Technical Report

Title: ***Borehole Geophysical Logging in DGR-1 and DGR-2***

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Authors: **Peeter Pehme and Michael Melaney**

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DGR Site Characterization Document
Intera Engineering Project 06-219

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Intera Engineering DGR Site Characterization Document		
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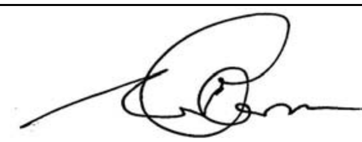
Approved by:	 Kenneth Raven	

Document Revision History		
Revision	Effective Date	Description of Changes
0	July 22, 2008	Initial Release
1	February 3, 2009	Updated formations in Figure 2, Table 6 and Appendix A to conform to results of November 2008 core workshop
2	June 17, 2010	Updated Tables 3, 4 and 5 and Appendix A for revised pick for top of Salina A1 Unit and general stratigraphy Added new Figure A.3 in Appendix A showing comparative plotting of repeated ATV logs of DGR-2 Minor editorial revisions to address NWMO comments of June 15, 2010
3	November 24	Revised structural and lithological interpretations of DGR-2 to account for borehole diameter variations using the Caliper 3-arm Log

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1 Introduction

Intera Engineering Ltd. has been contracted by the Nuclear Waste Management Organization (NWMO) to implement the Geoscientific Site Characterization Plan (GSCP) for the Bruce nuclear site located near Tiverton, Ontario. The purpose of this site characterization work is to assess the suitability of the Bruce site to construct a Deep Geologic Repository (DGR) to store low-level and intermediate-level radioactive waste. The GSCP is described by Intera Engineering Ltd., (2006, 2008).

This report summarizes the geophysical logging completed in two deep bedrock boreholes (DGR-1 and DGR-2), drilled as part of Phase I of the GSCP.

Work described in this Technical Report was completed in accordance with Test Plan TP-07-05 – DGR-1 and DGR-2 Borehole Geophysical Logging (Intera Engineering Ltd., 2007) and are plotted relative to the pertinent data presented in Technical Report TR-08-12 – Bedrock Formations in DGR-1, DGR-2, DGR-3 and DGR-4 (Intera Engineering Ltd., 2009a) and, Technical Report TR-07-06 – Drilling, Logging and Sampling of DGR-1 and DGR-2 (Intera Engineering Ltd., 2010). These Technical Reports and Test Plan were prepared following the general requirements of the Intera DGR Project Quality Plan (Intera Engineering Ltd., 2009b).

2 Background

Phase 1 GSCP investigations included a deep bedrock drilling program of two vertical 159 mm (6¼ inch) diameter continuously cored boreholes (DGR-1 and DGR-2) to depths of 462.9 and 862.3 meters below ground surface (mBGS), respectively. Both of these boreholes were drilled the same drill site, approximately 40 m apart from each other, at the Bruce site as shown on Figure 1. DGR-1 is located at NAD83 UTM Zone 17N, 4907753.24 m Northing and 454239.78 m Easting with a ground surface elevation of 185.71 m above sea level (mASL). DGR-2 is located at NAD83 UTM Zone 17N, 4907720.30 m Northing and 454208.92 m Easting with a ground surface elevation of 185.84 mASL.

DGR-1 was continuously cored from the top of bedrock (approximately 20 mBGS) to 15 m below the top of the Queenston Formation shale at 447.7 mBGS. DGR-1 was completed with steel casing from the ground surface to 182.3 mBGS which is approximately 3.7 m into the Salina F-Unit shale, leaving the lower 280.6 m section as an open borehole. DGR-2 was rotary drilled from ground surface to approximately 3 m below the top of Queenston Formation shale (~ 450 mBGS). DGR-2 was completed with steel casing from ground surface to the top of Queenston Formation shale. DGR-2 was then continuously cored from that depth to approximately 1 m into the Precambrian basement with a final depth of 862.25 mBGS.

