Technical Report

Title: ***Bedrock Formations in DGR-1 to DGR-6***

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DGR Site Characterization Document
Geofirma Engineering Project 08-200

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Engineering Ltd

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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 report summarizes the stratigraphy, geological contacts and nomenclature of bedrock formations encountered during drilling of two deep inclined bedrock boreholes (DGR-5 and DGR-6). In addition, the elevation of bedrock formations in DGR-5 and DGR-6 have been compared to the projected top of formations based on the triangulation (strike and dip calculations) between DGR-1/2, DGR-3, and DGR-4. Bedrock stratigraphy from DGR-1 to DGR-4 was previously reported in TR-08-12 (Intera Engineering Ltd., 2010a). Although these data have been included in this Technical Report for reference purposes, no changes have been made to these formation picks based on DGR-5 and DGR-6 information; however a slight correction to formation elevations has been applied to data from DGR-1 to DGR-4 to account for any minor borehole tilt or vertical deviation as described in Section 5.

Work described in this Technical Report (TR) was completed with data generated from Test Plan TP-09-01 – DGR-5 and DGR-6 Core Photography and Logging (Intera Engineering Ltd., 2009a) and Test Plan TP-08-15 – DGR-5 and DGR-6 Borehole Geophysical Logging (Intera Engineering Ltd., 2010b), which were prepared following the general requirements of the Intera 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 159 mm diameter boreholes (DGR-1 and DGR-2). Both of these boreholes were drilled at Drill Site 1 at the Bruce nuclear site as shown on Figure 1. DGR-1 was continuously cored from the top of bedrock (approximately 20 mBGS) to approximately 15 m into the top of the Queenston Formation shale (total depth 462.87 metres below ground surface, mBGS). DGR-2 was rotary drilled from ground surface to approximately 3 m into the top of the Queenston Formation (~450 mBGS) and then continuously cored to approximately 1 m into the Precambrian basement (total depth 862.12 mBGS). 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., 2010c) summarizes the Phase 1 drilling and core logging activities.

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). Both DGR-3 and DGR-4 were continuously cored from approximately 20 m below the top of bedrock (approximately 30 mBGS) into the top of the Cambrian sandstone to total depths of 869.17 and 856.98 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., 2010d) summarizes the Phase 2A drilling and core logging activities.

Phase 2B comprises the drilling, logging and testing of two deep inclined 143 mm diameter boreholes, DGR-5 (Drill Site #1) and DGR-6 (Drill Site #4). Both DGR-5 and DGR-6 were rotary drilled from the top of bedrock to approximately 15 m into the Salina Formation – F Unit (approximately 208 and 215 metres length below ground surface, mLBGS, respectively) and then continuously cored into the lower Ordovician limestone formations to depths of 807.15 mLBGS into the Kirkfield Formation and 906.16 mLBGS into the Gull River Formation,

