Technical Report

Title: ***Borehole Geophysical Logging in DGR-5 and DGR-6***

Document ID: **TR-09-03**

Authors: **Peeter Pehme and Michael Melaney**

Revision: **0**

Date: **April 7, 2011**

DGR Site Characterization Document
Geofirma Engineering Project 08-200

Geofirma
Engineering Ltd

Geofirma Engineering DGR Site Characterization Document		
Title:	Borehole Geophysical Logging in DGR-5 and DGR-6	
Document ID:	TR-09-03	
Revision Number:	0	Date: April 7, 2011
Authors:	Peeter Pehme (Waterloo Geophysics Inc.) and Michael Melaney	
Technical Review:	Kenneth Raven, Jim McLay (NWMO)	
QA Review:	John Avis	
Approved by:	Kenneth Raven	

Document Revision History		
Revision	Effective Date	Description of Changes
0	April 7, 2011	Initial Release

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF APPENDICES

1 Introduction

Geofirma Engineering Ltd. (formerly Intera Engineering Ltd.) has been contracted by the Nuclear Waste Management Organization (NWMO) on behalf of Ontario Power Generation to implement the Geoscientific Site Characterization Plan (GSCP) for the Bruce nuclear site 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 and 2008).

This Technical Report summarizes the geophysical logging completed at two deep inclined bedrock boreholes (DGR-5 and DGR-6) as part of Phase 2B of the GSCP.

Works described in this Technical Report (TR) were completed in accordance with Test Plan TP-09-11 – DGR- 5 and DGR-6 Borehole Geophysical Logging (Intera Engineering Ltd., 2009a) and are provided relative to the geological data presented in Technical Report TR-09-11 Bedrock Formations in DGR-1 to DGR-6 (Geofirma Engineering Ltd., 2011a) and, Technical Report TR-09-01 – Drilling, Logging and Sampling of DGR-5 and DGR-6 (Geofirma Engineering Ltd., 2011b). Work described in this Technical Report was completed following the general requirements of the DGR Project Quality Plan (Intera Engineering Ltd., 2009b)

2 Background

The GSCP comprises three phases of borehole drilling and investigations. The Phase 1 GSCP is described by Intera Engineering Ltd. (2006) and included the drilling, logging and testing of two deep vertical 152 mm diameter boreholes (DGR-1 and DGR-2) to total depths of 462.9 and 862.3 metres below ground surface (mBGS) respectively, and the drilling and testing of one shallow borehole, US-8, to a total depth of 200 mBGS. Both of these DGR boreholes were drilled at one location (Drill Site # 1), approximately 40 metres apart from each other. The shallow borehole (US-8) was drilled at a second location (Drill Site # 2); both drill sites are located at the Bruce nuclear site as shown on Figure 1. Phase 1 drilling and testing was completed between December 2006 and December 2007. TR-07-06 - Drilling, Logging and Sampling of DGR-1 and DGR-2 (Intera Engineering Ltd., 2010a) summarizes the Phase 1 drilling and core logging activities. The completed geophysics in these boreholes are described in Technical Report TR-07-08 – Borehole Geophysical Logging in DGR-1 and DGR-2 (Intera Engineering Ltd., 2010b).

The Phase 2 GSCP is described by Intera Engineering Ltd. (2008). Phase 2 is divided into two sub-phases, 2A and 2B. Phase 2A consisted of drilling, logging and testing of two deep vertical 143 mm diameter boreholes, DGR-3 (Drill Site #2) and DGR-4 (Drill Site #3) to total depths of 869.2 and 857.0 mBGS, respectively. Phase 2A was completed between March 2008 and September 2009. TR-08-13 - Drilling, Logging and Sampling of DGR-3 and DGR-4 (Intera Engineering Ltd., 2010c) summarizes the Phase 2A drilling and core logging activities. The completed geophysics in these boreholes are described in Technical Report TR-08-15 – Borehole Geophysical Logging in DGR-3 and DGR-4 (Intera Engineering Ltd., 2010d).

Phase 2B comprised the drilling, logging and testing of two deep inclined 143 mm diameter boreholes, DGR-5 (Drill Site #1) and DGR-6 (Drill Site #4). This work was completed between December 2008 and June 2010 and the drilling and core logging activities are described in TR-09-01 - Drilling, Logging and Sampling of DGR-5 and DGR-6 (Geofirma Engineering Ltd., 2011b). The purpose of drilling DGR-5 and DGR-6 was to complement the information that was collected from DGR-1 to DGR-4, confirm the predictability of the strike/dip of strata around and below the proposed DGR location, provide information on sub-vertical fracture networks (fracture orientation) and to further investigate specific areas identified during the 2D seismic study (TR-07-15, Intera Engineering Ltd., 2009c) showing seismic anomalies. The information gathered from DGR-5 and DGR-6 will assist with developing descriptive geosphere site models. The geophysical logging operations conducted during Phase 2B are described below.