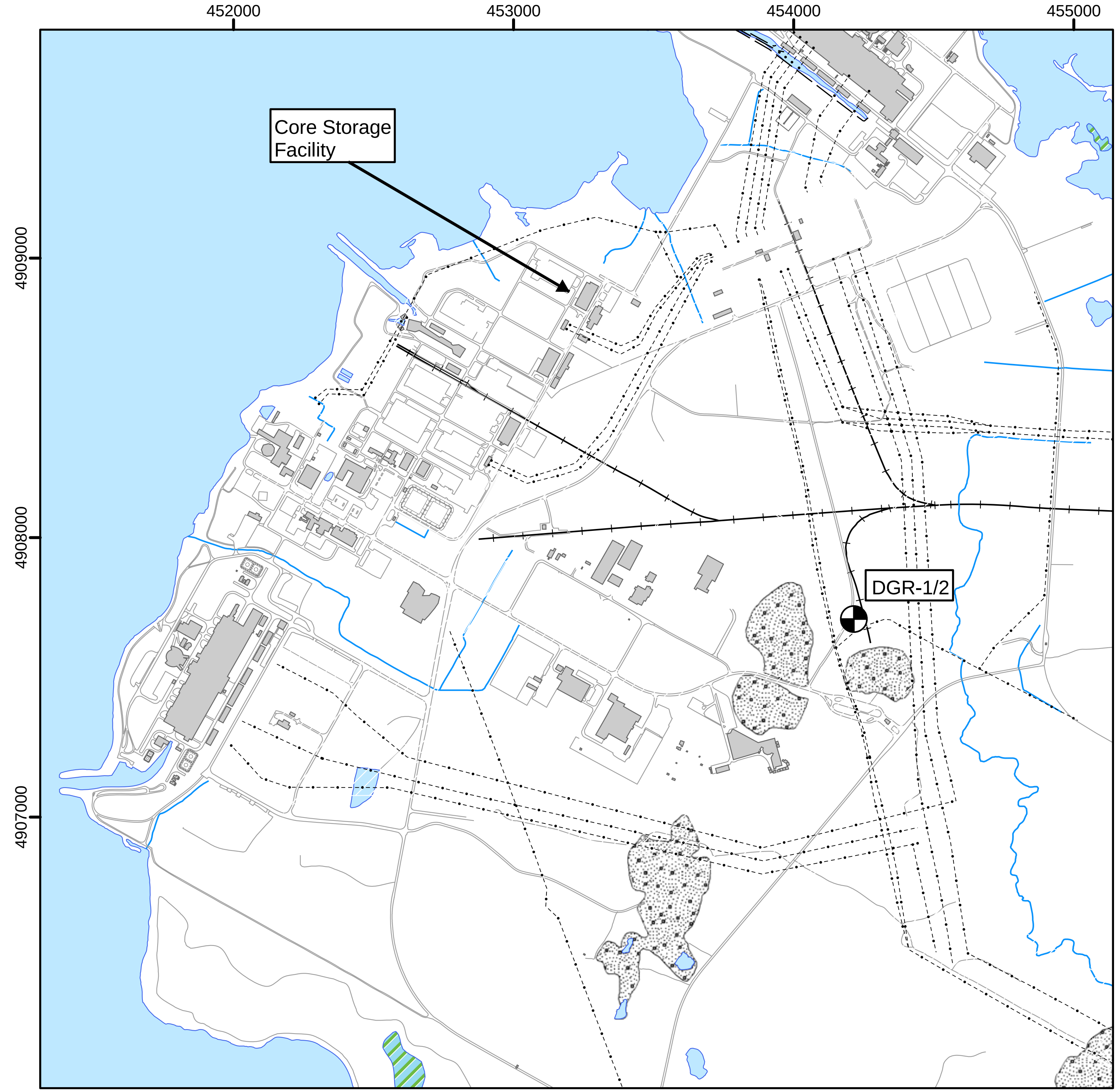
A detailed description of drilling, logging and casing activities for DGR-1 and DGR-2 can be found in TR-07-06 – Drilling, Logging and Sampling of DGR-1 and DGR-2 (Intera Engineering Ltd., 2010).

3 Methodology and Data Collection

3.1 Geophysical Logging of DGR-1 and DGR-2

Following the drilling operations at DGR-1, geophysical logging of DGR-1 took place in three phases:

- Initial geophysical logging between April 15, 2007 and May 2, 2007 by Layne Christensen Co. – Colog Division (Colog) based in Lakewood, Colorado, USA;
- Follow-up geophysical logging on May 9-10, 2007 by Lotowater Technical Services (Lotowater), based in Paris, Ontario, Canada. Lotowater also completed a limited set of geophysical logs to assess data collection issues (on-site electrical interference) during initial logging as discussed in Section 3.2;



OPG DGR
Site Characterization Plan

Legend

- Location of DGR-1/2
- Buildings
- Roads
- Railway
- Transmission Line
- Pits or Landfills
- Stream or Drainage

Location of DGR-1 and DGR-2 at the Bruce Site

Figure 1

N

Scale 1:20,000 (approx.)

0 130 260 520 780 1,040 Meters

Date: 17/10/2007
Drawn: NKP
Project: 06-219
Checked: SNS
P:/Projects/2006/06-219/QMS_DGR/TR_Working Files/TR-07-08/06-219_Site Location.mxd

Projection: UTM NAD 83 Zone 17

Data Credits:
NRVIS/OBM, MNR, Ontario Power Generation, Bruce Power

- Re-collection of a limited suite of geophysical logs between August 18 and 21, 2007 by Colog after data collection issues were resolved.

Likewise, in order to assess the stability of the Upper Ordovician shales (Queenston, Georgian Bay and Blue Mountain Formations), the geophysical logging of DGR-2 was completed in two phases:

- Immediately after drilling through the Upper Ordovician shales, the first phase of DGR-2 logging was conducted on the open interval from 450.7 to 650.0 mBGS by Lotowater on June 10, 2007. These preliminary logs provide a baseline condition for the borehole immediately following drilling and prior to any potential borehole degradation due to drilling fluid interaction or squeezing ground conditions.

- The second phase of DGR-2 logging was completed after completion of drilling DGR-2 to a total depth of 862.25 mBGS. However, because of high formation fluid pressures encountered in the Cambrian sandstone, DGR-2 was sealed with a removable production-injection packer from approximately 842 mBGS and below. Therefore, the second phase of geophysical logging for DGR-2 was completed from approximately 450.7 mBGS to approximately 842 mBGS by Colog from August 9 to 22, 2007. These logs include the Upper Ordovician shales and the Middle Ordovician argillaceous limestones.

Prior to completing a second round of hydraulic testing at DGR-2 a third ATV log was collected on June 26, 2009 by Lotowater. This log was collected between the approximate open interval of 449.7 to 836.8 mBGS. Upon comparison between the three sets of geophysical logs collected in DGR-2, no significant borehole wall stability or degradation issues were measured across the Upper Ordovician shales between June 10, 2007, August 9, 2007 and June 26, 2009.