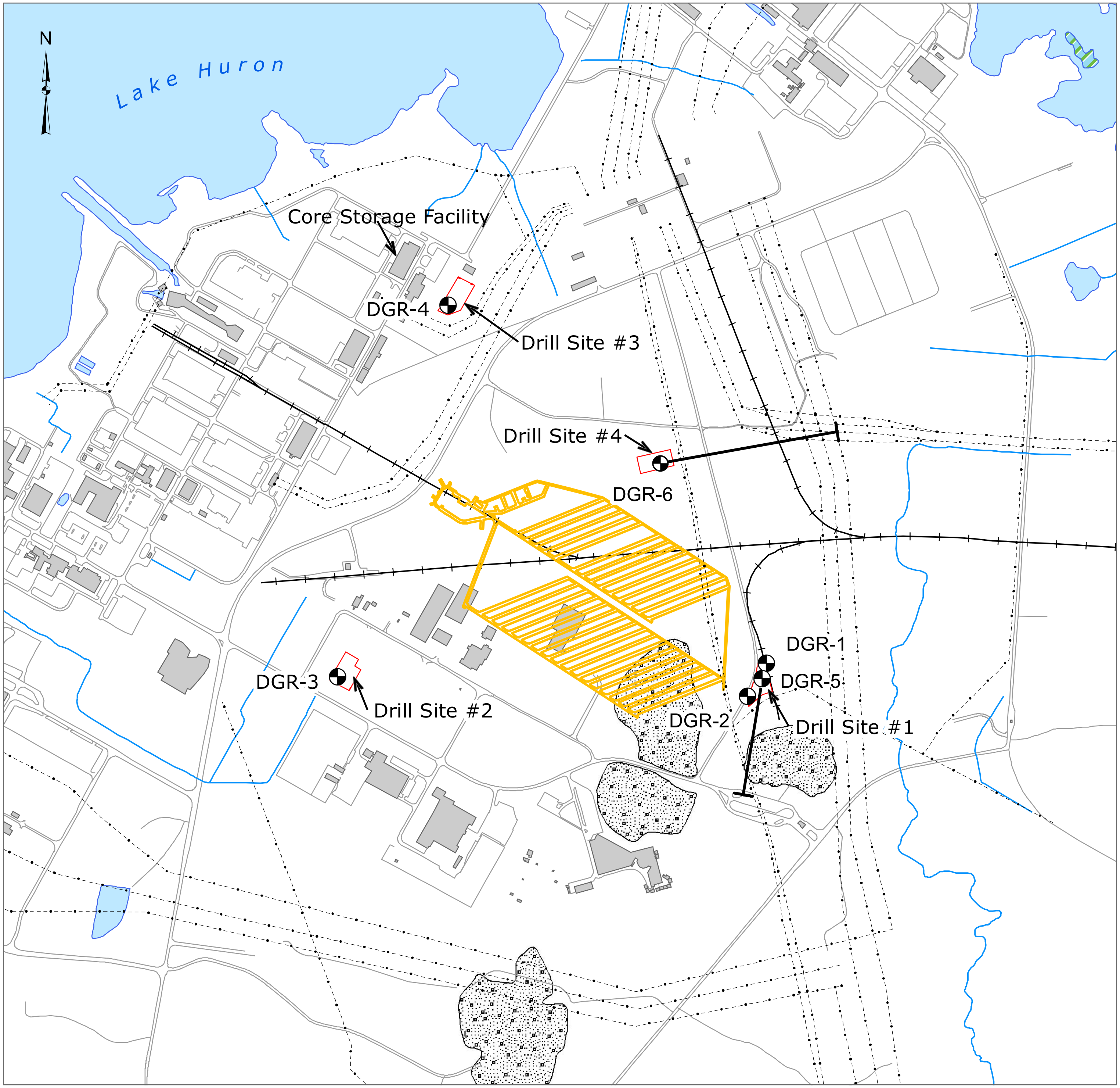

Figure 1
Location of Boreholes
DGR-1 to DRG-6
at the Bruce Nuclear Site

Scale 1:15,000

0 100 200 400 600 800
Meters

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

PROJECT No. 08-200 TR 09-11

PROJECT NWMO DGR Site Characterization Project

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

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P:\QMS_DGR\TR_WorkingFiles\TR-09-11 Bedrock Formations in DGR-1 to DGR-6\Figures\TR-09-11_SiteLocationDGR1-6_R0.mxd respectively. These boreholes were targeted at angles of approximately 60 and 65 degrees from horizontal, respectively. Final true vertical depths (TVDs) of approximately 752 and 785 mBGS were achieved for boreholes DGR-5 and DGR-6, respectively. Phase 2B work was completed between December 2008 and June 2010. TR-09-01 - Drilling, Logging and Sampling of DGR-5 and DGR-6 (Geofirma Engineering Ltd., 2011a) summarizes the Phase 2B drilling and core logging activities.

DGR-5 was drilled under Ministry of Natural Resources (MNR) Well License No. 11926 under the Oil, Gas and Salt Resources Act and is located at NAD83 UTM Zone 17N, 4907742.1 m Northing and 454221.8 m Easting with a ground surface elevation of 185.70 m above sea level (mASL). Similarly, DGR-6 was drilled under Ministry of Natural Resources (MNR) Well License No. 11942 and is located at NAD83 UTM Zone 17N, 4909317.0 m Northing and 453953.0 m Easting with a ground surface elevation of 183.5 mASL.

Two previous DGR Site Characterization Core Workshops were hosted at the Core Storage Facility on the Bruce nuclear site in an effort to obtain consensus on the stratigraphic nomenclature and formation descriptions for bedrock intersected by DGR-1 to DGR-4. The first Core Workshop was held on September 5 and 6, 2007 following Phase 1 drilling and logging activities and is summarized in TR-07-05 – Bedrock Formations in DGR-1 and DGR-2 (Intera Engineering Ltd., 2010e). The second Core Workshop was held on November 25 and 26, 2008 following Phase 2A drilling and logging activities and is summarized in TR-08-12 – Bedrock Formations in DGR-1, DGR-2, DGR-3, and DGR-4 (Intera Engineering Ltd., 2010a).

The nomenclature and stratigraphy developed for the Bruce nuclear site are consistent with the regional conceptual model developed by Armstrong and Carter (2006) and are consistent with the nomenclature and stratigraphy from other deep boreholes in the region.

The paperback Ontario Geological Survey open file report of Armstrong and Carter (2006) has recently been released as an updated and reformatted hard cover Special Volume publication (Armstrong and Carter, 2010). The subsurface bedrock stratigraphic nomenclature is the same in both of these publications, although Armstrong and Carter (2010) include a modernized stratigraphic chart that removes the Middle Silurian and re-assigns the Middle Ordovician units to an expanded Upper Ordovician. The stratigraphic chart of Armstrong and Carter (2006) is used in this Technical Report.

3 Geosynthesis Core Workshop (May 26 and 27, 2010)

A third Geosynthesis Core Workshop was held on May 26 and 27, 2010 at the Core Storage Facility on the Bruce nuclear site following the completion of boreholes DGR 5 and DGR 6. The purpose of the third workshop was to obtain consensus regarding the formation contacts selected for DGR-5 and DGR-6 and was attended by the following groups participating in the NWMO DGR Program:

- Nuclear Waste Management Organization, and,
- Geofirma Engineering Ltd. (GSCP Contractor).

