PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING, IGNACE AREA

WP10 – Rock Mass Classification for IG_BH01

APM-REP-01332-0303 **December 2022**

Golder Associates Ltd.

NUCLEAR WASTE MANAGEMENT ORGANIZATION
SOCIÉTÉ DE GESTION DES DÉCHETS NUCLÉAIRES

Nuclear Waste Management Organization
22 St. Clair Avenue East, 4th Floor
Toronto, Ontario
M4T 2S3
Canada

Tel: 416-934-9814
Web: www.nwmo.ca

REPORT

PHASE 2 INITIAL BOREHOLE DRILLING AND TESTING - IGNACE AREA

WP10 - Rock Mass Classification for IG_BH01

Submitted to:

Nuclear Waste Management Organization
4th Floor
22 St. Clair Avenue East
Toronto, Ontario, M4T 2S3

Submitted by:

Golder Associates Ltd.
6925 Century Avenue, Suite #100 Mississauga, Ontario, L5N 7K2 Canada

1671632 (1922)

NWMO Report: APM-REP-01332-0303

December 19, 2022

Distribution List

NWMO - 1 eCopy

Golder Associates Ltd. - 1 eCopy

WP10 REPORT – ROCK MASS CLASSIFICATION FOR IG_BH01

CLIENT INFORMATION

Project Name:	Phase 2 Initial Borehole Drilling – Ignace Area
Project Number:	1671632
Client PO Number:	PO 2000141 (formerly 01559 A-TGS)
Document Name:	1671632 (1922) rpt wp10 rock mass classification for ig_bh01 19dec2022 r7a-final.docx

Client:	Nuclear Waste Management Organization (NWMO)
Address:	22 St. Clair Avenue East, Fourth Floor
City:	Toronto
Province:	Ontario
Postal Code:	M4T 2S3
Client Contact:	Andrew Parmenter
Telephone:	647-259-3701
Email:	aparmenter@nwmo.ca

ISSUE/REVISION INDEX

Issue Code	Revision					Revision Details
	No.	By	Rev'd.	App.	Date	
RR	0	CM	JC		May 24, 2018	Draft released for review and comment
RI	1	AAN	JLC	GWS	October 8, 2019	Incorporated in APM-REP-01332-0238
RI	2	EJ	JLC	GWS	December 17, 2021	Final released for Information
RI	3	EJ	JLC	GWS	February 23, 2022	Final released for Information
RI	4	EJ	JLC	GWS	May 26, 2022	Final - address comments from GRG
RI	5	EJ	JLC	GWS	June 24, 2022	Final - address additional comments from GRG
RI	6	EJ	JLC	GWS	November 4, 2022	Final - address second set of comments from GRG
RI	7	EJ	JLC	GWS	December 19, 2022	Final - address final edits by NWMO

Issue Codes: RR = Released for Review and Comments, RI = Released for Information

SIGNATURES

Prepared by: ______________________

Eric Jaczkowski, M.A.Sc., P.Eng.
Rock Mechanics Engineer

Reviewed by: ______________________

Joe Carvalho, Ph.D., P.Eng.
Mining & Rock Engineering - Principal

Approved by: ______________________

George Schneider, M.Sc., P.Geo.
Senior Geoscientist - Principal

Table of Contents

FIGURES

1.0 INTRODUCTION

The Initial Borehole Drilling and Testing project in the Wabigoon and Ignace Area, Ontario is part of Phase 2 Geoscientific Preliminary Field Investigations of the NWMO's Adaptive Phased Management (APM) Site Selection Phase.

This project involves the drilling and testing of the first of three deep boreholes within the northern portion of the Revell batholith. The first drilled borehole, IG_BH01, is located a direct distance of approximately 21 km southeast of the Wabigoon Lake Ojibway Nation and a direct distance of 43 km northwest of the Town of Ignace. Access to the IG_BH01 drill site is via Highway 17 and primary logging roads, as shown on Figure 1.

The project was carried out by a team led by Golder Associates Ltd. (Golder) on behalf of the NWMO. The overall program is described in the Initial Borehole Characterization Plan (Golder, 2017). This report describes the rock mass characterization based on the data collected during the field activities for borehole IG_BH01 as described in the Work Package 3 (WP3) Data Report – Geological and Geotechnical Core Logging, Photography, and Sampling for IG_BH01 (Golder, 2018), and the subsequent analyses and compilation of the data as described in the WP4b Data Report – Geomechanical Testing of Core for IG_BH01 (Golder, 2022), the WP05 Data Report – Geophysical Well Logging for IG_BH01 (Golder, 2019), the WP10 – Geological Integration Report for Borehole IG_BH01 (Parmenter et al., 2022), and the Discrete Fracture Network Report for the Revell Site (Sykes et al., 2022).