3.2 Field Site Adjustments

Colog mobilized several logging systems and multiple probes to provide redundant capability for data collection. Calibration of the logging systems was completed as per TP-07-05. Field quality control processes indicated that some data collected in DGR-1 suffered from an irregular signal (noise) superimposed on the data. The source of the noise was initially suspected to be one or a combination of equipment problems (sondes, cables or consoles etc.) or site conditions, however, it was identified that a significant potential difference (2 volt and 56 mA AC) existed between the surface casing and a ground placed in a nearby wetland. It was later confirmed that an abandoned railroad spur running alongside DGR-1 was attached to a large grounding grid used as part of the plant infrastructure. To mitigate the signal noise the railroad track was cut after the Lotowater logging effort at DGR-1 on May 10th.

Because the quality of some data was compromised during initial logging in DGR-1, the acoustic televiewer, sonic and elog/gamma were re-logged during August 18-21, 2007, after borehole geophysical logging was completed in DGR-2. The original DGR-1 video log had been poor because of particulate in the water. During the interim borehole testing within DGR-1 the hole was flushed several times with fresh water and the video log was also repeated in August, 2007.

The Cambrian sandstone encountered near the bottom of DGR-2 (from 843.8 to 860.7 mBGS) was under high hydraulic pressure which created significant amounts of artesian flow. To facilitate both geophysical logging and packer testing, the borehole was sealed with a removable production-injection packer set immediately above the Cambrian sandstone. This limited borehole geophysical logging in DGR-2 to the approximate bedrock section of 450.7 to 842 mBGS.

Tables 1 and 2 summarize the details of geophysical data collection in DGR-1 and DGR-2, respectively. The tables provide the field depth closures which were used as the indicator of depth encoding consistency. Colog marked the logging cable when it was nearly fully extended to the bottom of the borehole during the collection of the first log in each hole (fluid resistivity and temperature), and subsequently noted the depth of that mark during the collection of other data sets as an additional method of depth quality control.

Table 1 Summary of Closure of Geophysical Logs in DGR-1 at the Bruce Site, (original depths measured in feet, down is positive, bottom ~463.1m)

Log	Temp/Fluid Resistivity	Total Gamma	Density	Neutron		Spectral Gamma	Caliper	Elog	ATV	Sonic	Video
				Long	Short						
Date	15-Apr	16-Apr	16-Apr	17-Apr	19-Apr	29-Apr	1-May	10-May	18-Aug	19-Aug	21-Aug
Direction of Data Collection	Down	Up	Up	Up	Up	Up	Up	Up	Down	Down	Down
Field Closure (m)	-0.37	0.55	-0.76	-0.37	0.00	-0.19	-0.46	-0.06	-0.20	-0.20	0.30

Table 2 Summary of Closure of Geophysical Logs in DGR-2 at the Bruce Site (original depths measured in feet, down is positive, bottom ~842.0m)

Log	Temp, Fluid Resistivity	Caliper	Total Gamma, Elog	Neutron	Density	Sonic	Caliper	Spectral Gamma	ATV	Video
Date	9-Aug	10-Aug	11-Aug	12-Aug	12-Aug	13-Aug	13-Aug	15-Aug	17-Aug	22-Aug
Direction of Data Collection	Down	Up	Up	Up	Up	Down	Up	Down	Up	Down
Field Closure (m)	0.09	0.18	-0.64	-0.46	-0.88	0.46	-0.18	0.82	0.64	0.49

3.3 Data Processing

Colog adjusted the individual data files for varying sensors to measuring point differences and field closure depth discrepancies (see Tables 1 and 2). Where applicable (e.g., apparent fluid resistivity, gamma-gamma, neutron and sonic) Colog also converted field instrument responses into the related physical property parameters (resistivity, density, porosity, P-wave velocity etc.) based on either field or bench calibrations. These data were delivered as digital paper copies (pdf) and as processed digital data in both Log ASCII Standard (LAS) and WellCad™ (WCL) formats.

3.4 Data Consolidation

The data provided by Colog was consolidated into two separate WellCad files for DGR-1 and DGR-2, respectively. The acquired data met the requirements of TP-07-05, though small depth discrepancies remain (see Tables 1 and 2). However, in anticipation of potential future detailed digital analysis or possible comparison to other data forms, the depths in the final compilation were adjusted as described below.

Of all the available data, the core is assumed to be the most accurate relative to depth. Amongst the geophysical logs, the acoustic televiewer (ATV) is assumed to be one of the most complete because of the high data density, slow collection speed, and the ability of the system to monitor and account for any data gaps. The ATV has the additional benefit of having features that are directly comparable to detailed core photographs. Based on correlation of fracture and bedding patterns near the bottom of the casing and close to the bottom of each borehole (Table 3), a correction for the ATV relative to the core was determined. Within reasonable errors the correction for DGR-1 is a simple shift of results down by 0.44m**.** However in DGR-2 the ATV – core correlation requires a shift of 0.69m and a stretch of approximately 0.49m over 314m or 0.16%.

Table 3 Correlation of Core Photos and ATV Logs (shift down is positive)

Borehole	***Core***	***ATV***	***Shift of ATV (m)***
DGR-1	190.97	190.55	0.42
	428.80	428.34	0.46
DGR-2	455.19	454.50	0.69
	768.89	767.71	1.18

The bottom of the casing and contacts between deep geologic units or fractures provide the basis for subsequent correlation of the individual geophysical logs against the ATV data. It is particularly attractive to use the bottom of the casing because it has a distinct signature on most geophysical logs, however it is used with some caution because of the possibility that the concrete used to seal the casing may complicate the interpretation and geologic contacts near the base of the casing are used for confirmation. Tables 4 and 5 summarize the final adjustment of all logs against the ATV for DGR-1 and DGR-2 respectively.

