae between classification systems (Milne et al. 1998), it is important that the values be derived independently. The use of these general formulae can lead to erroneous simplification and inadequate weighting of important parameters. For this reason, the list of determined geotechnical parameters should be sufficient to evaluate the required classification systems from first principles.

To establish an effective site specific geotechnical logging atlas, the following aspects should be included:

- *Geotechnical Program Context and Objectives:* Summary notes should be generated on the mineralization context, potential mining methods and geotechnical program objectives. Using this information, the more critical geotechnical aspects should be identified.
- *Data Capture Practices:* The structure of the input forms and applicable methodology should be highlighted. Detailed back-up procedures need to be established.
- *General Logging Process Definition:* A step-by-step list of procedural requirements, including the handling, logging, photography, sampling and storage of the drill core should be established.
- *Photography Guidelines:* The methodology by which to photograph cores within split tubes, core boxes as well as detailed photographs of specific geotechnical features, should be provided. All photographs, taken with consistent lighting, should include a scale and colour chart. This approach will generate photographs of consistent resolution and quality for future reference.
- *Geotechnical Feature Reference Slides:* A compiled group of detailed photographs highlighting typical geotechnical features (observed in drill core, outcrop, etc) should be established. As additional features are encountered, they should be photographed, classified and implemented to the reference section of the logging atlas.
- *Logging Parameter Definitions:* Detailed references on the methodology for assessing geotechnical parameters should be made readily available to logging staff.
- *Major Structures:* Clear documentation identifying such structural aspects as brittle/ductile cha-

racteristics, shear sense indicators and infill material types should be documented for reference.

- *Core orientation procedures:* Procedural documents (including troubleshooting) describing the specific orientation hardware(s) should be made available to field staff.
- *Logged Boxes Reference Slides:* Reference slides should include a set of photographs of logged/boxed cores (Fig. 3) of the various representative geotechnical conditions that are encountered at the site. These photos serve as a reference template during logging.
- *Geotechnical Testing:* Operational procedures for the specific hardware (e.g. Schmidt Hammer, point load tester) used on the site as well as a set of reference slides to classify successful tests, especially for point load tests should be supplied.
- *Sampling Procedures:* Notes should be included detailing sampling objectives, procedures and proper preservation of samples prior to testing.

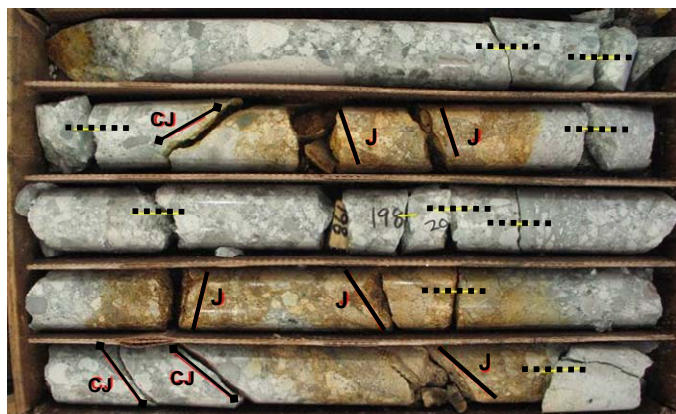


Figure 3. Reference marked-up and logged boxes to indicate good logging practices.

Once the atlas is finalized, it should be presented to the geotechnical logging team including senior geological/geotechnical personnel for review and discussion. It is important that senior site geological/geotechnical personnel buy into the proposed program as they form a critical part of the QA/QC process. The final document should then be printed in colour and a number of copies retained within the core shack and drill site (if applicable). In addition, a set of laminated reference charts should be developed and clearly mounted where the logging is to be undertaken.

5 CASE STUDIES

5.1 Ekati Diamond Mine – Alteration

Ekati diamond mine is located approximately 300 kilometres northeast of Yellowknife and 200 kilometers south of the Arctic Circle in the Northwest Territories, Canada. The Ekati operation consists of five open pits and three underground mines at vari-

ous stages of development. SRK Consulting has been involved in the transition from open pit to underground mining at the Koala, Koala North and Panda kimberlite orebodies (Jakubec et al. 2004). The kimberlite orebodies exhibit typical pipe geometries (diatreme and crater facies) and are hosted in Archean granitoids.

SRK was employed to geotechnically characterize the kimberlite and granitoid host within the deeper levels of the Koala orebody. This work was undertaken as part of the underground feasibility study. As an initial task, SRK developed a site specific geotechnical logging system. Using this system, over 70 drill holes were geotechnically logged.