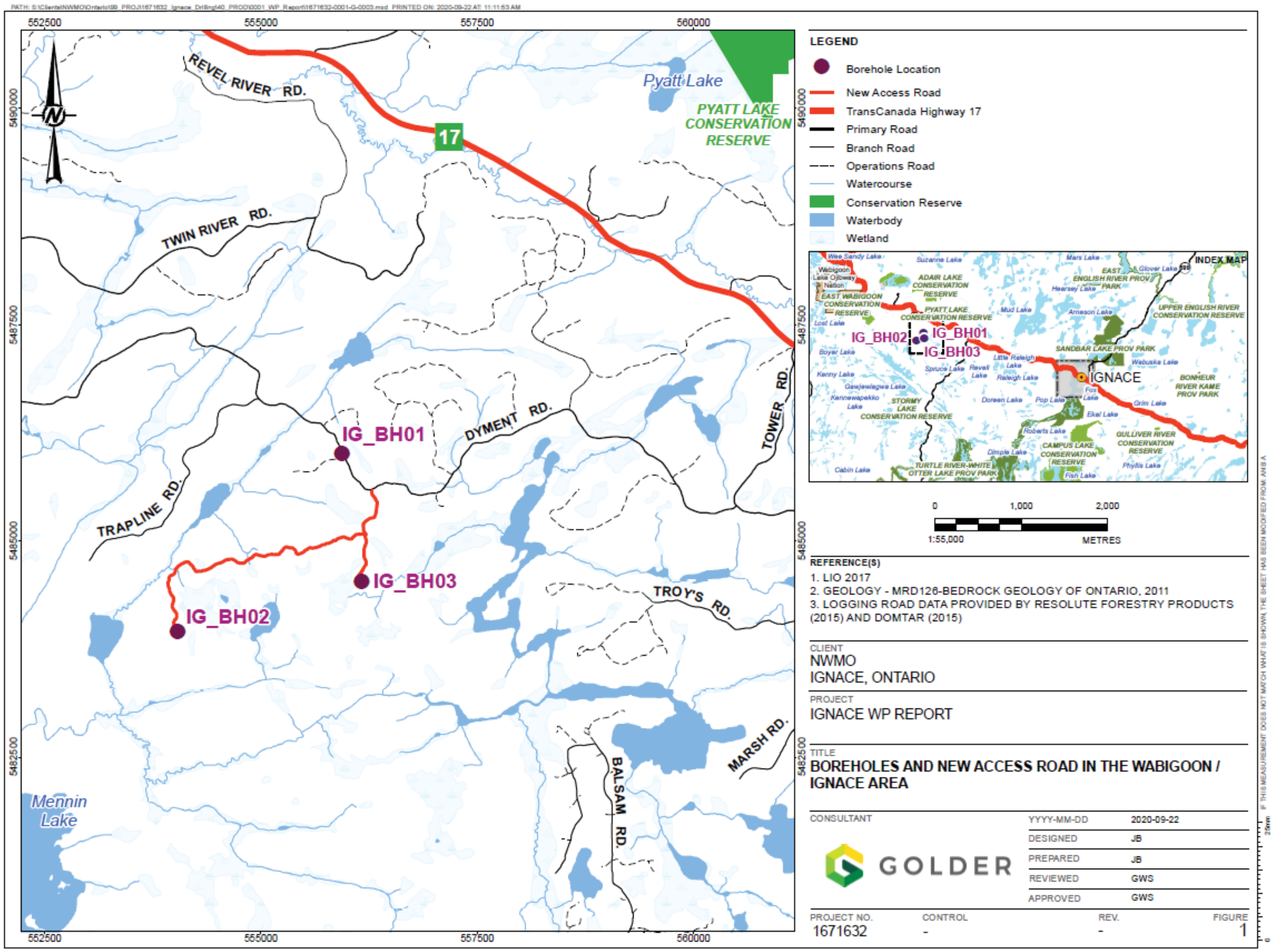

Figure 1: Location of IG_BH01 in relation to the Wabigoon / Ignace Area

2.0 BACKGROUND INFORMATION

2.1 Geological Setting

The approximately 2.7 billion year old Revell batholith is located in the western part of the Wabigoon Subprovince of the Archean Superior Province. The batholith is roughly elliptical in shape trending northwest, is approximately 40 km in length, 15 km in width, and covers an area of approximately 455 km^2. Based on geophysical modelling, the batholith is approximately 2 km to 3 km thick through the center of the northern portion (SGL, 2015). The batholith is surrounded by supracrustal rocks of the Raleigh Lake (to the north and east) and Bending Lake (to the southwest) greenstone belts (Figure 2).

Borehole IG_BH01 is within an investigation area of approximately 19 km^2 in size situated in the northern portion of the Revell batholith. Bedrock exposure in this area is very good due to minimal overburden, few water bodies, and relatively recent logging activities. Ground elevations generally range from 400 to 450 m above sea level. The ground surface broadly slopes towards the northwest as indicated by the flow direction of the main rivers in the area (Revell and Mennin rivers). Local water courses within the investigation area tend to flow to the southwest towards Mennin Lake (Figure 1).

Four main rock units are identified in the supracrustal rock group: mafic metavolcanic rocks, intermediate to felsic metavolcanic rocks, metasedimentary rocks, and mafic intrusive rocks (Figure 2). Sedimentation within the supracrustal rock assemblage was largely synvolcanic, although sediment deposition in the Bending Lake area may have continued past the volcanic period (Stone, 2009; Stone, 2010a; Stone, 2010b). All supracrustal rocks are affected, to varying degrees, by penetrative brittle-ductile to ductile deformation under greenschist- to amphibolite-facies metamorphic conditions (Blackburn and Hinz, 1996; Stone et al., 1998). In some locations, primary features, such as pillow basalt or bedding in sedimentary rocks are preserved, in other locations, primary relationships are completely masked by penetrative deformation. Uranium-lead (U-Pb) geochronological analysis of the supracrustal rocks produced ages that range between 2734.6 +/-1.1 Ma and 2725 +/-5 Ma (Stone et al., 2010).

Three main suites of plutonic rock are recognized in the Revell batholith, including, from oldest to youngest: a Biotite Tonalite to Granodiorite suite, a Hornblende Tonalite to Granodiorite suite, and a Biotite Granite to Granodiorite suite (Figure 2). Plutonic rocks of the Biotite Tonalite to Granodiorite suite occur along the southwestern and northeastern margins of the Revell batholith. The principal type of rock within this suite is a white to grey, medium-grained, variably massive to foliated or weakly gneissic, biotite tonalite to granodiorite. One sample of foliated and medium-grained biotite tonalite produced a U-Pb age of 2734.2+/-0.8 Ma (Stone et al., 2010). The Hornblende Tonalite to Granodiorite suite occurs in two irregularly-shaped zones surrounding the central core of the Revell batholith. Rocks of the Hornblende Tonalite to Granodiorite suite range compositionally from tonalite through granodiorite to granite and also include significant proportions of quartz diorite and quartz monzodiorite. One sample of coarse-grained grey mesocratic hornblende tonalite produced a U-Pb age of 2732.3+/-0.8 Ma (Stone et al., 2010). Rocks of the Biotite Granite to Granodiorite suite underlie most of the northern, central and southern portions of the Revell batholith. Rocks of this suite are typically coarse-grained, massive to weakly foliated, and white to pink in colour. The Biotite Granite to Granodiorite suite ranges compositionally from granite through granodiorite to tonalite. A distinct potassium (K)-Feldspar Megacrystic Granite phase of the Biotite Granite to Granodiorite suite occurs as an oval-shaped body in the central portion of the Revell batholith (Figure 2). One sample of coarse-grained, pink, massive K-feldspar megacrystic biotite granite produced a U-Pb age of 2694.0+/-0.9 Ma (Stone et al., 2010).

The bedrock surrounding IG_BH01 is composed mainly of massive to weakly foliated felsic intrusive rocks that vary in composition between granodiorite and tonalite, and together form a relatively homogeneous intrusive complex. Bedrock identified as tonalite transitions gradationally into granodiorite and no distinct contact relationships between these two rock types are typically observed (SRK and Golder, 2015; Golder and PGW, 2017). Massive to weakly foliated granite is identified at the ground surface to the northwest of the feldspar-megacrystic granite. The granite is observed to intrude into the granodiorite-tonalite bedrock, indicating it is distinct from, and younger than, the intrusive complex (Golder and PGW, 2017).

West-northwest trending mafic dykes interpreted from aeromagnetic data extend across the northern portion of the Revell batholith and into the surrounding greenstone belts. One mafic dyke occurrence, located to the northwest of IG_BH01, is approximately 15-20 m wide (Figure 2). All of these mafic dykes have a similar character and are interpreted to be part of the Wabigoon dyke swarm. One sample from the same Wabigoon swarm produced a U-Pb age of 1887+/-13 Ma (Stone et al., 2010), indicating that these mafic dykes are Proterozoic in age. It is assumed based on surface measurements that these mafic dykes are sub-vertical (Golder and PGW, 2017).