In addition, the following geology experts from the Ontario government [Ministry of Natural Resources (MNR), Ontario Geological Survey (OGS)], the federal government [Geological Survey of Canada (GSC)], and university [University of Western Ontario (UWO)] attended the third workshop and assisted in reaching consensus on the identification of the top of bedrock formations:

- Terry Carter, Chief Geologist (MNR, Petroleum Resources Centre),
- Derek Armstrong, Paleozoic Geologist (OGS, Ministry of Northern Development and Mines), and,
- Chris Smart, Associate Professor, Department of Geography (University of Western Ontario).

4 Bedrock Formation Pick Methodology

During drilling operations, continuous bedrock core was collected in 10 ft (3 m) core runs and logged by an on-site geologist. Core logging generally followed the guidelines of Armstrong and Carter (2006) for stratigraphic logging and nomenclature as described in TP-09-01 (Intera Engineering Ltd., 2009a). A summary of core logging results from DGR-5 and DGR-6 drilling operations is included in TR-09-01 - Drilling, Logging and Sampling of DGR-5 and DGR-6 Core (Geofirma Engineering Ltd., 2011a).

Following drilling operations at each inclined borehole, geophysical logging was completed by Layne Christensen Co. – Colog Division based in Lakewood, Colorado following TP-09-11 (Intera Engineering Ltd., 2009c). The results of borehole geophysical logging are summarized and presented as part of TR-09-03 – Borehole Geophysical Logging of DGR-5 and DGR-6 (Geofirma Engineering Ltd., 2011b).

The depths of each geologic formation, member or unit contact were selected based on a combination of information from rock core and borehole geophysical logs. The borehole geophysical logs that proved most useful in identifying geological contacts were natural gamma and neutron with additional support using bed resolution density. Following the methods of Armstrong and Carter (2006), final geophysics picks were based on the natural gamma log even when the neutron or bed resolution density log was used to identify a change in formation. In the case of large increases or large decreases in natural gamma response, the pick was selected as the mid-point of the inflection (increase or decrease).

Initial bedrock formation contact depths were selected during the May 2010 Core Workshop. Subsequent discussions between Terry Carter, Derek Armstrong and Sean Sterling of Intera noted the extensive brecciation within the Salina Formation B, C, D and E Units and resulted in a significant change to the top contact depth of the Salina C and Salina D Units in DGR-6. The revised formation picks for these units attempt to follow the same methodology used in other DGR boreholes, however there is no clear formation pick in core nor in borehole geophysical logs of DGR-6 for these units.

5 Determination of True Vertical Depth (TVD)

All field data pertaining to drilling and borehole logging depths was recorded in units of metres along the borehole axis. Data from the four vertical boreholes (DGR-1 to DGR-4) were recorded in units of metres below ground surface (mBGS) while data from the two inclined boreholes (DGR-5 and DGR-6) were recorded in units of metres length below ground surface (mLBGS). Therefore, it is obvious that the depth data from the inclined boreholes require a conversion to "true vertical depth" (TVD) in order to calculate formation top elevations, formation thicknesses, strike and dip of rock strata, and to better compare relative depths between boreholes. Although the requirement for this conversion is apparent for the data collected from the inclined boreholes (DGR-5 and DGR-6) it is also true for the data collected from the vertical boreholes (DGR-1 to DGR-4). Vertical boreholes are conceptualized as being perfectly straight; however they can deviate slightly such that the length along the borehole axis does not equal the true vertical depth below ground surface.

The conversion from depth along borehole axis to TVD was uniformly applied to all DGR borehole data using the borehole orientation data collected with either an acoustical televiewer tool or a gyroscopic tool. These tools provide a northing and easting coordinate along with a TVD for each measured point along the borehole axis. Borehole orientation data is further discussed along with other borehole geophysical data collected in TR-07-08 (Intera Engineering Ltd., 2010f) for DGR-1 and DGR-2, in TR-08-15 (Intera Engineering Ltd., 2010b) for DGR-3 and DGR-4, and TR-09-03 (Geofirma Engineering Ltd., 2011b) for DGR-5 and DGR-6.

This conversion from depth along borehole axis to TVD resulted in a slight change in bedrock formation top elevations compared to those presented in TR-08-12 (Intera Engineering Ltd., 2010a) for DGR-1 to DGR-4. Due to the nature of the conversion the new elevations are slightly higher compared to those previously reported.

6 Results

The drilling and testing of boreholes DGR-1 to DGR-6 has resulted in the identification of 34 distinct Paleozoic bedrock formations, members or units at the Bruce nuclear site. These bedrock formations, members or units are logged in accordance with the stratigraphic nomenclature of Armstrong and Carter (2006). Formation geology was very consistent between DGR-1 to DGR-6 boreholes. No major lithofacies changes within individual formations, members or units were detected between DGR boreholes.

The final formation picks for DGR-1 to DGR-6 are summarized in Table 1 and Table 2.