Table 4 Final Depth Adjustments of DGR-1 Geophysical Logs (down is positive).

	Shallow (m)		***Deep (m)***	
Log	***ATV / Ac Caliper***	***Core***	***ATV / Ac Caliper***	***Core***
Temp Fluid Res.	-0.35	0.07	-0.39	0.08
Caliper	0.02	0.44	-0.35	0.12
Density	0.12	0.54	0.32	0.79
Elog / Gamma	-0.66	-0.24	-0.05	0.42
Neutron	-0.19	0.23	0.17	0.64
Spectral Gamma	-0.67	-0.25	0.03	0.5
Sonic	0.18	0.6	-0.3	0.17
Video	NA	NA	NA	NA
ATV / Ac Caliper		0.42		0.46

Table 5 Final Depth Adjustments of DGR-2 Geophysical Logs (down is positive).

	Shallow (m)		***Deep (m)***	
Log	***ATV / Ac Caliper***	***Core***	***ATV / Ac Caliper***	***Core***
Temp Fluid Res.	0.13	0.83	0.35	0.51
Caliper	0.63	1.33	1.02	1.18
Density	0.27	0.97	-0.25	-0.09
Elog / Gamma	0.91	1.61	0.65	0.81
Neutron	1.07	1.77	0.58	0.74
Spectral Gamma	0.06	0.76	0.32	0.48
Sonic	-1.53	-0.83	1.38	1.54
Video	NA	NA	NA	NA
ATV / Ac Caliper		0.69		1.18

4 Geophysical Logging Results

A summary of bedrock stratigraphy based on dominant lithology is presented in Table 6 and illustrated in Figure 2. The rationale for identifying each bedrock formation and the contact depths can be found in Technical Report TR-08-12 – Bedrock Formations in DGR-1, DGR-2, DGR-3 and DGR-4 (Intera Engineering Ltd., 2009a).

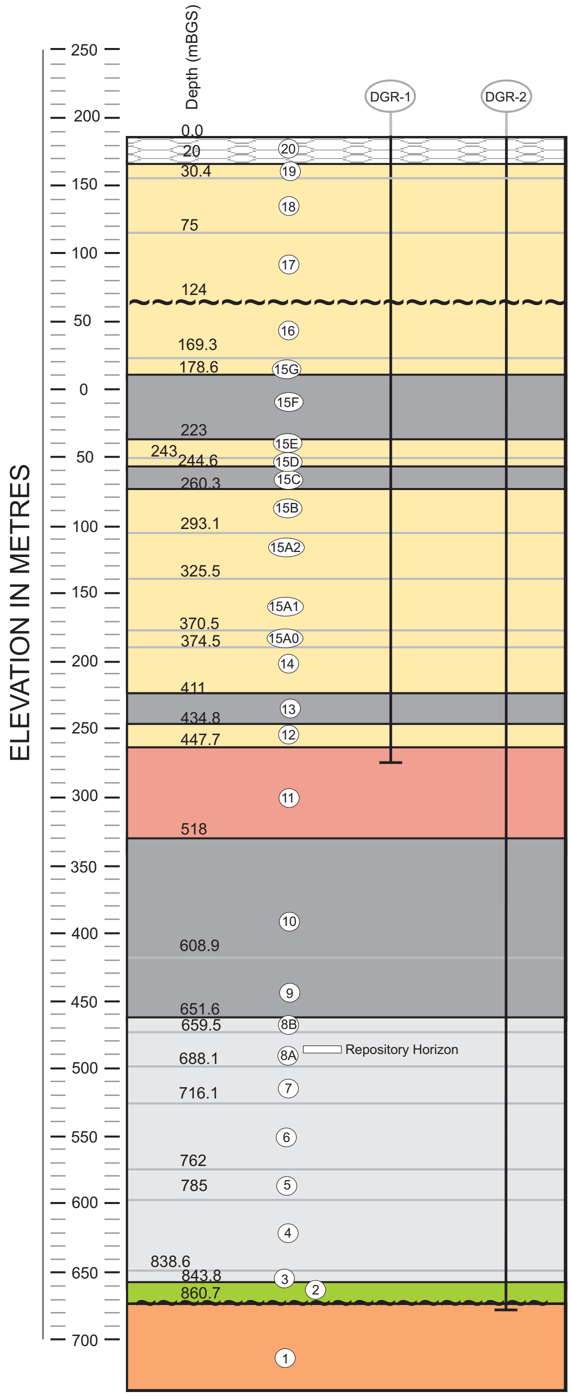
Table 6 Formation Summary and Bedrock Stratigraphy

Formation	***Bedrock Stratigraphy***
Devonian & Silurian	
Lucas	Brownish-Grey Argillaceous Dolostone
Amherstburg	Brown-Grey Dolostone
Bois Blanc	Brown-Grey Dolostone with Shale and Chert
Bass Islands	Brown Fine-Grained Dolostone
Salina (Units G, E, D, B and A)	Dolostone/Dolomitic Shale/Anhydritic Dolostone
Salina (Units F and C)	Dolomitic Shale and Shale
Guelph, Goat Island, Gasport, Lions Head and Fossil Hill	Dolostone and Dolomitic Limestone
Cabot Head	Green and Grey Shale
Manitoulin	Dolostone with Limestone and Minor Shale
Upper Ordovician	
Queenston	Red Shale
Georgian Bay	Greenish-Grey Shale
Blue Mountain	Dark Grey Shale
Middle Ordovician	
Cobourg	Shale and Argillaceous Limestone
Sherman Fall	Argillaceous Limestone
Kirkfield	Argillaceous Limestone
Coboconk	Fine-Grained Bioturbated Limestone
Gull River	Lithographic Limestone
Shadow Lake	Siltstone and Sandstone
Cambrian	Sandstone
Precambrian	Granitic Gneiss

The geophysical logs for DGR-1 and DGR-2 are compiled against the bedrock stratigraphic logs generated in TR-08-12, are provided as poster-size plots in Figures A.1, and A.2 and of Appendix A. Figure A.3 of Appendix A compares the ATV, Acoustical Caliper, Azimuth, Tilt, collected June 2007, August 2007, and June 2009. It also compares the 1-arm Caliper (June 2007) and 3-arm Caliper (August 2007) logs. Specifics of the parameters measured in each borehole geophysical log are provided in Appendix B. Comments regarding the individual data tracks on Figures A.1, A.2 and A.3 are provided below.