Long, narrow valleys are located along the western and southern limits of the investigation area (Figure 1). These local valleys host creeks and small lakes that drain to the southwest and may represent the surface expression of structural features that extend into the bedrock. A broad valley is located along the eastern limits of the investigation area and hosts a more continuous, un-named water body that flows to the south. The linear and segmented nature of this waterbody’s shorelines may also represent the surface expression of structural features that extend into the bedrock.

Regional observations from mapping have indicated that structural features are widely spaced (typical 30 to 500 cm spacing range) and dominantly comprised of sub-vertical joints with two dominant orientations, northeast and northwest trending (Golder and PGW, 2017). Interpreted bedrock lineaments generally follow these same dominant orientations in the northern portion of the Revell batholith (Figure 2; DesRoches et al., 2018). Minor sub-horizontal joints have been observed with minimal alteration, suggesting they are younger and perhaps related to glacial unloading. One mapped regional-scale fault, the Washeibemaga Lake fault, trends east and is located to the west of the Revell batholith (Figure 2). Additional details of the lithological units and structures found at surface within the investigation area are reported in Golder and PGW (2017).

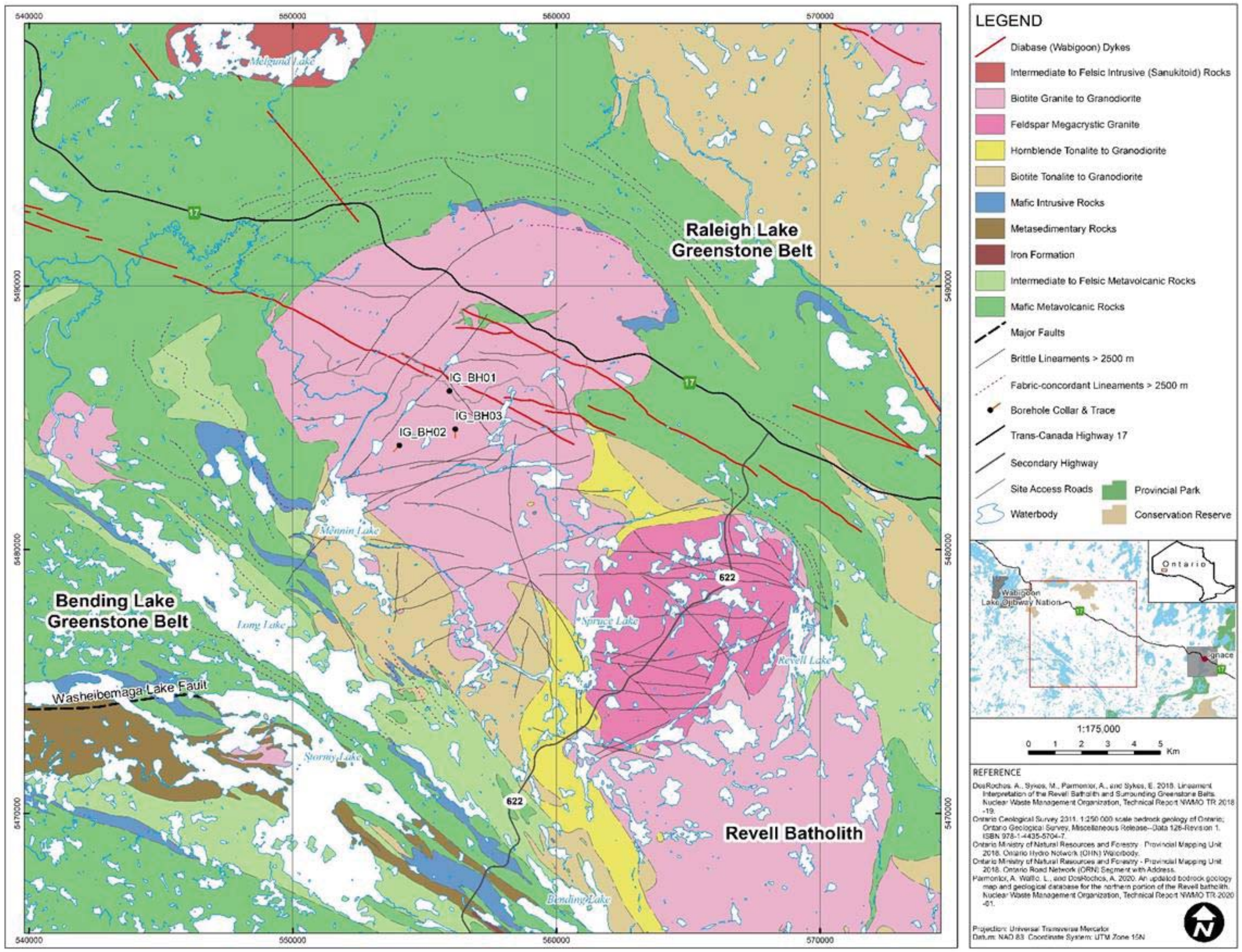

Figure 2: Geological setting and location of boreholes IG_BH01, IG_BH02 and IG_BH03 in the northern portion of the Revell batholith

3.0 OBJECTIVE

The objective of this report is to present the methodology and results for the development of the Rock Mass Rating (RMR) Index profile (along borehole) for IG_BH01. The report also presents a summary of the final structure log developed through the integration of structures identified during core logging (WP03, Golder 2018) and downhole televiewer logging (WP05, Golder 2019), which is an important input into the RMR Index presented herein.

4.0 FINAL STRUCTURE LOG

The orientation of all structures measured during core logging, as described in the WP03 data report (Golder 2018), are initially defined based on alpha and beta angles relative to (1) the core axis, and (2) an arbitrary reference line drawn along the length of each core run. Since the core retrieved from the borehole (IG_BH01) is not oriented, these relative orientation angles (beta for planes; delta for lineations) for each logged structure need to be corrected to a true orientation in order to produce the final structure log for IG_BH01. As part of this process, structures were also interpreted by the geophysical team (WP05) using optical and acoustic televiewer logs independently of the structures picked from the core logging. Interpreted structure orientations were corrected from apparent dip and dip direction to true dip and dip direction (i.e., relative to true north), using the final Tilt and Azimuth logs, as described in the WP05 data report (Golder 2019).

Once both WP03 and WP05 interpretations were completed, they were integrated as a specific task as part of completion of the WP10 geological integration report for IG_BH01 (Parmenter et al., 2022). This comparison identified structures that are common to both televiewer logs and core logging, based on similar position along borehole and relationship to adjacent structures, and possibly structure type and its characteristics (e.g., geological aperture). The complete methodology used in integrating the structures into a final structure log is included in Appendix D of the WP10 report (Parmenter et al., 2022).