Table 1 contains a summary of the following data:

- lithologic description of each formation;
- primary evidence used to make each pick (core or geophysics data);
- type of contact (i.e. sharp or gradational);
- the rationale for each pick;
- the formation pick rationale used by Armstrong and Carter (2006); and
- a relative indication of the difficulty of each pick.

Table 2 shows the top of formation picks and also includes the following data:

- the depth of the top of formation, member, or unit expressed in units of metres length below ground surface along borehole axis (mLBGS);
- the corresponding core run number for future reference to archived core boxes and core photography;
- the corresponding “true vertical depth” (TVD) (i.e. depth along borehole axis corrected for borehole deviation) expressed as metres below ground surface (mBGS);
- the calculated formation top elevation;
- difference between the top of formations in DGR-1/-2 and DGR-3 to DGR-6;
- the calculated thickness of each formation; and,
- the pick rationale – core or geophysics.

Figure 2 graphically presents the bedrock stratigraphy and formation depths of at the Bruce nuclear site based on DGR-1 and DGR-2 borehole data.

6.1 Identification of Stratigraphic Marker Beds

Similar to DGR-1 through DGR-4, several laterally continuous and distinct beds or horizons were encountered during drilling in DGR-5 and DGR-6. Due to start and end depths of coring in DGR-5 and DGR-6, only two of the previously reported marker beds were encountered in DGR-5 and four in DGR-6. These thin (<20 cm thick) stratigraphic markers provide a useful and accurate means of determining the three dimensional attitude (i.e. strike and dip) of rock strata that contains the marker beds in the vicinity of the proposed DGR. Table 3 lists and describes the five previously reported marker beds and indicates the depth and elevation of the top of each bed in each borehole. Appendix A provides the core photographs illustrating the appearance of each of the marker beds in boreholes DGR-1. DGR-2, DGR-3, DGR-4, DGR-5, and DGR-6.