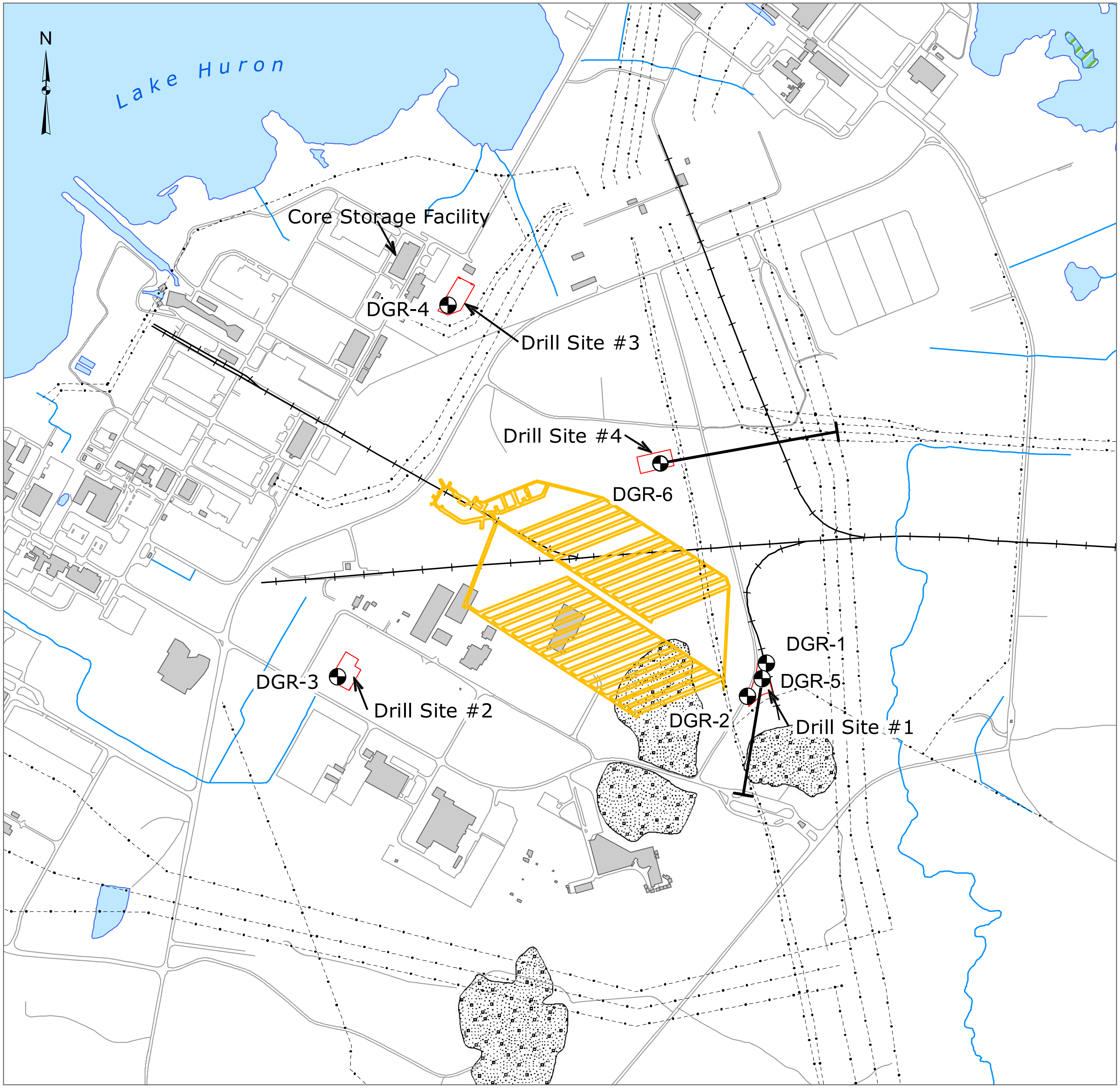


Figure 1
Location of Boreholes DGR-1 to DRG-6 at the Bruce Nuclear Site

Scale 1:15,000

PROJECTION: UTM NAD 83 Zone 17N
SOURCE: NRVIS/OBM, MNR, OPG, NWMO

PROJECT No. 08-200 TR-09-03

PROJECT NWMO DGR Site Characterization Project

DESIGN: NMP
CAD/GIS: NMP
CHECK: GDB
REV: 0

DATE: 07/04/2011

Geofirma Engineering Ltd

P:\QMS_DGR\TR_WorkingFiles\TR-09-03 Borehole Geophysical Logging of DGR-5 & DGR-6\Figure\TR-09-03_SiteLocationDGR1-6_R0.mxd

3 Methodology and Data Collection

3.1 Geophysical Logging of DGR-5 and DGR-6

Geophysical logging conducted at DGR-5 was completed in one phase:

- Geophysical logging was conducted between November 8, 2009 and November 26, 2009 by Layne Christensen Co. – Colog Division (Colog) based in Lakewood, Colorado, USA. This logging was completed across the approximate open borehole section of 205 to 807 mLBGS (metres length below ground surface).

Geophysical logging conducted at DGR-6 was completed in one phase:

- Geophysical logging was conducted between February 23, 2010 and March 15, 2010 by Layne Christensen Co. – Colog Division (Colog) based in Lakewood, Colorado, USA. This logging was completed across the approximate open borehole section of 212 to 896 mLBGS.

3.2 Field Site Adjustments

Colog mobilized several different logging systems and multiple probes to provide redundant capability for data collection. Calibration of the logging systems were completed as per TP-09-11. Field quality control processes indicated that some data collected in DGR-5 and DGR-6 suffered from an irregular signal (noise) superimposed on the resistivity and fluid conductivity data. Irregularities in the acoustic televiewer (ATV) data from DGR-5 were identified during quality review and several additional data sets were collected to confirm the cause of the borehole wall variations. Electrical/magnetic noise in DGR-6 was particularly problematic for the Advanced Logic Technology (ALT) ATV probe and ultimately the finalized logs were collected with a High Resolution Acoustic Televiewer (HRAT) made by Robertson Geologing Ltd for DGR-6. Additional borehole orientation data were collected with a deviation probe. Details are provided below.