Note that geological aperture is an estimated measurement of the open space between two adjacent fracture surfaces determined visually during geological core logging, during interpretation of downhole televiewer logs, or during the integration of data from these two sources. For our purposes, geological apertures are estimated values only because there are multiple possible sources of uncertainty in how a reported aperture value relates to the true aperture of a fracture identified as broken. There are uncertainties related to measurement inaccuracy, including where the opening is very small, where the opposing fracture planes are not parallel or fit poorly together, or due to limits in televiewer resolution. In addition, effects due to drilling or decompression may create or enhance the visible open space identified as aperture. Finally, aperture measured in core or on a borehole wall is only a local aperture that is not necessarily representative over the entire fracture.

The result of the integrated structure log includes a table that captures a complete set of attributes of each structure recorded either from core logging, televiewer logging, or a combination of both. Where certain attributes are duplicated between the two logging approaches (i.e., structure type, or position along borehole) decisions are made to carry forward the most accurate value to the final structure log. For example, orientation data will be obtained from the televiewer logged structures, whereas structure type should be obtained from core logging structures. Table 1 shows an example of the integrated structure log compilation. Figure 3 shows a stereographic plot of the integrated final structures by type (top) and a contoured plot of all integrated final structures (bottom).

Table 1: Example of Final Structure Log Compilation

Structure #	Reference Line	Beta CF	Beta CF St. Dev.	Final position along borehole	Corr_ Alpha	Corr_ Beta	True_ Dip	True_ DDIR	Type	Condition	Width (cm)	Geological Aperture (mm)	Infill Thickness (mm)
45	RL011	200.40	0.00	6.99	69	175	2	93	JN	BR	-	5	0
49	RL012	263.35	6.03	7.45	62	188	8	214	JN	BR	-	0	0
50	RL012	263.35	6.03	7.51	60	238	25	283	JN	PIN	-	0	0
51	RL012	263.35	6.03	7.52	18	106	68	103	JN	BR	-	1	1
52	RL012	263.35	6.03	7.65	67	233	19	294	JN	PIN	-	0	0
53	RL012	263.35	6.03	8.20	22	317	84	326	JN	BR	-	0	0
54	RL012	263.35	6.03	8.29	17	102	70	100	JN	IN	-	0	1

NOTE:
Beta CF – Beta Correction Factor for the reference line
Beta CF St. Dev. – Standard deviation for Beta Correction Factor for the reference line

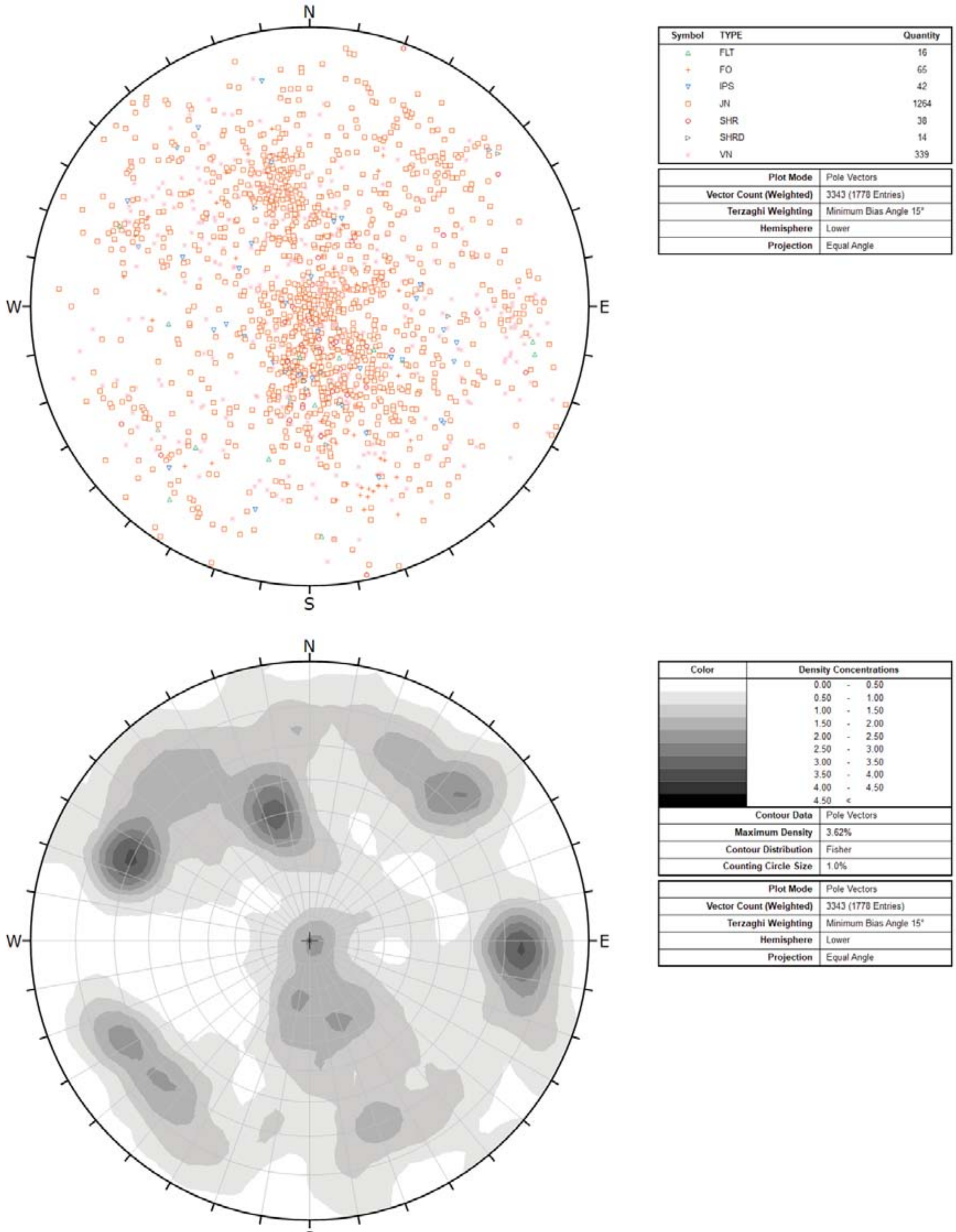

Figure 3: Stereographic projection of all integrated final structures: Top: structures by type; Bottom: contour plot (with Terzaghi weighting)

5.0 ROCK MASS CLASSIFICATION

One of the widely used rock mass classifications is the Rock Mass Rating (RMR) system of Bieniawski (1973, 1976, and 1989). The classification includes information on the strength of the intact rock material, Rock Quality Designation (RQD), the spacing and surface properties of the structural discontinuities as well as ratings for the influence of subsurface groundwater and an adjustment for discontinuity orientation relative to the orientation of an engineered structure (e.g., tunnel). This classification was developed primarily for the estimation of the support requirements in tunnels, but its use has been expanded to cover many other fields (Hoek, 2018).