Table 1. Summary of Bedrock Formation Picks in DGR-1 to DGR-6

Stratigraphic Nomenclature	Stratigraphic Description	Primary Evidence for Pick	Geological Contact Description	Core Pick Rationale	BH Geophysical Pick Rationale	Armstrong and Carter (2006)	Difficulty of Pick
Lucas Formation	Brownish grey, grey and brown, fine-grained, hard, argillaceous dolostone with abundant bituminous laminae (stromatolitic laminations). Formation is locally very vuggy with partial calcite infilling. Shaly layers with subordinate dolomite in few places. Formation has brecciated appearance in few spots due to light coloured dolostone fragments in matrix of grey calcite. Rock becomes cherty with depth. Rock also becomes fossiliferous near bottom of formation, including stromatoporoids, brachiopods and corals.	top of bedrock	top of bedrock	top of bedrock, known lithology	NA		NA
Amherstburg Formation	Light brown to grey, fine- to coarse-grained, hard, fossiliferous (stromatoporoids, corals, brachiopods), cherty dolostone with abundant bituminous shale laminae and zones. Locally vuggy with secondary calcite, pyrite and quartz mineralization in places and locally extensively fractured with fractures commonly infilled with calcite and pyrite.	core	Sharp to gradational depending on colour change	First sharp change from tan coloured dolostone to dark brown bituminous dolostone	No distinguishing features	change from light brown, very fine-grained, evaporitic dolostones of the Lucas change to a dark brown, organic-looking (dolostone or limestone) with bituminous partings; does not appear possible to pick the contact consistently on geophysical logs	core = difficult geophysics = very difficult
Bois Blanc Formation	Light to dark grey to brown to tan, fine- to medium-grained, hard, fossiliferous (corals, brachiopods) cherty dolostone with some black bituminous shale laminae and zones. Chert is abundant and is found as light grey to white nodules and less commonly as up to 10-cm thick layers, some with dolostone clasts. Shale laminae are absent near the base of the formation. Slightly vuggy in places. Extensively fractured in few zones with calcite and, less commonly, pyrite found on fracture surfaces. Calcite stringers common throughout.	core	gradational	medium grained dolostone to fine grained limestone	flat natural gamma ray response (no distinguishing features)	dominated by white chert	core = difficult geophysics = difficult
Bass Islands Formation	Light grey to brown to tan, very fine- to fine-grained, hard dolostone with some to trace shale and bituminous laminae and intervals. Argillaceous-rich dolostones intervals are grey-blue with shale and dolostone intraclasts. Vuggy in very few places, with vugs in-filled with calcite. Trace evaporite mineral moulds. Trace amount of zones are fractured with calcite in-filling. Trace amount of anhydrite layers and in-filled fractures in bottom part of formation.	core	sharp	abrupt change from cherty-shaly dolostone to tan-grey very fine grained dolostone	flat natural gamma ray response (no distinguishing features)	oolitic beds in upper few m	core = easy geophysics = difficult
Salina Formation - G Unit	Grey-blue to grey-green, very-fine grained, soft, argillaceous dolostone with some to abundant white to pink-orange anhydrite/gypsum veins and layers throughout. Tan to brown, very-fine grained, hard, dolostone near middle of formation.	core, natural gamma log	sharp	change to grey-green shaly dolostone with anhydrite/gypsum	first large increase in natural gamma after very low gamma of "cleaner" Bass Islands Formation	average of 9 m above the more reliable F Unit top	core = easy but use approximate 9 m thickness to pick correct shale interval geophysics = easy
Salina Formation - F Unit	Dolomitic shale and suborindate dolostone. Dolomitic shale is grey-green to grey-blue with rusty brown-red mottling and diffuse staining with abundant cm-thick white and pink-orange anhydrite/gypsum veins and layers throughout; anhydrite/gypsum nodules are less common. Dolostone found near bottom of the formation and is light grey to light brown, very fine-grained, hard, and contains trace to some anhydrite/gypsum nodules and veins and locally contains dark grey to black bituminous laminae.	natural gamma log, core	sharp	change from brown dolostone to green shale	sharp increase in natural gamma response (higher shale content)	shale and gamma log	core = easy geophysics = extremely easy
Salina Formation - E Unit	Interbeded dolostone, dolomitic shale and argillaceous dolostone. Dolostone is grey tan to brown, very fine-grained, massive, and with dark grey to black bituminous laminae and trace anhydrite/gypsum veins. Dolomitic shale is grey to grey blue, soft, with abundant anhydrite/gypsum veins and layers. Argillaceous dolostone is tan-brown, very fine-grained, hard, massive, and contains trace amount of anhydrite/gypsum veins and layers. Formation is locally brecciated.	natural gamma log, core, drilling rate increases	sharp	pick based on geophysics and is made either at abrupt change to grey-green shale from tan dolostone or beneath approximately 0.5 m of massive green shale which may coincide with top of a brecciated layer of grey-green shale with anhydrite/gypsum	increase in natural gamma response below low gamma signature of tan dolostone; neutron log shows a drop after an interval approximately 5 m in length of elevated neutron reponse	increase in gamma in response to shale beds that mark top of E Unit	core = very easy to identify change from tan dolostone to grey-green shale geophysics = difficult with gamma alone; easier when combined with neutron