1 Geologic Interpretation: The stratigraphic interpretation is provided from TR-08-12.

2 Gamma Total Count (counts per second (cps)): Collected with elog probes.



LEGEND - BRUCE SITE STRATIGRAPHY

PLEISTOCENE
- 20 SURFICIAL DEPOSITS

MIDDLE DEVONIAN
- 19 LUCAS FORMATION - DOLOSTONE
- 18 AMHERSTBURG FORMATION - DOLOSTONE

LOWER DEVONIAN
- 17 BOIS BLANC FORMATION - CHERTY DOLOSTONE
- ~~~~~~ SILURIAN / DEVONIAN DISCONTINUITY

UPPER SILURIAN
- 16 BASS ISLANDS FORMATION - DOLOSTONE
- 15 SALINA FORMATION
- 15G G UNIT - ARGILLACEOUS DOLOSTONE
- 15F F UNIT - DOLOMITIC SHALE
- 15E E UNIT - BRECCIATED DOLOSTONE AND DOLOMITIC SHALE
- 15D D UNIT - ANHYDRITIC DOLOSTONE
- 15C C UNIT - DOLOMITIC SHALE AND SHALE
- 15B B UNIT - ARGILLACEOUS DOLOSTONE AND ANHYDRITE
- 15A2 A2 UNIT - DOLOSTONE AND ANHYDRITIC DOLOSTONE
- 15A1 A1 UNIT - ARGILLACEOUS DOLOSTONE AND ANHYDRITIC DOLOSTONE
- 15A0 A0 - BITUMINOUS DOLOSTONE

MIDDLE SILURIAN
- 14 GUELPH, GOAT ISLAND, GASPORT, LIONS HEAD AND FOSSIL HILL FORMATIONS - DOLOSTONE AND DOLOMITIC LIMESTONE

LOWER SILURIAN
- 13 CABOT HEAD FORMATION - SHALE
- 12 MANITOULIN FORMATION - CHERTY DOLOSTONE AND MINOR SHALE

UPPER ORDOVICIAN
- 11 QUEENSTON FORMATION - RED SHALE
- 10 GEORGIAN BAY FORMATION - GREY SHALE
- 9 BLUE MOUNTAIN FORMATION - DARK GREY SHALE

MIDDLE ORDOVICIAN
- 8 COBOURG FORMATION
- 8B COLLINGWOOD MEMBER - BLACK CALCAREOUS SHALE AND ARGILLACEOUS LIMESTONE
- 8A LOWER MEMBER - ARGILLACEOUS LIMESTONE
- 7 SHERMAN FALL FORMATION - ARGILLACEOUS LIMESTONE
- 6 KIRKFIELD FORMATION - ARGILLACEOUS LIMESTONE
- 5 COBOCONK FORMATION - BIOTURBATED LIMESTONE
- 4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
- 3 SHADOW LAKE FORMATION - SILTSTONE AND SANDSTONE

CAMBRIAN
- 2 CAMBRIAN SANDSTONE
- ~~~~~~ CAMBRIAN / PRECAMBRIAN UNCOMFORMITY

PRECAMBRIAN
- 1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS

NOTE:
1. SUBSURFACE STRATIGRAPHIC NOMENCLATURE AFTER ARMSTRONG AND CARTER (2006)

Bedrock Stratigraphic Column at the Bruce Site **TR-07-08: Borehole Geophysical Logging in DGR-1 and DGR-2**	Prepared by: ADG Reviewed by: KGR
FIGURE 2 — Doc. No.: TR-07-08_Figure 2-BR Stratigraphy DGR-1_2_R2.cdr	Date: 16-Jun-10

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3 Spectral Gamma Spectra (keV) and Total Count (cps): 512 equal sized windows centered at energy levels from 1118.28 keV to 12434 keV. Electrical noise negatively influenced communication with this probe in DGR-1 and the final product is the coalition of five separate files with minor overlap or gaps at the transitions from one file to the next. The energy spectrum has been divided into counts per second (cps) of thorium (Th), potassium (K), and uranium (U).

4 Gamma-Gamma Short spaced (g/cc) and Long Spaced (g/cc): Density is estimated by Colog from bench calibration.

5 Compensated Density (g/cc) and Relative Density Porosity (%): Gamma-Gamma density estimate compensated for background gamma emissions using short and long spaced sensors. Relative density porosity is based on a matrix density of 3.3 g/cc and indicates the relative changes of porosity with depth.

6 Resistivity 16" and 64" (Ohm-m): All elog data collected in DGR-1 suffered from electrical noise, even after the rail lines were cut (see discussion above). Data collected by Lotowater is considered the least affected and is provided in Figure A.1.

7 Single Point Resistivity (Ohms) and Spontaneous Potential (mV): The data in DGR-1 is also that collected by Lotowater due to the electrical noise encountered by Colog in DGR-1.