5.1 Geomechanics Classification, Rock Mass Rating (RMR) Index

The RMR Index described herein is based on the RMR'89 classification. However, it incorporates information from only five of six characteristics: strength of the intact rock material, the spacing and/or number of fractures, and surface properties of the fractures, as well as ratings for the influence of subsurface groundwater, where interpreted to be present. Because of the unknown orientation of potential excavations, no adjustment can be made for the discontinuity orientations at this time. The RMR index therefore describes the rock mass independent of orientation and adjustments will have to be made when utilizing it for tunnel or shaft support estimations. For tunnels and shafts, the RMR = RMR Index - (0 to 12) points when accounting for orientation.

The RMR Index is therefore based on the sum of the following five ratings:

R_1 – Strength of intact rock material (Max rating = 15) – Based on laboratory testing (UCS); Strength Index values obtained during drilling/logging also correlate well with the UCS values and show consistency over the full length of the borehole;
R_2 – Drill core quality RQD (%) (Max rating = 20) – Compiled from core logging by run;
R_3 – Spacing of discontinuities (Max rating = 20) – Compiled from core logging by run;
R_4 – Condition of discontinuities (Max rating = 30) – Compiled from core logging for each individual fracture and compiled by run; the minimum value for the run was used in the estimation of RMR; and
R_5 – Groundwater condition (Max rating = 15) – Compiled from hydraulically conductive features (HCF) identified during hydrogeological testing (20 m long straddle packer tool) of the borehole and supported by Flowing Fluid Electrical Conductivity (FFEC) logs.

As noted above, the RMR Index describes the rock mass characteristics independently of orientation.

A description of the ratings, based on the above five parameters can be found in Table 2. Table A7 of Appendix A of the WP03 Data Report (Golder 2018) provides more detailed descriptions of the condition of discontinuities (therein referred to as Joint Condition Rating or JCR), compared to the original RMR'89 table, and were tailored for this project. When assigning the RMR Index rating for UCS, RQD and Spacing parameters, interpolations were carried out between defined rating categories. When assigning the RMR Index rating for the Groundwater condition parameter to areas coincident with HCFs, the general condition of 'Damp' was applied ($R_5 = 10$).

Table 2: Rock Mass Rating System (Geomechanics Classification of Rock Masses, 1989)

<table>
<tr><td colspan="3">Parameter</td><td colspan="7">Ranges of Values</td></tr>
<tr><td rowspan="3">1</td><td rowspan="2">Strength of intact rock material</td><td>Point-load strength index (MPa)</td><td>>10</td><td>4 – 10</td><td>2 – 4</td><td>1 – 2</td><td colspan="3">For this low range, uniaxial compressive test is preferred</td></tr>
<tr><td>Uniaxial compressive strength (MPa)</td><td>>250</td><td>100 – 250</td><td>50 – 100</td><td>25 – 50</td><td>5 – 25</td><td>1 – 5</td><td><1</td></tr>
<tr><td colspan="2">Rating</td><td>15</td><td>12</td><td>7</td><td>4</td><td>2</td><td>1</td><td>0</td></tr>
<tr><td rowspan="2">2</td><td colspan="2">Drill core quality RQD (%)</td><td>90 – 100</td><td>75 – 90</td><td>50 – 75</td><td>25 – 50</td><td colspan="3"><25</td></tr>
<tr><td colspan="2">Rating</td><td>20</td><td>17</td><td>13</td><td>8</td><td colspan="3">3</td></tr>
<tr><td rowspan="2">3</td><td colspan="2">Spacing of discontinuities</td><td>>2 m</td><td>0.6 – 2 m</td><td>200 – 600 mm</td><td>60 – 200 mm</td><td colspan="3"><60 mm</td></tr>
<tr><td colspan="2">Ratings</td><td>20</td><td>15</td><td>10</td><td>8</td><td colspan="3">5</td></tr>
<tr><td rowspan="2">4</td><td colspan="2">Condition of discontinuities</td><td>Very rough surfaces
Not continuous
No separation
Unweathered wall rock</td><td>Slightly rough surfaces
Separation < 1 mm
Slightly weathered walls</td><td>Slightly rough surfaces
Separation < 1 mm
Highly weathered walls</td><td>Slickensided surfaces
or
Gouge < 5 mm thick
or
Separation 1 – 5 mm
Continuous</td><td colspan="3">Soft gouge > 5 mm thick
or
Separation > 5 mm
Continuous</td></tr>
<tr><td colspan="2">Rating</td><td>30</td><td>25</td><td>20</td><td>10</td><td colspan="3">0</td></tr>
<tr><td rowspan="4">5</td><td rowspan="2">Groundwater condition</td><td>Inflow per 10 m tunnel length (L/min)</td><td>None</td><td><10</td><td>10 – 25</td><td>25 – 125</td><td colspan="3">>125</td></tr>
<tr><td>Ratio (Joint water pressure / Major principal stress)</td><td>or
0
or</td><td>or
<0.1
or</td><td>or
0.1 – 0.2
or</td><td>or
0.2 – 0.5
or</td><td colspan="3">or
>0.5
or</td></tr>
<tr><td></td><td>General conditions</td><td>Completely dry</td><td>Damp</td><td>Wet</td><td>Dripping</td><td colspan="3">Flowing</td></tr>
<tr><td colspan="2">Rating[1]</td><td>15</td><td>10</td><td>7</td><td>4</td><td colspan="3">0</td></tr>
</table>

[1] – based on analysis of hydraulic conductivity testing of an HQ borehole (96 mm)

6.0 SUMMARY OF ROCK MASS CLASSIFICATION PARAMETERS

The identified parameters used to determine rock mass classification were measured directly in the field, and based on integration of some field information, including development of final structure log and determination of hydraulically conductive features. Both field measurements and laboratory testing data were utilized for the strength factor in this system. The parameters used to develop the rock mass classification, are based on the data presented in the following documents:

- WP03 Data Report – Geological and Geotechnical Core Logging, Photography and Sampling for IG_BH01 (Golder, 2018)
- acQuire core logging database
- Final structure log from WP10 - Geological Integration Report for IG_BH01 (Parmenter et al., 2022)
- WP04b Data Report – Geomechanical Testing of Core for IG_BH01 (Golder, 2022)
- Discrete Fracture Network (DFN) Model Report for the Revell Site (Sykes et al., 2022)

The following subsections provide a summary of the input to the RMR Index presented below for the five ratings listed above in Section 5.1.

6.1 Strength

A total of 61 field strength index measurements were made during the logging of IG_BH01. These discrete measurements were taken opportunistically while breaking the core with a geological hammer strike when sampling or fitting core into the core boxes. All but one of these field tests were carried out on the tonalite.