Salina Formation - D Unit	Light grey-blue, fine-grained anhydritic dolostone; locally slightly vuggy.	natural gamma log, core	gradational	dolostone transitioning to anhydritic dolostone	prominent "scoop dip" decrease in gamma log	thin anhydritic dolostone layer where no Salina D Unit salt is present	core = easy if expecting a thin layer of anhydritic dolostone at that depth, otherwise difficult geophysics = difficult by itself, but aligns with core depths
Salina Formation - C Unit	Grey-blue, massive to laminated dolomitic shale with trace to some anhydrite and gypsum nodules, laminae and thin beds.	natural gamma log, core	gradational	blue-grey and brown anhydritic dolostone transitioning to grey dolomitic shale	increased natural gamma (shale content)	increase in gamma response corresponding to transition from dolostones to shales	core = relatively easy geophysics = easy
Salina Formation - B Unit	Argillaceous dolostone grading downwards to dolostone near base of unit. Dolomitic shale is grey-green with abundant anhydrite/gypsum veins, layers and nodules. It is locally brecciated with dolostone clasts. Dolostone is tan-brown, very fine-grained with abundant white anhydrite/gypsum nodules and veins, and abundant dark brown-black laminae.	natural gamma log, core	sharp	top of thin, brown, anhydritic dolostone layer (B Unit Marker Bed) below red-green shale	start of long decrease in natural gamma log	decrease in gamma response	core = B Unit Marker Bed is easy to identify geophysics = difficult by itself, but aligns with core depths
B Unit Evaporite	Interbedded light to dark grey dolostone and bluish-grey anhydrite/gypsum, grading to mottled dolostone and anhydrite with depth.	natural gamma log, core	gradational	gradational change from brown dolostone to interbedded brown dolostone and light grey anhydrite/gypsum	picked at lowest natural gamma response following gradual decline in gamma log	anhydrite-rich zone at bottom of B Unit	core = easy geophysics = relatively easy
Salina Formation - A2 Unit	Dolostone with subordinate argillaceous dolostone and dolomitic shale. Dolostone, argillaceous dolostone and dolomitic shale are locally interbeded. Dolostone is tan to grey, very fine- to fine-grained, laminated to massive, locally with dark brown to black bituminous laminae and less common anhydrite /gypsum layers; strong sulphur odour in places. Argillaceous dolostone is grey-brown with trace anhydrite/gypsum and pyrite flecks and has sulphurous odour when broken. Dolomitic shale is brown to dark grey, soft and friable and locally contains dolostone clasts and distorted bedding.	natural gamma log, core,	sharp to fairly sharp	laminated grey-brown dolostone with dark to black (organic-rich) thin layers	slight increase in natural gamma compared to gamma trough of B-Unit Evaporite	sharp transition from anhydrite (B Unit) to carbonates (A2 Unit)	core = easy (immediately below anhydrite) geophysics = relatively easy
A2 Unit Evaporite	Mottled grey-blue, very fine-grained, laminated to massive anhydritic dolostone.	neutron log, core	gradational	anhydrite/gypsum-rich dolostone (predominantly anhydrite); anydrite may be overlain by "A2 Shale Bed" as seen in DGR3 and DGR4	sharp decrease in neutron log, very minor decrease in natural gamma log; gamma decrease more pronounced in DGR3 and DGR4 due to overlying "A2 Shale Bed".	below A2 Unit shale bed; anhydrite more prevalent at top and bottom of the A2 Unit Evaporite	core = easy to pick anhydrite rich zone (contact is where it is predominatly anhydrite - difficult to determine which unit it belongs to) geophysics = difficult by itself (gamma)
Salina Formation - A1 Unit	Grey to tan-grey argillaceous dolostone with limestone and some to abundant dark grey, petroliferous shale laminae, beds and shale-rich intervals, and trace to some anhydrite/gypsum veins and layers. Dolostone and anhydrite/gypsum are locally brecciated. Upper 2-3 m is abundantly vuggy.	density log, gamma, neutron	gradational	start of vuggy brown dolostone; is coincident with bottom of lowermost anhydritic dolostone	bottom of last anhydrite/gypsum layers with densities ~ 3 g/cc as shown on density log; slight and gradual increase in natural gamma following low of A2 Unit Evaporite. Neutron log shows decline after peak.	sharp transition from anhydrite/gypsum (A2 Unit Evaporite) to carbonates (A1 Unit)	core = easy to pick start of vuggy zone geophysics = easy (density log) to see last high density spike