8 Neutron, Near and Far (cps): An indicator of hydrogen (water) content with formation water content inversely proportional to probe response (i.e. lower values represent higher water content).

9 Acoustic Televiewer Travel Time (0.1*usec): Effectively a measure of borehole diameter displayed on a shaded grey scale.

10 Acoustic Televiewer Amplitude: The reflected pulse amplitude displayed as a colour spectrum.

11 Structural Interpretation (Lithologic Boundaries): Dip and dip direction of major and some minor lithologic boundaries are interpreted from the ATV amplitude images. The degree of dip from horizontal is indicated by the position of a plotted point where 0^o represents a horizontal feature and 90^o represents a vertical feature. The dip direction of the lithological features is represented by a vector line that extends from the center of the plotted dip indicator to the azimuth direction of the feature's dip. An azimuth angle of 0^o (vertical) represents true north and rotating in a clockwise fashion by 90^o represents an easterly dipping direction. The boundaries are qualitatively grouped (see Table 7) according to how distinctly different material above and below the boundary appear on the detailed acoustic image. Note that only a representative number of minor lithologic boundaries have been interpreted so as to provide an indication of bedding complexity and not overwhelm the diagram.

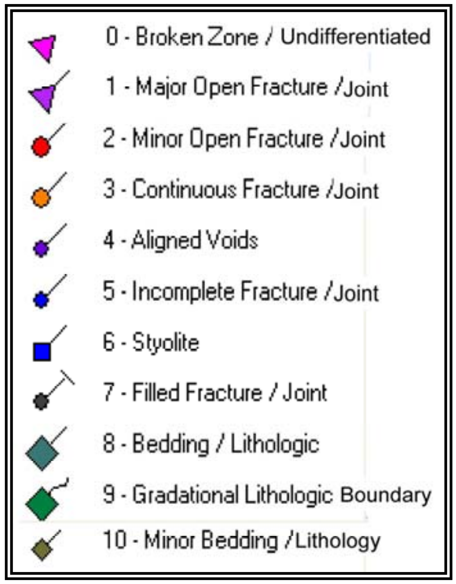
12 Structural Interpretation (Discontinuities): The dip and dip direction of interpreted discontinuities are plotted as described in point 11. This log presents the interpreted boundaries that could represent discontinuities. Note that this interpretation is intentionally conservative, in that when a feature on the ATV image might be either a lithologic boundary or a discontinuity it has been designated in this preliminary interpretation as a discontinuity.

13 Virtual Caliper Log (inches): Borehole diameter calculated from the average travel time of the ATV reflection around the circumference of the borehole assuming a fluid velocity of 1680 m/sec (Advanced Logic Technologies, 2006) .

14 Caliper 3-arm (inches): Borehole diameter based on the average extension of three caliper arms across the borehole.

15 Sonic Data Near sensor (signal vs time (µsec)): Signal is sensor response over a fixed time (µsec) window after a pulse has been emitted by the probe.

Table 7 Potential Discontinuities and Lithologic Boundaries Interpreted from ATV Images



16 Sonic Data Far sensor (signal vs time (µsec)): Sensor response over a fixed time (µsec) window after a pulse has been emitted by the probe shown as a grey scale.

17 Sonic velocities, P and S wave (m/sec): Calculated from interval times of the interpretation of P and S wave arrivals at the near and far sensor. P-wave arrival is the first arrival of energy to the sensor and S-wave manifests as a large amplitude event that arrives later. Note that the first arrival is generally clear and relatively unambiguous, whereas the S-wave arrival is within other energy forms, often not distinct and consequently a subjective interpretation. During the preparation of this report, revisions were made to both the interpreted early P-wave arrival times and the later S-wave arrival times.

18 Fluid Temperature (ºC), Temperature Gradient (ºC/m) and Variability (ºC): Temperature is measured with the fluid resistivity. Temperature Gradient is calculated from the difference in temperature over a 0.1 metre interval and temperature variability is calculated by subtracting the broadly smoothed (over 5m) temperature from the original data.

19 Fluid Resistivity (Ohm-m): Calculated from the apparent fluid resistivity readings calibrated against fresh water and brackish drilling solution samples.

20 Borehole Tilt (deg) and Azimuth (deg): Calculated from the magnetometers and tilt meters used for orientation within the ATV probe.

5 Data Quality and Use

A summary of the individual technologies (sondes) and their strengths and limitations, is provided in Appendix B. General considerations common to all sondes with regard to data quality, specifically electrical noise, depth accuracy, data density and logging speed are discussed below.

5.1 Electrical Noise

Based on the pervasiveness of the electrical noise described in Section 3.1 on different instrumentation, the noise is a site specific condition that appears to be related to power generation activities. Although the abandoned rail line was cut and logs were repeated to minimize the impact on data quality, an overprint of interference remains on electrical logs collected in DGR-1 and through the upper part of DGR-2 (in the Queenston Formation shale).

5.2 Depth

All depths were measured in feet relative to the top of casing at the time of logging and later converted to ground surface based on field measurements of casing height and survey data. The contractual specification for depth control is a maximum discrepancy of 0.1% of the total depth which can only be assessed as 0.2% of the distance traveled upon return to surface. That value provides an indication of slippage errors, but it does not assess the ability of the system to count properly and a systematic error at depth cannot be determined from that value alone. The industry standard for assessing depth encoder accuracy is the comparison of a direct measurement of a relatively short cable length (e.g., 100 ft) against the cable extracted from the winch. Additional markers were placed on the cable when the probe was near the bottom of the casing and when the cable was nearly full extended (approximately 5 m above the bottom). The variation of the depth of the intermediate and deep tape marks provide a secondary check on depth measurement. These marks also provide a method to assess whether the errors present are in the open portion of the borehole or within the casing.