Tables 1, 2, 3 and 4 summarize the details of geophysical data collection in DGR-5 and DGR-6, respectively. The tables provide the field depth closures which were used as the indicator of depth encoding consistency. Colog marked the logging cable at 200 metre intervals as well as 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 the marks 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-5 at the Bruce Nuclear Site, (original depths measured in feet along borehole, down is positive)

Log	***Temp, Fluid Resist.***	***Caliper***	***Total Gamma, E-log***	***Neutron***	***Density***	***Sonic***	***Spectral Gamma***	***ATV (ALT)***	***Gyro***
Date[†]	8-Nov	9-Nov	11-Nov	21-Nov	17-Nov	10-Nov	15,16-Nov	18,19 – Nov	21 –Nov
Direction of Data Collection	Down	Up	Up	Up	Up	Up	Up	Up	Both
Field Closure (m)	0.16	-0.31	-0.17	-0.08	-0.24	-0.13	-0.15	-0.17	0.07

[†] In the case of multiple runs of a probe only the date of data provided in compilation is provided

Table 2 Summary of Closure of Geophysical Logs in DGR-6 at the Nuclear Bruce Site (original depths measured in feet along borehole, down is positive)

Log	*Temp, Fluid Resist.*	*Caliper*	*Total Gamma, E-log*	*Neutron*	*Density*	*Sonic*	*Spectral Gamma*	*ATV (HRAT)*	*Gyro*	*Magnetic Deviation*
Date[†]	23-Feb	24-Feb	2-Mar	1-Mar	28-Feb	3-Mar	26, 27-Feb	14,15-Mar	24-Feb	10-Mar
Direction of Data Collection	Down	Up	Up	Up	Up	Up	Up	Up	Both	Up
Field Closure (m)	-0.32	-0.19	-0.20	-0.20	-0.22	-0.22	-0.19	-0.27	0.33	-.25

[†] In the case of multiple runs of a probe only the date of data provided in compilation is provided

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 (conductivity, density 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 were consolidated into separate WellCad files for DGR-5 and DGR-6. The acquired data met the requirements of TP-09-11, though small depth discrepancies remain (see Tables 1 and 2). In order for consistent comparison of different 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 regarded to be the most complete log. This is due to 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 identification of correlated fractures and bedding patterns with a high degree of confidence between the core logs and ATV data, a “best-fit” linear correction for the ATV relative to the core was determined. An exception to this process was adopted in DGR-6 because drilling related discontinuities in portions of the borehole wall caused the extraction of the ATV probe to be irregular (jerky) in parts and the potential for depth discrepancies was recognized. As the neutron probe is collected continuously the entire length of the borehole, its gamma response relative to geologic boundaries in the core was used for the initial depth refinement and the tape marks placed every 200 metres along the cable were used as the depth reference against which the ATV was adjusted. As a quality control and final (minor) adjustment, the ATV was then compared against core logs and core photography (see TP-09-01, Intera Engineering Ltd., 2009d) for procedures of the core logging process). Other logs were subsequently adjusted to the virtual caliper log created from ATV data or the gamma response collected with neutron log. The bottom of the casing and boundaries between geologic units or fractures along with common parameter (e.g., changes in borehole diameter or gamma levels) 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 there is the possibility that the concrete used to seal the casing may complicate the interpretation. Also, the borehole quality at the casing interface with the in-situ rock can be poor further complicating this boundary location. Consequently, deeper geologic features roughly evenly distributed through the borehole are used as the primary markers. Tables 3 and 4 summarize the final adjustment of all logs against the ATV for DGR-5 and DGR-6, respectively.

Table 3 Final Depth Adjustments of DGR-5 Geophysical Logs (down is positive).

Log	***Based on Data*** *(adjustments made relative to data already depth corrected along borehole)*				***Corrected Against***	***Based On***
	Shallow (m)	***Intermediate (m)***		***Deep (m)***		
ATV (ALT)	0.09 (@326.31m)	-0.09 (@487.26m)	-0.241 (@582.91m)	0.16 (@699.61m)	Core	Image
Caliper	-0.11 (@205.40m)	-0.26 (@449.45m)	-0.31 (@637.88m)	-0.45 (@794.08m)	ATV Cal.	Borehole Diameter
Density	-0.26 (@205.36m)	-0.31 (@449.45m)	-0.38 (@697.27m)	-0.62 (@727.79m)	ATV Cal.	Borehole Diameter
Sonic	-0.10 (@229.15m)	0.15 (@557.95m)	0.15 (@637.88m)	-0.41 (@794.2m	ATV Cal.	Borehole Diameter
Neutron	0.23 (@223.89m)	0.23 (@411.67m)	0.26 (@575.77m)	0.57 (@799.20m)	Density	Gamma
Spectral Gamma	-0.97 (@224.33m)	-0.89 (@348.54m)	-0.87 (@630.93m)	-0.45 (@759.59m)	Density	Gamma
E-log / Gamma	1.45 (@223.89m)	1.37 (@411.67m)	1.42 (@575.77m)	1.72 (@799.20m)	Density	Gamma
Temp Fluid Res.					Not Adjusted	
Gyro					Not Adjusted	

Table 4 Final Depth Adjustments of DGR-6 Geophysical Logs (down is positive).