Overall, the tonalite was classified as strong (R4) in four (7%) occurrences, very strong (R5) in 47 (77%) occurrences and extremely strong (R6) in 10 (16%) occurrences. One strength index measurement was collected within an amphibolite layer at approximately 655 m along borehole, resulting in an R5 measurement (very strong rock). In general, the rock can be classified as very strong rock (R5). This agrees with the results of the laboratory tests (3 tests), which reported an average UCS value of 220 MPa (Golder, 2022).

6.2 RQD

In general, the rock is considered to be excellent rock quality, averaging 99% RQD along the borehole. The distribution of RQD ranges between 80% and 100%. When considering the core runs where other rock types, such as felsic dykes or amphibolite lenses were encountered, RQD values are observed to be slightly reduced. This slight reduction is observed in particular when considering core runs with the amphibolite unit, where the average RQD is approximately 95% (Golder, 2018).

6.3 Fracture Spacing

Overall, 5% of the core by length has broken structure spacing less than 0.3 m, while less than 1 m of core (approximately 0.1% by length) has fracture spacing less than 0.1 m. The lowest measured broken spacing was 0.06 m. The typical broken structure spacing is reduced in the upper borehole, where the upper 100 m of the borehole show broken spacing at approximately 1-3 m, while at greater depths, the typical fracture spacing increases to greater than 3 m. The core runs containing dykes have decreased broken structure spacing of typically 0.3 – 1 m.

The true fracture spacing can only be estimated after all measured discontinuities are plotted on a stereonet and sets are identified. This usually results in spacings greater than the inverse of the fracture frequency from the logs. For the purpose of RMR Index estimation, the inverse of the fracture frequency was used.

6.4 Condition of Discontinuities

The condition of discontinuities was recorded in all core logging data for all fracture types (i.e., faults, joints, veins) as a Joint Condition Rating (JCR). It is a frictional index based on intactness, geological aperture, rock wall strength, shape, roughness, infill character, and infill type of all fracture types (joints, faults and veins). The JCR ratings range from 0 for low frictional strength up to 30 for intact structures. Broken structures are assigned JCR ratings between 0 and 27. Of the complete set of structures (n = 1860), 69% are intact or partially intact (JCR=30). The broken structures are typically rough and undulating with hard surfaces and hard mineral infills or clean (JCR = 27), and progress in decreasing frequency through the lower frictional strength categories. There is a slight increase in frequency for JCR rating of 16 as all soft mineral coatings yield that rating regardless of shape and roughness of the surface.

The minimum JCR for the run was adopted when calculating the RMR for the run. A separate assessment with the average JCR for the run showed very little difference from the minimum JCR assessment.

6.5 Groundwater

As part of the workflow in developing a site-scale discrete fracture network (DFN) model (Sykes et al., 2022), intervals with groundwater were identified as hydraulically conductive features (HCFs) by either correspondence to the location of an opportunistic water sample (OGW), or to an interpreted inflow during flowing fluid electrical conductivity (FFEC) logging. A total of eight (8) HCF intervals were identified in IG_BH01 (Table 3). All core runs that overlap with locations of HCF intervals are assigned a rating of 10 (out of 15) indicating ‘damp’ conditions. The remainder of the core runs along the borehole are assigned a rating of 15 indicating ‘dry’ conditions. Figure 4 below includes the locations of the HCF intervals in IG_BH01.

Table 3: Summary of Hydraulically Conductive Feature intervals for IG_BH01 (from Sykes et al., 2022)

Borehole ID	HCF ID	From [m down hole]	To [m down hole]
IG_BH01	IG_BH01_HCF_1	39.55	44.27
IG_BH01	IG_BH01_HCF_2	214.56	218.28
IG_BH01	IG_BH01_HCF_3	549.51	550.71
IG_BH01	IG_BH01_HCF_4	624.01	631.99
IG_BH01	IG_BH01_HCF_5	769.01	774.99
IG_BH01	IG_BH01_HCF_6	775.69	776.26
IG_BH01	IG_BH01_HCF_7	894.36	896.32
IG_BH01	IG_BH01_HCF_8	921.93	923.01

7.0 SUMMARY OF ROCK MASS CLASSIFICATION BY RUN

The RMR Index described herein per core run is based on the RMR'89 classification. The data collected from borehole IG_BH01 were used to assemble the geotechnical information.

The information for the five parameters comprising RMR'89 was compiled as follows:

R_1 – Based on laboratory testing (UCS) and Strength Index values;

R_2 – Compiled from core logging by run;

R_3 – Spacing of discontinuities – Compiled from distances between fractures recorded from core logging by run;

R_4 – Condition of discontinuities– Compiled from core logging for each discontinuity individually, compiled by run; and

R_5 – Groundwater condition – Compiled from hydraulically conductive features identified during hydrogeological testing of the borehole and supported by FFEC logs (Sykes et al., 2022).

The RMR Index describes the rock mass characteristics independently of discontinuity orientations. An additional adjustment should be applied once the engineering application is known.

Figure 4 shows a summary of rock mass characteristics, including the components of RMR'89, and the RMR Index profile by run along the borehole.