5.3 Data Density

All of the probes with the exception of video (which is continuous) are measured at regular intervals based on number pulses emitted by a depth encoder wheel. The sampling intervals vary according to the particulars of the detection speed of the sensor, the spacing between sources - detectors and the basic resolution of the sensor. It is critical that the data sampling frequency be synchronized with the logging speed to optimize data quality. All data densities collected were at or better than the specifications of TP-07-05.

5.4 Logging Speed

The influence of logging speed varies with the nature of the sensor, whether the probe is actively emitting a signal or passively detecting natural variations and the time required to collect a reading (time constant). Refer to Appendix B for additional comments regarding the nature of the probes. In general increasing logging speed will smooth variations in the data and decrease resolution. All logging speeds were at or below the specifications of TP-07-05.

5.5 ATV Structural Features

Acoustic televiewer (ATV) logs provide images of the borehole wall that are not available by any other geophysical logging techniques or other borehole investigation methods. Consequently, ATV is an invaluable tool that is interpreted to provide information on both structural and lithological/stratigraphic features intersecting boreholes DGR-1 and DGR-2. However, as noted in point 12 of Section 4, the identification of structural features and discontinuities from ATV logs is intentionally conservative. Many of the structural features identified as major open, minor open and continuous fractures or joints, especially in the Ordovician shale and argillaceous limestone formations in DGR-2, are, based on detailed comparison to core, representative of thin mm to cm-scale layers and lenses of coarse grained limestone, siltstone and dolostone rather than fractures.

5.6 Summary

In consideration of the qualifications on data quality described above, the data presented in this Technical Report are suitable for providing the framework for development of Phase 1 geological, hydrogeological and geomechanical descriptive site models of the Bruce DGR site.

6 References

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APPENDIX A

Figure A.1 – Compiled Geophysical Logs for DGR-1

Figure A.2 – Compiled Geophysical Logs for DGR-2

Figure A.3 – DGR-2 ATV Comparison Log

Figure A.1: Summary of DGR-1 Borehole Geophysics

Prepared by: PP & MAM
Checked by: PP

Doc. TR-07-08_DGR-1 BH Geophysics_R2

Figure A.2: DGR-2 Borehole Geophysical Logs

Contact Legend

- Casing
- End of Borehole
- Formation Contact
- Ground Surface
- Stratigraphic Contact

Stratigraphic Legend

- Ash
- Dolostone
- Limestone
- Argillaceous Limestone
- Sandstone
- Shale
- Granite Gneiss
- Interbedded Shale and Argillaceous Limestone
- Interbedded Shale and Limestone
- Interbedded Shale and Limestone/Siltstone
- Interbedded Argillaceous Limestone and Shale
- Interbedded Siltstone and Sandstone

ATV Structural Legend

- Broken Zone / Undifferentiated
- Major Open Fracture / Joint
- Minor Open Fracture / Joint
- Continuous Fracture / Joint
- Aligned Voids
- Incomplete Fracture / Joint
- Styolite
- Filled Fracture / Joint
- Bedding / Lithologic
- Gradational Lithologic Boundary
- Minor Bedding / Lithology

ATV Lithological Legend

- Broken Zone / Undifferentiated
- Major Open Fracture / Joint
- Minor Open Fracture / Joint
- Continuous Fracture / Joint
- Aligned Voids
- Incomplete Fracture / Joint
- Styolite
- Filled Fracture / Joint

Prepared by: PP & MAM
Checked by: PP

Doc. TR-07-08_DGR-2 BH Geophysics_R3

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Figure A.3: DGR-2 ATV Comparison Log

Contact Legend

- Casing
- Formation Contact
- Ground Surface
- Stratigraphic Contact

Stratigraphic Legend

- Ash
- Dolostone
- Limestone
- Argillaceous Limestone
- Shale
- Interbedded Shale and Argillaceous Limestone
- Interbedded Shale and Limestone
- Interbedded Shale and Limestone/Siltstone
- Interbedded Argillaceous Limestone and Shale
- Interbedded Siltstone and Sandstone

Prepared by: MAM
Checked by: KGR

Doc. TR-07-08 DGR-2 BH ATV Log Comparison_R0

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APPENDIX B

Geophysical Sonde Measurements

Geophysical Sonde Measurements

The following is a brief description of the various geophysical logs collected within DGR-1 and DGR-2. This description is not intended to be a thorough discussion of the nuances of the instruments, but an introduction for the uninitiated reader. For a complete discussion refer to either a standard geophysical text or an instrument manufactures' owners manual such as is available at "http://www.mountsopris.com/downhole_tools.htm".

Gamma:

Method	Detection of gamma level radiation in counts per second (cps) emitted by the formation. Primarily a measurement of potassium, but also uranium and thorium content, which are preferentially concentrated in clays particles.
Major Applications	Primarily lithology in terms of varying clay content Grouts / Seals
Strengths	Passive device (no down hole energy sources) Large historic data base (but data quality of older sensors can be poor). Relatively sensitive to changes in lithology (primarily potassium but depends on sensor). Can be operated in the open hole or through steel or PVCcasing, or FLUTe sleeve. Small sample volume.
Limitations	Cannot differentiate lithologies with no contrast in their gamma emission. Therefore all geologic boundaries are not detectable. Comparisons and interpretation are normally qualitative unless a large local database is available. Background noise arises from the statistical nature of gamma emissions (can be problematic for older detectors) Relationship to clay content invalid where source rock is an emitter (e.g. granitic sandstones) Some grouts and concrete can also create background noise because of their clay content.