Log	***Based on Data*** *(adjustments made relative to data already depth corrected along borehole)*				***Corrected Against***	***Based On***
	Shallow (m)	***Intermediate (m)***		***Deep (m)***		
Neutron					Casing, Core	Gamma – Major Lith.
Caliper	0.12 (@200.00m)			0.23 (@800.00m)	Neutron (Tape)	Tape Marks
ATV (HRAT)	-0.23 (@214.92m)	-0.72 (@517m)	-1.13 (@792 m)	-1.39 (@877.05m)	Caliper, Core	Borehole Diameter, Features
Density*	0.23 (@203.51m)	0.08 (@263.96m)	0.15 (@429.91m)	0.19 (@877.05m	Neutron	Gamma
Sonic	0.00 (@200m)	0.00 (@400m)	-0.00 (@600m)	0.00 (@800m)	Neutron	Tape, Features
Spectral Gamma	-0.27 (@237.14m)	-0.48 (@467.87m)	-0.43 (@738.27m)	-0.46 (@864.28m)	Neutron	Gamma
E-log / Gamma	1.30 (@237.74m)	1.35 (@429.91m)	1.38 (@738.13m)	1.48 (@877.25m)	Neutron	Gamma
Temp Fluid Res.	0.21 (@200m)	0.28 (@400m)	0.36 (@600m)	0.47 (@800m)	Neutron	Tape
Gyro					Not Adjusted	
Magnetic Deviation					Not Adjusted	

**Density log combines 2 data sets combined (diff adjustment required)*

4 Geophysical Logging Results

Bedrock stratigraphy presented in the DGR-5 and DGR-6 geophysical plots are identified in Technical Report TR-09-11 – Bedrock Formations and Contacts in DGR-1 to DGR-6 (Geofirma Engineering Ltd., 2011a). Figure 2 provides an illustrated summary of bedrock stratigraphy found in DGR-5 and DGR-6.

The geophysical logs for DGR-5 and DGR-6, complied against bedrock stratigraphic logs generated in TR-09-11, are provided as poster-size plots in Figures A.1 and A.2 of Appendix A. 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 and A.2 are provided below relative to depth along borehole. All logs have been adjusted to reference ground surface as permanent datum.

1 - Geologic Interpretation: The stratigraphic interpretation is provided from TR-09-11.

2 - Gamma Total Count (counts per second (cps)): Collected with neutron, density and E-log probes.

3 - Spectral Gamma Spectra (keV) and Total Count (cps): 512 equal sized windows centered at energy levels from 1118.28 keV to 12434 keV. The energy spectrum has been divided into counts per second (cps) of thorium (Th), potassium (K), and uranium (U).

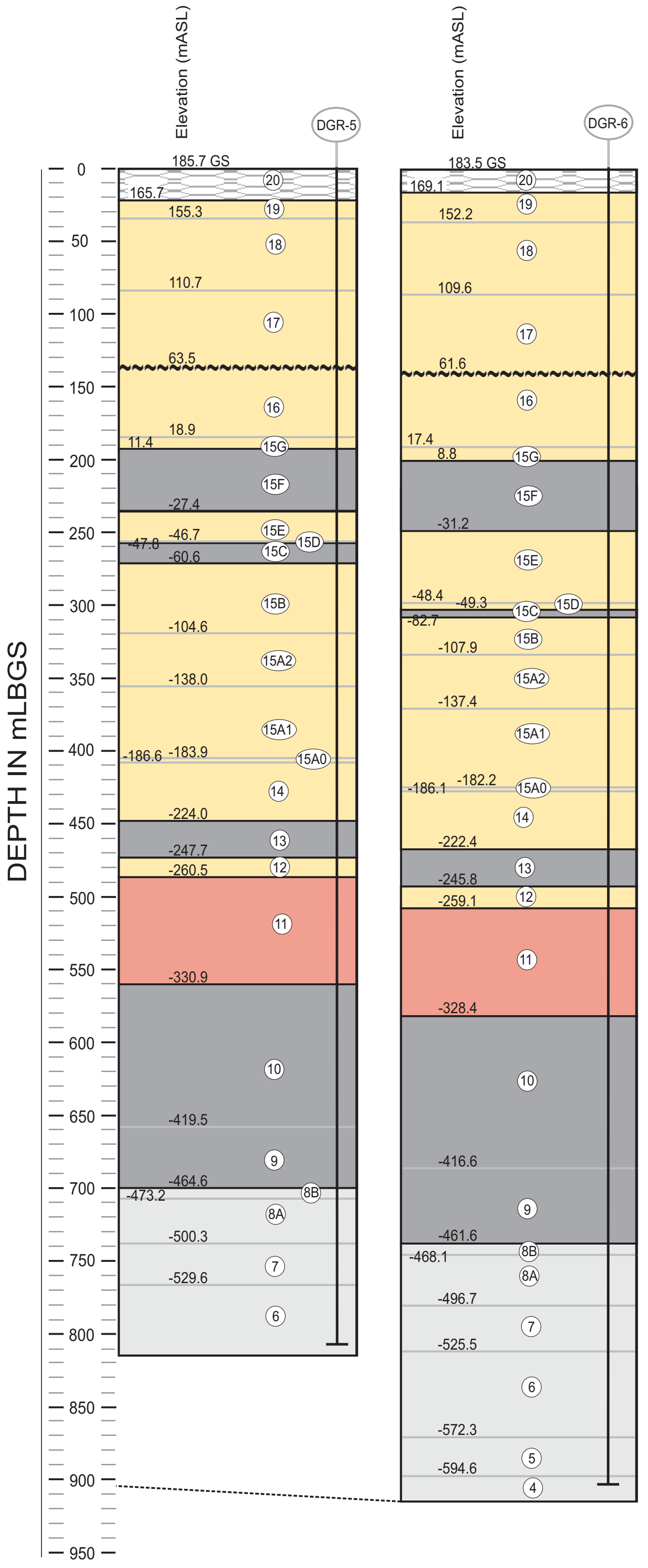
4 - Gamma-Gamma Short spaced (g/cc) and Long Spaced (g/cc): Density is estimated by Colog from bench calibration. A very close source – sensor, termed the “Bed Resolution Density” is available of refined interpretation of bedding boundaries.

5 - Resistivity 16” and 64” (Ohm-m): The E-log data collected suffered from electrical noise making it un-interpretable with regards to absolute values in both DGR-5 and DGR-6. A ten point moving average filter applied to the data for both DGR5 and DGR6 only had a slight effect on data presentation. This noise is apparently accentuated by the presence of conductive borehole fluid which also causes unrealistically low resistivity values throughout DGR-5 and uniformly low values in DGR-6.