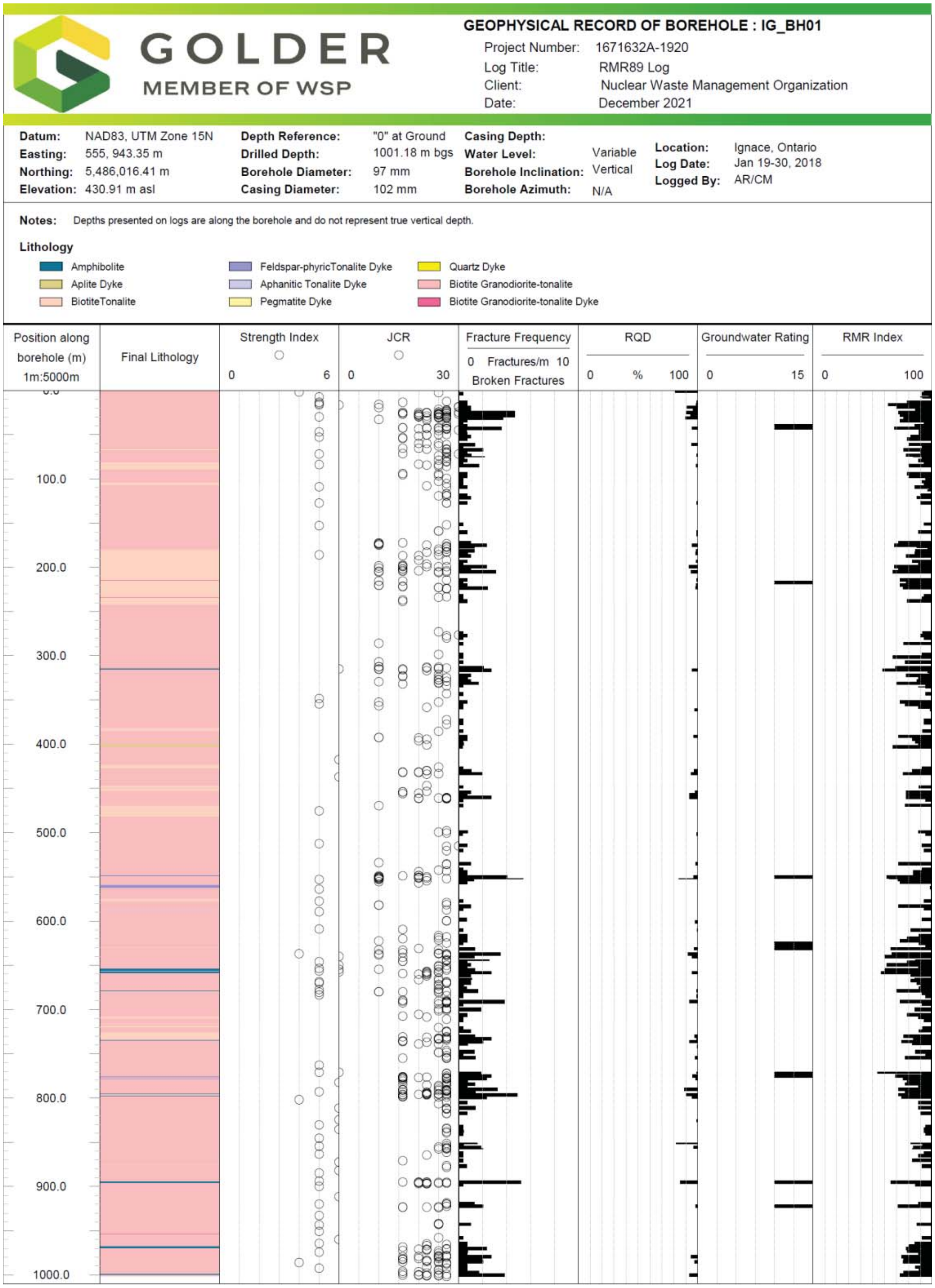

Figure 4: Summary profile of rock mass characteristics, including components of RMR'89, used to develop the RMR Index (rightmost column) for IG_BH01

8.0 SUMMARY OF ROCK MASS RATING INDEX DISTRIBUTION BY SECTIONS OF BOREHOLE IG_BH01

Distributions of the RMR Index for 100 m sections along the borehole are presented in Figure 5. This presentation of the data by borehole section in the form of histograms was made to allow an assessment of the variability of the rock quality with position along borehole. Mean and median values for the RMR Index are presented in Table 4 and RMR Index, by core run, is shown on Figure 4 alongside the borehole profile.

Table 4: Summary of mean and median values for RMR Index for borehole IG_BH01

Depth (position along borehole) Interval	RMR Index		
(m)	min	mean	median
0 – 100	63	85	87
100 – 200	68	92	96
200 – 300	67	92	99
300 – 400	58	89	93
400 – 500	67	93	99
500 – 600	62	91	99
600 – 700	57	84	88
700 – 800	54	86	88
800 – 900	65	93	99
900 – 1001.18	71	90	95

8.1 Adjustments to RMR Data for Engineering Use

8.1.1 Groundwater Ratings

The groundwater ratings used to generate the RMR Index profile were based on analysis of field hydrogeological testing of 20 m intervals in the more conductive features as identified from core logging and FFEC testing that was done as part of development of a site-scale DFN for the Revell Site (Sykes et al., 2022). The hydraulic conductivity values that led to the identification of the more conductive zones are representative only for the size of the HQ borehole (96 mm).

When using these data for engineering analysis or design of larger excavations, e.g., tunnels or shafts, a re-assessment of the groundwater conditions will be required to replace the ratings provided in this report.

8.1.2 Rating Adjustments for Discontinuity Orientations

The RMR Index ratings presented in this report will need to be adjusted by an additional parameter, namely, the influence of the orientation of the discontinuities. This step is usually left to the user of the data because the influence of the discontinuity orientations depends on the engineering application (see Table 5 and Table 6).

Table 5: Rating Adjustment for Discontinuity Orientations (see also Table 6)

Strike and Dip Orientations of Discontinuities		Very Favourable	Favourable	Fair	Unfavourable	Very Unfavourable
Ratings	Tunnels and mines	0	-2	-5	-10	-12
	Foundations	0	-2	-7	-25	-25
	Slopes	0	-5	-25	-50	-60

Table 6: Effect of Discontinuity Strike and Dip on Orientation in Tunnelling

Strike perpendicular to tunnel axis		Strike parallel to tunnel axis	
Drive with dip - Dip 45 – 90°	Drive with dip - Dip 20 – 45°	Dip 45 – 90°	Dip 20 – 45°
Very favourable	Very favourable	Very unfavourable	Fair
Drive against dip - Dip 45-90°	Drive against dip - Dip 20-45°	Dip 0-20° - Irrespective of strike	
Fair	Unfavourable	Fair	

Modified after Wickham et al (1972)