Resistivity:

Method	Galvanic measurement of resistivity, with various configurations of current and potential electrodes. Averages over electrode spacing, typically 0.5 to 2 m. Provides spontaneous potential and single point resistance
Major Applications	Primarily lithology in terms of electrical resistivity (i.e. water / clay content) Conductive porewater Clay-sandstone boundaries (SP)
Strengths	Large historic data base but varying electrode configurations can make comparison problematic. Works best in highly resistive environments. Sensitivity to borehole diameter and therefore can be used to detect large fractures; however, technique with typical electrode spacings (0.5 – 2m) is too unreliable for unsupported fracture detection.
Limitations	Results highly dependent on borehole diameter, grounding and electrode configurations. Only works in an open hole and below the water table

Spectral Gamma:

Method	Detection of gamma radiation emitted from the formation, partitioned into energy ranges ("windows" or "channels"), 512 in this case. Used to differentiate mineralogy (potassium, uranium and thorium content).
Major Applications	Primarily detailed lithology as determined by their clay mineral content.
Strengths	Passive device, no on-probe source. Potential for better differentiation of geologic units than total count gamma but requires long exposure to source rock (see below)
Limitations	Due to statistical nature of sources and degree of segregation accurate results require long exposure to source rock, ideally collected as stationary measurements, but an impractical option unless specific target unit is predetermined. Comparisons and interpretation are normally qualitative unless a <u>local</u> database is available.

Acoustic Televiewer:

Method	Both signal amplitude and travel time of the reflection of an acoustic pulse off the borehole wall.
Major Applications	Primarily dip and dip direction of fractures and lithologic contacts. Borehole rugosity. Some lithologic information is interpretable Provides borehole diameter Provides borehole orientation.
Strengths	Provides measurement of fracture dip and dip direction Independent of the clarity of the water
Limitations	Only works below water table Can be difficult to differentiate between fractures and lithology changes Some “thin bed exaggeration”, Although discontinuities can be identified the instrument provides no information about water movement.

Neutron (Porosity):

Method	Measurement of hydrogen content by exposing formation to neutrons from a source on the probe.
Major Applications	Hydrogen content. By inference, lithologic contacts, water content and porosity.
Strengths	Moderate resolution Good repeatability
Limitations	Some measurement noise due to the statistical nature of a nuclear log Influenced by borehole diameter variations.

Gamma-Gamma (Density):

Method	Measurement of electron density obtained by exposing formation to gamma radiation from a source in the probe. Dual sensor (near and far) used to minimize influence of background gamma emissions
Major Applications	Density. By inference, lithologic contacts and porosity
Strengths	Only tool to measure formation density directly. Provides single arm caliper from collimating arm.
Limitations	Tends to be noisy Influenced by borehole diameter and therefore probe collimated against borehole wall Conversion of probe values to density requires calibration against samples

Full Waveform Sonic:

Method	Detection of a sonic pulse emitted by the probe that travels along the borehole wall Measurement of the compressional (P), shear (S) and Stoneley seismic velocities.
Major Applications	Calculation of bulk modulus General rock competence and lithology
Strengths	Quantitative and highly detailed measurement of material properties.
Limitations	Influenced by borehole diameter Later arrivals (S, Tube and Stoneley) can be difficult to identify

Fluid Resistivity:

Method	Galvanic measurement of fluid resistivity with small electrode array. Calibrated against solutions of known conductivity on surface
Major Applications	Primarily identification of conductive porewater Potential fracture zones
Strengths	Large historic data base but varying electrode configurations can make comparison problematic. Works best in highly resistive environments. Sensitivity to borehole diameter and therefore can be used to detect large fractures; however, technique with typical electrode spacings (0.5 – 2m) is too unreliable for unsupported fracture detection.
Limitations	Can be influenced by borehole wall

Temperature:

Method	Direct measurement of borehole fluid temperature in degree C.
Major Applications	Primarily detection of change in annulus water temperature resulting from water movement through and between fractures. Some lithologic information due to variable thermal conductivities.
Strengths	Changes in hydrogeologic conditions generally overshadow geologic variations. Detection of very small aperture fractures that are hydrogeologically significant In some cases water movement in or out of the borehole can be resolved
Limitations	A temperature contrast must exist; therefore a fracture with water at matrix temperature (either moving or not) would be undetectable, however the long term stabilization process from drilling can create a detectable anomaly. Borehole must be water filled and allowed time to thermally stabilize from previous activities prior to logging. Near-surface temperature fluctuations can influence shallow data.

Caliper:

Method	Mechanical measurement of borehole diameter based on the extension of three caliper arms.
Major Applications	Borehole diameter and rugosity Fracture/void detection Casing depth
Strengths	Simple direct quantitative measurement of hole diameter Uninfluenced by other activities in borehole, or water clarity
Limitations	Measurement is only at fixed points within borehole circumference and may not be quantitatively representative of all features Narrow deep features are not accurately measured. Resolution can vary with length of arms.

Video:

Method	VHS video camera recording down length of borehole
Major Applications	Primarily fracture and void detection Water movement into borehole above water table and in some cases in to / out of fractures Rugosity and rock competence Casing length and screen conditions
Strengths	Real time inspection of actual conditions Basic interpretation is simple but refined interpretation requires experience.
Limitations	Requires clear borehole fluid. Decreased resolution in cloudy conditions Most of the analysis is qualitative, although semi-quantitative estimates of aperture and/or orientation are possible.