6 - Single Point Resistivity (Ohms) and Spontaneous Potential (mV): These two logs were also collected with the E-Log probe which suffered from signal noise issues, similar to the resistivity data discussed above.

7 - Neutron, Near and Far (cps): These logs provide an indication of hydrogen (water) content. The formation water content is inversely proportional to probe signal response (i.e. lower values represent higher water content).

8 - Acoustic Televiewer Travel Time (0.1*µsec): Effectively a measure of borehole diameter displayed on a shaded grey scale. The electrical and magnetic noise in DGR-6 was particularly strong and precluded the use of the acoustic ATV data collected with the ALT probe, which was used in DGR-1, DGR-2, DGR-3, DGR-4 and DGR-5. The HRAT Robertson probe was eventually selected to collect the ATV data for DGR-6. The ATV logs collected in DGR-5 and DGR-6 show sections having a slight elliptical trend in borehole shape. Examples of this trend in DGR-5 at 636.5 mLBGS and DGR-6 at 447.4 mLBGS are presented in Figure A.3. Moreover irregularities in the maximum are a combined result of actual borehole diameter and distorted return signal (noise). This borehole shape is presumably caused by additional wear on the lower side of the borehole during drilling operations. These sections are identified by the asymmetric dark bands in the ATV images. In addition, portions of DGR-6 have a “thread” like groove winding around the borehole wall, Figure A.4, a condition confirmed by the 3-arm caliper. This groove has a approximate thickness of 1.4 cm. Virtual caliper logs (cm) also presented on Figure A.4 are defined with the minimum (blue), maximum (green) and average (brown) borehole diameter.



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

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

Interpreted Bedrock Stratigraphy at Bruce Site from DGR-5 and DGR-6 Data
Technical Report: TR-09-03 Borehole Geophysical Logging in DGR-5 and DGR-6

Prepared by: NMP

Reviewed by: GDB

FIGURE 2

Doc. No.: TR-09-03_Figure 2_R1.cdr

Date: Apr 7, 2011

Geofirma Engineering Ltd

9 - Acoustic Televiewer Amplitude: The reflected pulse amplitude displayed as a colour spectrum. All ATV data were referenced to the high side of the boreholes during data collection. Portions of the ATV image in both DGR-5 and DGR-6 are of poor quality because of decentralization of the probe due to borehole enlargement, and degradation of signal amplitude from rock flour coating of the borehole wall.

10 - 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 and 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 eastern dipping direction. The boundaries are qualitatively grouped (see Table 5) 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. Interpretation of both lithology and structures were completed against the "high side" of the borehole and subsequently corrected for borehole azimuth and dip. The level of detail of the interpretation deteriorates with the quality of the image in both DGR-5 and DGR-6. Pink and red shading are used to indicate those portions of the where poor images partially impeded and limited interpretation.

11 - Structural Interpretation (Discontinuities): The dip and dip direction of interpreted discontinuities are plotted as described in point 10. This log presents the interpreted boundaries that could represent discontinuities. Note this interpretation is intentionally conservative, in that when a feature on the ATV image might be either a lithologic boundary, a drilling induced irregularity on the borehole wall, or a discontinuity, it has been designated in this preliminary interpretation as a discontinuity. Both DGR-5 and DGR-6 are inclined; those features most likely to be drilling induced are perpendicular to the borehole axis and are identified in a separate column to differentiate them other features in the borehole.

12 - Virtual Caliper Log (cm): Borehole diameter calculated from the average travel time of the ATV reflection around the circumference of the borehole assuming a fluid velocity of 1,488 m/sec (Advanced Logic Technologies, 2006). Discrepancies with both sharp and gradual changes, in the apparent diameter of the borehole between these data and the three arm caliper occur which are attributed to variations in fluid density.

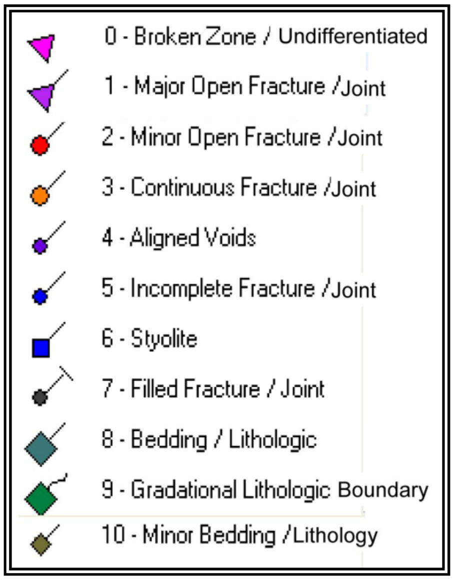
13 - Caliper 3-arm (cm): Borehole diameter based on the average extension of three caliper arms across the borehole.

14 - 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.

15 - 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.

16 - 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. The P-wave arrival is the first energy to reach the sensor and the S-wave manifests as a large amplitude event that arrives later. Note 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. The irregularity of the borehole wall in these inclined holes made the arrivals indistinct in portions of the data and averaging over 5 traces was used to improve the signal to noise ratio.

Table 5 Potential Discontinuities and Lithologic Boundaries Interpreted from ATV Images



0 - Broken Zone / Undifferentiated
1 - Major Open Fracture /Joint
2 - Minor Open Fracture /Joint
3 - Continuous Fracture /Joint
4 - Aligned Voids
5 - Incomplete Fracture /Joint
6 - Styolite
7 - Filled Fracture / Joint
8 - Bedding / Lithologic
9 - Gradational Lithologic Boundary
10 - Minor Bedding /Lithology

17 - 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.