Prepared by : SNS
Reviewed by : KGR
TR-09-11_Tables 1 to 5_R0.xlsx

Table 1. Summary of Bedrock Formation Picks in DGR-1 to DGR-6

Stratigraphic Nomenclature	Stratigraphic Description	Primary Evidence for Pick	Geological Contact Description	Core Pick Rationale	BH Geophysical Pick Rationale	Armstrong and Carter (2006)	Difficulty of Pick
A1 Unit Evaporite	Interlaminated to interbedded to massive and mottled brown dolostone and bluish-grey anhydritic dolostone.	density log, core	gradational	start of light blue-grey anhydritic dolostone	sharp increase in density log, start of slight decrese in gamma log	sharp transition between dark brown-grey dolostones and lighter grey-blue anhydritic dolostone	core = easy geophysics = easy based on density log
Salina Formation - A0 Unit	Grey-brown to black, fine-grained, thinly laminated, petroliferous dolostone with abundant black bituminous laminae.	density log, core	gradational	lower extent of anhydrite/gypsum nodules in dolostone and appearence of dark, thinly laminated bituminous dolostone	small but sharp decrease in density and natural gamma log; located in middle of neutron plateau	dark, thinly laminated bituminous dolostone	core = difficult on own, but aligns with geophysics (density log) geophysics = difficult on own, but aligns with core
Guelph Formation	Brown to grey-brown, very fine- to medium-grained (i.e. sucrosic) petroliferous dolostone with grey-brown bituminous shale laminae and beds. Formation grades downwards from very vuggy to non-vuggy. Trace anhydrite nodules within upper part of formation.	core, neutron and density logs	relatively sharp	start of brown sucrosic dolostone (upper limit of small vugs) following laminated brown dolostone of Salina A0	sharp decrease in neutron log and density log	sucrosic and fossiliferous dolostone	core = easy geophysics = easy based on density log and neutron log
Goat Island Formation	Light grey to brown, very-fine grained, massive, hard dolostone with stylolites and some dark grey irregular bituminous laminae.	natural gamma log, density log, neutron log, core	gradational	change from brown porous and sucrosic dolostone (Guelph) to very fine grained, light grey to brown dolostone	picked at inflection point of increase in natural gamma log which is co-located on the neutron log prior to an increase; increase to a steady density value ~ 2.8 g/cc at same depth that neutron log values increase	elevated gamma response, change to finer grained, cleaner carbonates	core = easy geophysics = easy
Gasport Formation	Light to dark grey-brown, very fine- to coarse-grained dolomitic limestone with pits and vugs that are in-filled with pyrite and calcite. Also contains tan-grey mottled, diffuse shale laminae.	natural gamma log, core	gradational	lighter grey, coarser grained, more porous dolostone compared to Goat Island	consistently low gamma response below higher response of Goat Island; decrease in gamma log is co-located at inflection point of increase in neutron to a plateau	drop in gamma response, transition from grey, fine grained dolostone to light grey-blue-white, coarser grained, more porous dolostone	core = difficult geophysics = difficult
Lions Head Formation	Mottled light grey to grey-brown, very fine to fine-grained dolostone with trace shale and siltstone clasts and laminae	natural gamma log, core	gradational	increased brown-grey shale content (thin layers) and smaller grain size	slightly elevated gamma response below Gasport and above Fossil Hill; pick is located at at a slight increase in the natural gamma log which corresponds in the neutron log to a minor peak or plateau that precedes a significant decline	gradual upward decrease in gamma from Lions Head into overlying Gasport	core = difficult geophysics = difficult
Fossil Hill Formation	Mottled light grey to tan-grey, coarse-grained dolostone with few shale and siltstone clasts and laminae, stylolites, and medium- to coarse-grained interbeds.	natural gamma log, core	gradational	lighter colour, finer grained, presence of numerous shale partings	small and gradual decrease (spoon shaped dip) in gamma log; corresponds to inflection point of large increase in neutron log	Lions Head has more elevated gamma response but lithologies are very similar although the Fossil Hill has a more brownish colour than the grey to white dolostone of the overlying Lions Head	core = moderately difficult due to gradational nature and ambiguity of formation names/descriptions geophysics = moderately difficult but directly above Cabot Head and aligns with core
Cabot Head Formation	Shale grading with depth to interbedded shale and limestone. Shale is diffusely banded or mottled red and maroon; in-filled mud cracks tentatively identified. Limestone is grey, coarse-grained (wacke- to packestone), dolomitic, with bituminous laminae and contains variable amounts of green shale.	natural gamma log and neutron log	sharp	sharp change from dolostone to massive green shale	sharp increase in gamma response, sharp decrease in neutron log	massive grey shale and increase in gamma response	core = extremely easy geophysics = extremely easy
Manitoulin Formation	Dolostone, shale, limestone and argillaceous dolostone. Dolostone is mottled grey-blue to grey-tan, fine- to coarse-grained, fossiliferous, and contains variable amounts of limestone, grey-green calcareous shale laminae and beds, black organic-rich laminae, and stylolites. Argillaceous dolostone is mottled grey-green to grey-blue, medium- to coarse-grained, slightly fossiliferous (brachiopods), is variably argillaceous. Formation locally contains variable amount of light grey-tan cm-thick chert layers and nodules.	natural gamma log	gradational	lowermost significant shale bed of Cabot Head Fm; coincides with change from shale with carbonate interbeds in Cabot Head to dolomite	drop in gamma log and increase in neutron log to plateau; lighter colour in ATV	lowermost significant shale bed as indicated by drop in gamma response	core = moderately difficult geophysics = moderately difficult
Queenston Formation	Red to maroon shale. The red to maroon shale is calcareous to non-calcareous and contains subordinate amounts of grey-green shale and grey to brown dolostone, limestone and siltstone. Locally contains gypsum and anhydrite nodules and halite in-filled fractures. Green shale in middle of the formation is interbedded with cm- to tens of cm-thick grey to dark grey, fossiliferous (brachiopods) limestone beds.	core, natural gamma and neutron logs	sharp (but appears more gradational in DGR4)	sharp contact from coarse grained fossiliferous dolostone of overlying Manitoulin to predominantly red and green interbedded shale (near first evidence of red shale) of Queenston; contact appears much more gradational in core in DGR4 and DGR1 where overlying Manitoulin consists of interlayered green shale and grey dolostone; in DGR4, pick was made where there was a subtle change from interlaminated green shale and grey dolostone to massive green shale	sharp increase in natural gamma and sharp decrease in neutron; geophysical log signature not as sharp in DGR1	transition from tan to grey dolostones (Manitoulin) / red shales (Queenston), with elevated natural gamma in Queenston	core = easy (where colour and lithology change is sharp) geophysics = easy (where change in gamma and neutron is sharp)
Georgian Bay Formation	Shale with subordinate limestone interbeds. Green to blue-grey shale interbedded with light grey, fossiliferous (crinoids, brachiopods, shell fragments and trace fossils), hard limestone beds and grey, calcareous siltstone beds. Trace in-filled fractures, commonly with halite; pyrite mineralization on fractures surfaces less common. Trace anhydrite and gypsum nodules. Fossiliferous limestone beds decrease in abundance with depth from some to trace. Petroliferous and sulphurous odour noted with depth. Core disking common.	core	gradational	below lowest evidence of red shale which coincides with start of grey carbonate layers interlaminated with green shale	spikey gamma response due to elevated gamma in shale layers and decrease in gamma in limestone beds	highest negative limestone spike on gamma ray which coincides with downward transition from red to green shale	core = relatively easy geophysics = difficult
Blue Mountain Formation	Green-blue to grey-blue and transitioning to grey to dark grey with depth, fossiliferous (crinoids, brachiopods) shale interbedded over upper part of formation with cm-thick grey siltstone and fossiliferous limestone beds. Shale has a petroliferous and sulphurous odour. Locally contains calcite in-filled fractures with pryite mineralization on fracture surfaces. Pyritization of fossils locally common. Core disking common.	core	gradational	lowest significant thin calcareous limestone bed greater than 10 cm thick	last "significant" carbonate bed identified in natural gamma log as last "significant" dip in gamma preceding less variable gamma log in Blue Mountain that is due to thinner and less frequent limestone beds	most difficult pick that is not attempted, however it is arbitrarily defined as base of lowest "significant" limestone bed	core = relatively easy geophysics = extremelely difficult
Blue Mountain Formation - Lower Member	Grey to dark grey shale with trace siltstone interlaminae and petroliferous odour. Core disking common. Interbedded with mottled grey, fine- to medium-grained, fossiliferous, hard limestone with depth.	core	gradational	subtle colour change from dark brown to black shale; upper member breaks into cm-thick pucks whereas lower member is more fissile and is prone to disking	no change in gamma log response		core = difficult geophysics = extremelely difficult
Coburg Formation - Collingwood Member	Dark grey to black, organic-rich, calcareous shale interbedded with grey, very fine- to coarse-grained, fossiliferous (brachiopods, crinoids, shell fragments), locally bioturbated, hard limestone. Petroliferous odour. Limestone is locally mottled grey to dark brown-grey, very-fine grained, fossiliferous, argillaceous and seeps hydrocarbons.	core	sharp	top of grey-brown-black calcareous shale; a phosphatic lag that shows as a mm-thick dark black irregular bed may separate the overlying Blue Mountain from the Cobourg	lower natural gamma log response compared to Blue Mountain	increase in carbonate and decrease in clay content, changes in colour from blue-grey to dark grey-black to grey-brown, slight decrease in gamma log	core = relatively easy geophysics = extremely easy