Using previous site experience and discussions with Ekati staff, critical elements were highlighted with respect to the geotechnical character of the rockmass. In addition to standard geotechnical concerns (e.g. structures, geology), alteration within the rockmass, specifically the orebody, was identified as the most important parameter to geotechnically characterize.

The alteration within the Koala kimberlite was identified as the major variable in rockmass quality. Within the Koala pipe, alteration dramatically affects porosity and rock strength with higher levels of alteration exhibiting the highest degrees of secondary porosity and weakest rock strength. A simple, but effective system of classifying this alteration during core logging was introduced. The level of alteration observed in both the kimberlite and country rock were graded on a relative scale from “none” to “intense”. The scale is described below and depicted in Figure 4:

- None (rating “0”)
- Minor (rating “1”)
- Moderate (rating “2”)
- Intense (rating “3”)

Additionally, an alteration code (“AA”) was entered into the logging database if the alteration was moderate or intense for the purpose of rapid identification and sorting. To aid logging staff, photographs and descriptions of alteration levels were added to the logging manual (Fig. 4).

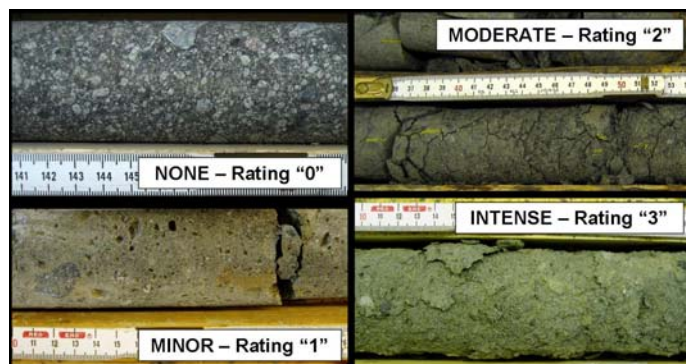


Figure 4. Alteration levels were classified for all kimberlites and defined in the logging atlas.

5.2 Quimsacocha Gold Project – Alteration and defects

Wholly owned by IAMGOLD Inc., the Quimsacocha gold project is located in southern Ecuador. The epithermal gold deposit is hosted within quartz breccias which have intruded intermediate volcanics. An underground scenario is the leading mining method option although the open pit option is still being explored. Target mining depths using the open pit scenario are approximately 150m.

The project is currently advancing through Pre-Feasibility and the need for advanced geotechnical data collection has recently increased. SRK was employed to develop a site specific geotechnical logging system and train technical staff in geotechnical data collection.

After discussions with IAMGOLD staff and visits to the project site, SRK devised a site specific geotechnical logging system which focused on several geotechnical aspects.

The rockmass at Quimsacocha is characterized by zoned alteration, with the orebody representing both the central core and highest rock strength within the zonation. Recognizing that rock strength was inherently tied to the alteration zoning, SRK instituted alteration and micro-defect classification systems to characterize these important parameters (Fig. 5). To aid logging staff, photos and descriptions of alteration levels were added to a site-specific logging manual.

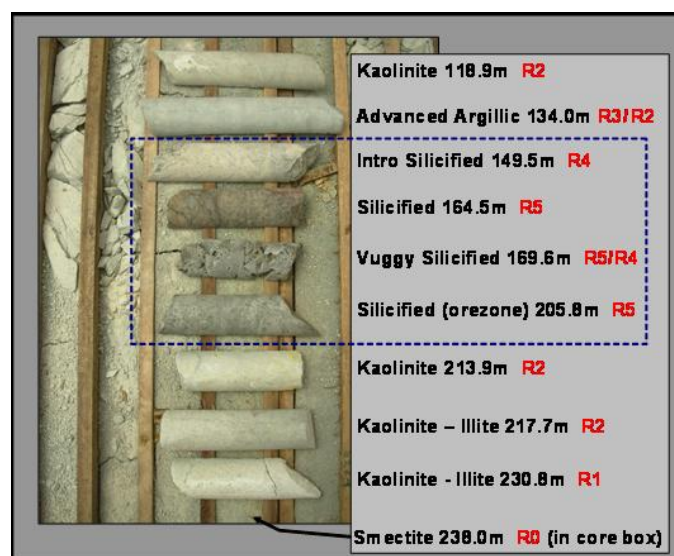


Figure 5. Within the logging atlas, alteration was classified in terms of type and level of alteration. Note the correlation between alteration type and rock strength.