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

19 - Borehole Tilt (deg) and Azimuth (deg): Calculated from the magnetometers and tilt meters used for orientation within the ATV probe for DGR5. Although the HRAT probe ultimately used in DGR6 did gather an image and provide borehole tilt, the magnetic noise compromised portions of the orientation data. Orientation data collected during drilling is combined to create the azimuth log in DGR6 and for conversion from apparent to true dip of features interpreted from the ATV amplitude log.

5 Data Quality and Use

A summary of the individual technologies (sondes), 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

Electrical noise which appeared to be a site specific condition related to power generation activities was problematic on a broad range of instrumentation during data collection at DGR-1 and DGR-2. Although the electrical noise also compromised the quality of the E-log data and is particularly distinct when the borehole fluid is electrically conductive (brine), utilizing different equipment (newer generation) for other measurements and lowering data transfer rates minimized the overall impact on the DGR-3, DGR-4 and DGR-5 data. The electrical noise at DGR-6 was particularly strong and a magnetic component was evident in sondes that relied on magnetometers for azimuthal orientation (ATV and deviation). Identifying the most accurate approach to manage these issues proved to be quite an arduous task. Multiple sets of logs at varying logging speeds along with utilizing different sonde manufacturers were used to combat these site conditions. Whether these influences are related to location on site, vary over time or are a combination both, their existence should be considered in future testing activities and analysis of data.

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 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 access whether the errors present are in the open portion of the borehole or within the casing.

5.3 Data Density

All of the probes are measured at regular intervals based on the 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-09-11 (Intera Engineering Ltd., 2009a).

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-09-11.

5.5 Full Waveform Sonic Processing

Full waveform sonic logs provide insight into rock integrity and competency. This log can also provide information on porosity, permeability, and lithology. Processing these logs to calculate compressional wave (P) and shear wave (S) velocities can be useful to determine the Shear, Young and Bulk moduli. Both the P and S wave velocities were calculated for DGR-5 and DGR-6 geophysical logs. However, it proved difficult to differentiate the arrival time of the S wave in portions of the logs due to a combination of borehole enlargements and irregularities in the borehole wall related to the drilling process. Running averages of traces (5) were used to improve differentiation of P and S wave arrivals.

5.6 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-5 and DGR-6. However, as noted in point 11 of Section 4, the identification of structural features and discontinuities from ATV logs is intentionally conservative. Since both boreholes are inclined features perpendicular to the borehole axis were interpreted and presented in separate columns because these are most likely to be artefacts of the drilling process. Consequently these interpretations are less conservative than those for the four vertical holes previously drilled. However 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, 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 or joints.

Note also that the interpretation of ATV logs in these inclined boreholes is completed relative to the original borehole orientation and then subsequently converted from an “apparent” to “true” dip and dip-direction. The accuracy of the final orientation of the features depends not only on the original matching of curves to the image, but also the data quality of borehole tilt, azimuth and diameter measurements. These dependencies will be accentuated when the features are (or nearly) flat lying and consequently, the quality of the interpretation of structural and lithologic tadpoles will vary along the borehole.

5.7 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 2 geological, hydrogeological and geomechanical descriptive site models of the Bruce DGR site.

6 References

Advanced Logic Technologies ALT, 2006, WellCad™ Software.

Geofirma Engineering Ltd., 2011a. Technical Report: Bedrock Formations in DGR-1 to DGR-6, TR-09-11, Revision 0, April 7, Ottawa.

Geofirma Engineering Ltd., 2011b. Technical Report: Drilling, Logging and Sampling of DGR-5 and DGR-6, TR-09-01, Revision 0, April 6, Ottawa.

Intera Engineering Ltd., 2010a. Technical Report: Drilling, Logging and Sampling of DGR-1 and DGR-2, TR-07-06, Revision 1, June 17, Ottawa.

Intera Engineering Ltd., 2010b. Technical Report: Borehole Geophysical Logging in DGR-1 and DGR-2, TR-07-08, Revision 2, June 17, Ottawa.

Intera Engineering Ltd. 2010c. Technical Report: Drilling, Logging and Sampling of DGR-3 and DGR-4, TR-08-13, Revision 0, February 11, Ottawa.

Intera Engineering Ltd., 2010d. Technical Report: Borehole Geophysical Logging of DGR-3 and DGR-4, TR-08-15, Revision 0, February 12, Ottawa.

Intera Engineering Ltd., 2009a. Test Plan for DGR-5 and DGR-6 Borehole Geophysical Logging, TP-09-11, Revision 0, November 5, Ottawa.

Intera Engineering Ltd., 2009b. Project Quality Plan, DGR Site Characterization, Revision 4, August 14, Ottawa.

Intera Engineering Ltd., 2009c. Technical Report: 2D Seismic Survey of the Bruce Site, TR-07-15, Revision 0, February 2, Ottawa.

Intera Engineering Ltd., 2009d. Test Plan for DGR-5 and DGR-6 Core Photography and Logging, TP-09-01, Revision 0, July 14, Ottawa.

Intera Engineering Ltd., 2008. Phase 2 Geoscientific Site Characterization Plan, OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Report INTERA 06-219.50-Phase 2 GSCP-R0, OPG 00216-PLAN-03902-00002-R00, April, Ottawa.

Intera Engineering Ltd., 2006. Geoscientific Site Characterization Plan, OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Report INTERA 05-220-1, OPG 00216-REP-03902-00002-R00, April, Ottawa.