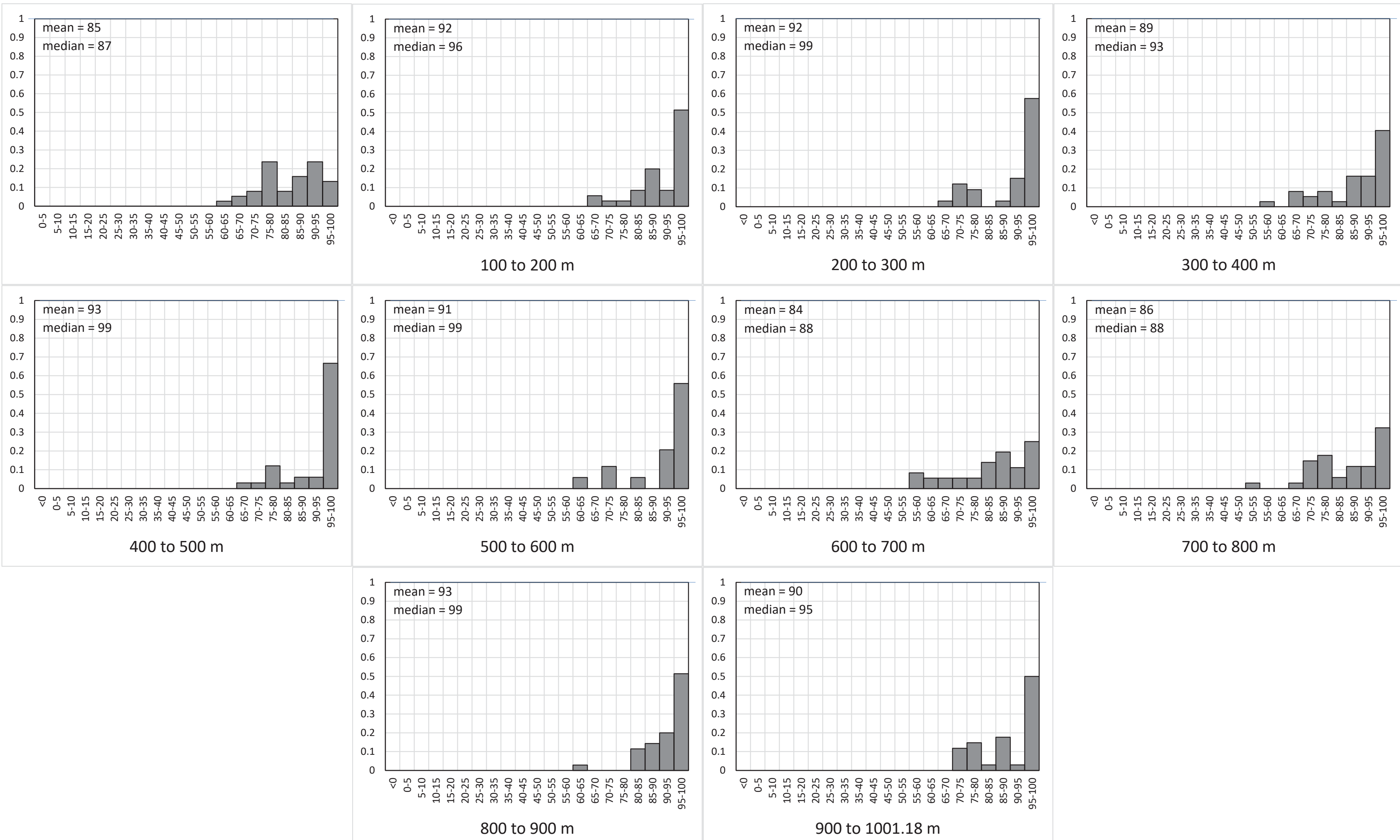

Figure 5: RMR Index distribution for 100 m sections of borehole IG_BH01 (RMR Index by run)

9.0 REFERENCES

Blackburn, C.E. and Hinz, P., 1996. Gold and base metal potential of the northwest part of the Raleigh Lake greenstone belt, northwestern Ontario-Kenora Resident Geologist's District; in Summary of Field Work and Other Activities 1996, Ontario Geological Survey, Miscellaneous Paper 166, p.113-115.

Bieniawski, Z.T. 1973. Engineering classification of jointed rock masses. Trans S. Afr. Inst. Civ. Engrs 15, 335-344.

Bieniawski, Z.T. 1974. Geomechanics classification of rock masses and its application in tunnelling. In Advances in Rock Mechanics 2, part A: pp.27-32. Washington, D.C.: National Academy of Sciences.

Bieniawski, Z.T. 1989. Engineering rock mass classifications. New York: Wiley.

Golder, 2017. Initial Borehole Characterization Plan – Phase 2 Initial Borehole Drilling and Testing – Ignace Area

Golder (Golder Associates Ltd.) and PGW (Paterson, Grant and Watson Ltd.), 2017. Detailed Geological Mapping – Ignace Ontario – APM Phase 2 Assessment. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-01332-0225

Golder, 2018. Phase 2 Initial Borehole Drilling and Testing, Ignace Area. WP3 Data Report ‑ Geological and Geotechnical Core Logging, Photography and Sampling for IG_BH01. NWMO Report Number: APM-REP-01332-0230

Golder, 2019. Phase 2 Initial Borehole Drilling and Testing, Ignace Area. WP5 Data Report - Geophysical Well Logging for IG_BH01. NWMO Report Number: APM-REP-01332-0234.

Golder, 2022. Phase 2 Initial Borehole Drilling and Testing, Ignace Area. WP4b Data Report ‑ Geomechanical Testing of Core for IG_BH01. NWMO Report Number: APM-REP-01332-0232

Hoek, E. 2018. Practical Rock Engineering (2018 ed.). https://www.rocscience.com.

Parmenter, A., Waffle, L. and DesRoches, A., 2020. An updated bedrock geology map and geological database for the northern portion of the Revell batholith (No. NWMO-TR-2020-08). Nuclear Waste Management Organization.

Parmenter, A., Waffle, L., DesRoches, A., Carvalho, J., Neufeld, A. 2022. Phase 2 Initial Borehole Drilling and Testing, Ignace Area. WP10 – Geological Integration Report for Borehole IG_BH01 (No. APM-REP-01332-0260). Nuclear Waste Management Organization.

SGL (Sander Geophysics Limited), 2015. Phase 2 Geoscientific Preliminary Assessment, Acquisition, Processing and Interpretation of High-Resolution Airborne Geophysical Data, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization (NWMO). NWMO Report Number: APM-REP-06145-0002

SRK (SRK Consulting, Inc.) and Golder, 2015. Phase 2 Geoscientific Preliminary Assessment, Observation of General Geological Features, Township of Ignace, Ontario. Prepared for Nuclear Waste Management Organization. NWMO Report Number: APM-REP-06145-0004.

Stone, D., 2009. Geology of the Bending Lake Area, Northwestern Ontario; *in* Summary of Field Work and Other Activities 2009. Ontario Geological Survey. Open File Report 6240.

Stone, D., 2010a. Geology of the Stormy Lake Area, Northwestern Ontario; *in* Summary of Field Work and Other Activities 2010. Ontario Geological Survey, Open File Report 6260.

Stone, D., 2010b. Precambrian geology of the central Wabigoon Subprovince area, northwestern Ontario. Ontario Geological Survey, Open File Report 5422.

Stone, D., Halle, J. and Chaloux, E., 1998. Geology of the Ignace and Pekagoning Lake Areas, Central Wabigoon Subprovince; *in* Summary of Field Work and Other Activities 1998, Ontario Geological Survey, Misc. Paper 169.

Stone, D., Davis, D.W., Hamilton, M.A. and Falcon, A., 2010. Interpretation of 2009 Geochronology in the Central Wabigoon Subprovince and Bending Lake Areas, Northwestern Ontario, *in* Summary of Field Work and Other Activities 2010, Ontario Geological Survey, Open File Report 6260.

Sykes, E., DesRoches, A. and Parmenter, A. 2022. Discrete Fracture Network for the Revell Site. (No. NWMO-TR-2022-21). Nuclear Waste Management Organization.

Wickham, G.E., Tiedemann, H.R. and Skinner, E.H. 1972. Support determination based on geologic predictions. In Proc. North American rapid excav. tunneling conf., Chicago, (eds K.S. Lane and L.A. Garfield), 43-64. New York: Soc. Min. Engrs, Am. Inst. Min. Metall. Petrolm Engrs.

GOLDER
MEMBER OF WSP

golder.com