In terms of rockmass classification, primary alteration zoning, generated during epithermal mineralization, provides the basic geotechnical conditions within the mineralized zone. These background conditions were classified using a system modified from

IAMGOLD's geology group. By using this system, training was minimized and senior geologists were able to confidently establish alteration levels based on type (e.g. smectite, kaolinite) and intensity (minor, moderate and intense). Using these data, an alteration model is currently being constructed which will serve as the most important tool for future geotechnical studies (mine design, slope/underground stability).

In addition to alteration classification, SRK recommended that micro-defects within the rockmass (veinlets, microbrecciation, and dissolution) also be quantitatively assessed. Similar to the alteration classification, micro-defects are assessed based on their weakening effect on the rockmass. Both intensity (none, minor, moderate and intense) and type are being classified by IAMGOLD geologists and geotechnicians. Obtaining information on micro-defects will provide future workers with greater confidence at several important stages including mining method selection, stability and blasting.

5.3 Voisey's Bay - Defects

The Voisey's Bay nickel deposit is located 350 km north of Happy Valley-Goose Bay in Labrador, Canada. Voisey's Bay Nickel Company (VBNC) is a wholly-owned subsidiary of Inco Ltd. and is responsible for developing the Voisey's Bay project. The deposit is hosted within the Voisey's Bay Intrusion which is mafic in composition and is dominantly composed of olivine gabbro and troctolite with variable amounts of leucotroctolite, melatroctolite, olivine norite, gabbro-norite and ferrodiorite. Mineralization occurs within a number of potential ore deposits as either a massive sulphide or disseminated ore of variable sulphide content.

The more massive sulphide ores of these deposits can have relatively low IRS as a result of well developed micro-fracturing (see Fig. 6) and there is a potential relationship between percentage sulphide content and IRS within the disseminated sulphide zone (Fig. 7). The impact of this low strength on rock mass performance is not adequately reflected when evaluating using existing classification systems and it is suggested that IRS would need to be a bigger portion of the rock mass rating.

For this reason it was considered that there needed to be a higher level of resolution of the IRS within a narrow range as this may become a critical aspect in the mine design. If engineering judgment during the later design process warrants that IRS should have a higher weighting in an engineered Rock Mass rating calculation to be representative of the rock mass performance, then this detail may prove invaluable in optimizing the chosen mining method.

Attempts to quantify the micro fracturing and relate this to rock strength proved difficult and it was

considered best to evaluate the variation in strength of the sulphides on a regular basis using a Schmidt hammer. In contrast to just empirically logging it as a R3 (25 – 50 MPa) range with the occasional point-load test, a sizeable data set would be set up with a higher resolution. This detail could become very important when defining geotechnical domains and the associated mine design parameters.

Also of high importance to future mining methods is the understanding of strength variations within a potential orebody due to the varying sulphide content. Accordingly, the point load testing and UCS testing program needed to be tailored to ensure that representative sulphide ranges were tested.



Figure 6. Detailed photograph of sampled massive sulphide core indicating the extent of micro-fracturing/defects.

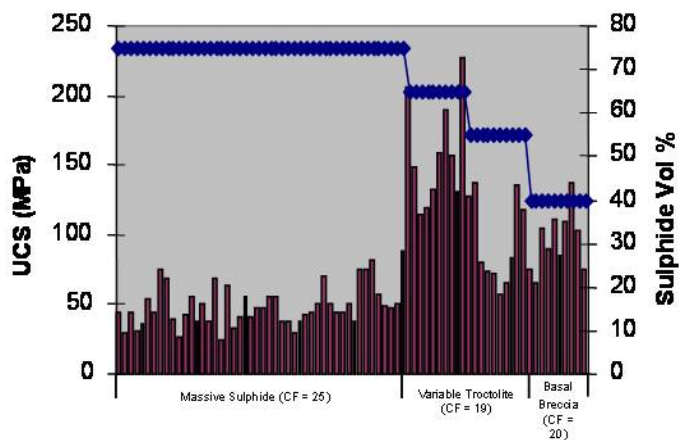


Figure 7. Variations in point load strengths within the massive and disseminated sulphide zones.

6 CONCLUSION

In summary:

- Each site is geotechnically unique and should be treated as such. Time and expertise must be invested in order to obtain the highest, most relevant data collected from drilling programs. Sub-

stantial time and cost benefits can be realized through a customized more focused geotechnical data gathering program than a general 'blanket' approach.

- The site-specific logging atlas should be completed only after a site visit where senior geotechnical personnel are able to liaise with site personnel.
- Senior geological and geotechnical site staff should be involved in initial orientation and training as they play a major role in ongoing QA/QC.
- The most common geotechnical factors which must be customized on a site specific basis include alteration/weathering, rock strength, discontinuity assessment and micro-defects.

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