APPENDIX A

Compiled Geophysical Logs and Borehole Shape Examples of DGR-5 and DGR-6

Figure A.1: DGR-5 Borehole Geophysical Logs

Contact Legend

🟥	Casing
━	End of Borehole
—	Formation Contact
～	Ground Surface
-----	Stratigraphic Contact

Stratigraphic Legend

- Dolostone
- Anhydritic Dolostone
- Argillaceous Dolostone
- Cherty Dolostone
- Limestone
- Argillaceous Limestone
- Dolomitic Limestone
- Shale
- Dolomitic Shale
- Brecciated Dolostone
- Brecciated Anhydritic Dolostone
- Brecciated Argillaceous Dolostone
- Brecciated Dolomitic Shale
- Argillaceous Dolostone and Dolomitic Shale
- Interbedded Shale and Argillaceous Limestone
- Interbedded Shale and Carbonate Beds
- Interbedded Shale and Dolostone
- Interbedded Shale and Limestone
- Interbedded Shale and Limestone/Siltstone
- Interbedded Argillaceous Limestone and Shale
- Interbedded Dolomitic Shale and Dolostone

ATV Structural Legend

- ▼ Broken Zone / Undifferentiated
- ▼ Major Open Fracture / Joint
- ● Minor Open Fracture / Joint
- ● Continuous Fracture / Joint
- ● Aligned Voids
- ● Incomplete Fracture / Joint

ATV Perpendicular Legend

- ● Continuous Fracture / Joint
- ● Aligned Voids
- ● Incomplete Fracture / Joint
- ◆ Bedding / Lithologic
- ◆ Gradational Lithologic Boundary
- ◆ Minor Bedding / Lithology

ATV Lithological Legend

- ● Minor Open Fracture / Joint
- ◆ Bedding / Lithologic
- ◆ Gradational Lithologic Boundary
- ◆ Minor Bedding / Lithology

Prepared by: PP & MAM
Checked by: KGR

Doc. TR-09-03_DGR-5 BH Geophysics_R0

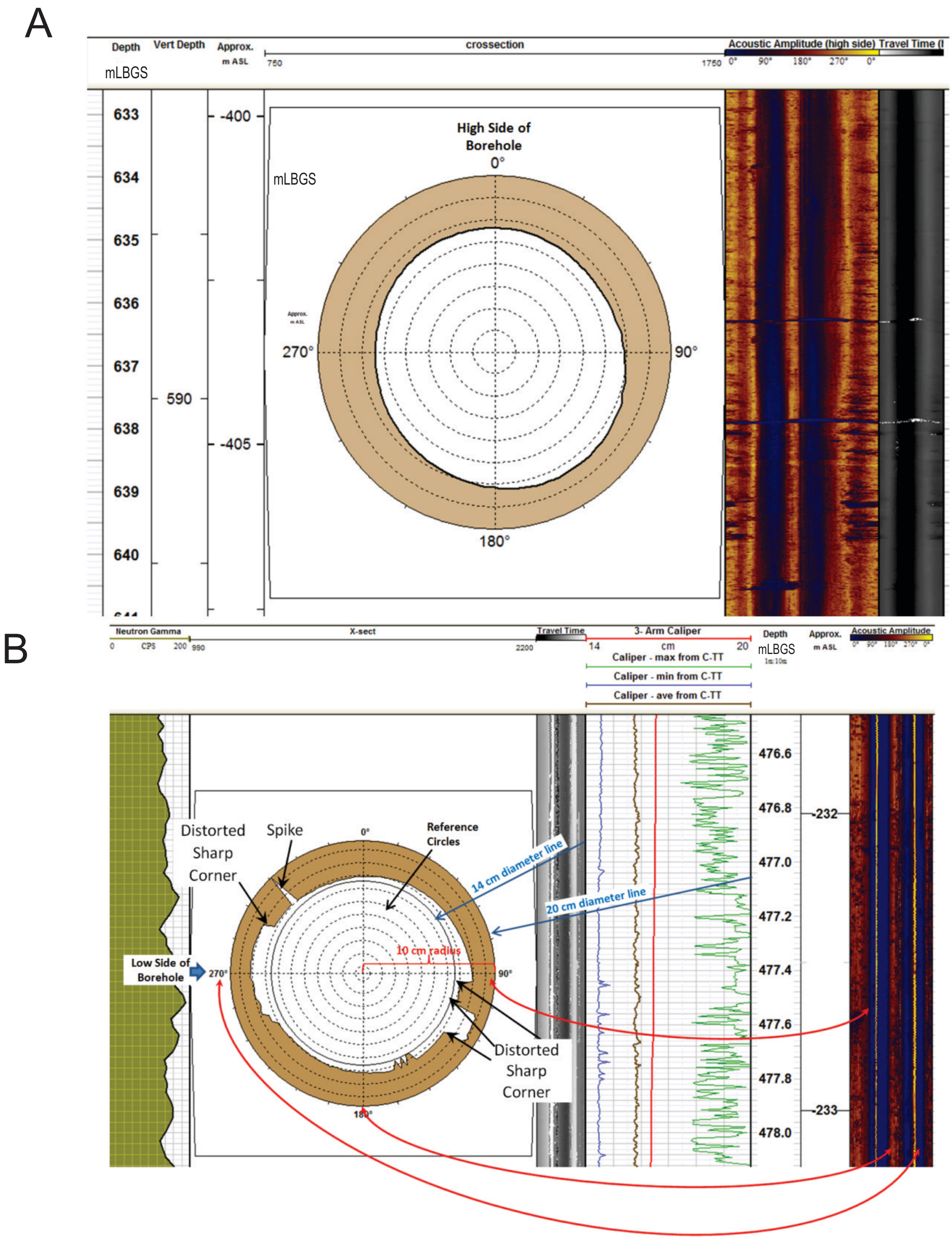
Geofirma Engineering Ltd

Figure A.2: DGR-6 Borehole Geophysical Logs

Prepared by: PP & MAM
Checked by: KGR

Doc. TR-09-03_DGR-6 BH Geophysics_R0

Geofirma Engineering Ltd



A) Cross-sectional representation of DGR5 (636.5 mLBGS), and B) A cross-sectional representation of DGR6 (477.4 mLBGS) based on ATV travel-time (diameter) showing oblate borehole - TR-09-03 Borehole Geophysical Logging of DGR-5 & DGR-6

Prepared by: NMP

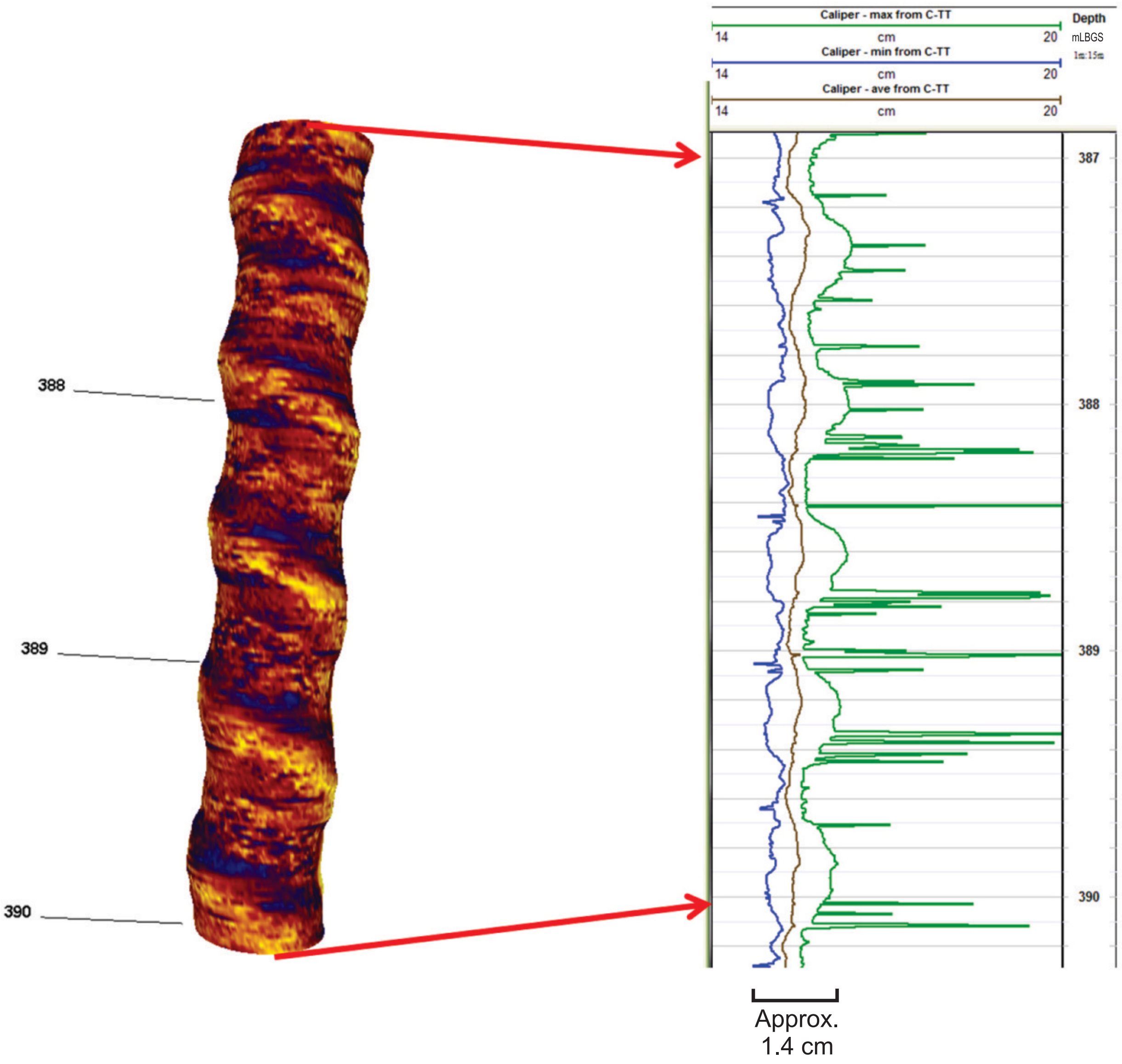
Reviewed by: KGR

Date: 07-Apr-11

FIGURE A.3

Doc. No.:P:\QMS_DGR\TR_WorkingFiles\TR-09-03 Borehole Geophysical Logging of DGR-5 & DGR-6\Figure\Figure A3_TR-09-03-CrossSectional-DGR-5 & DGR-6.cdr

Geofirma Engineering Ltd



3D representation of DGR6 (387-390 mLBGS) based on ATV travel-time (diameter) and amplitude (colour) showing spiralling enlargement of borehole. Virtual caliper logs (cm) from ATV travel time assuming fluid velocity of 1600 m/s, minimum (blue), maximum (green) and the average (brown) - TR-09-03 Borehole Geophysical Logging of DGR-5 & DGR-6	Prepared by: NMP Reviewed by: KGR
FIGURE A.4 Doc. No.:P:\QMS_DGR\TR_WorkingFiles\TR-09-03 Borehole Geophysical Logging of DGR-5 & DGR-6\Figure\Figure A4_TR-09-03-DGR-6-on-ATVTravelTime	Date: 07-Apr-11

Geofirma
Engineering Ltd

APPENDIX B

Geophysical Sonde Measurements

Geophysical Sonde Measurements

The following is a brief description of the various geophysical logs collected within DGR-5 and DGR-6. 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 PVC casing, 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 local 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.