Table 1. Summary of Bedrock Formation Picks in DGR-1 to DGR-6

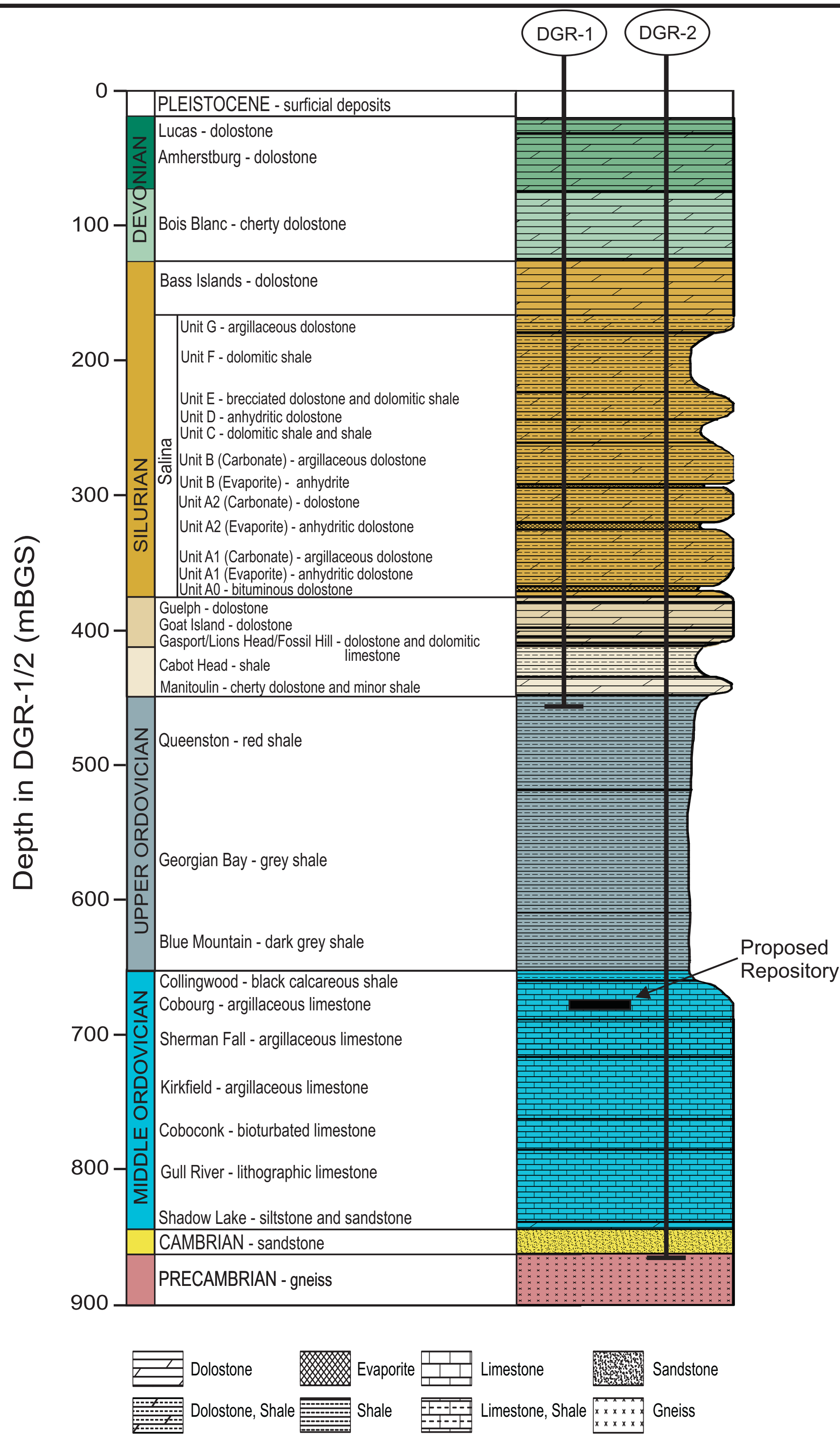
Stratigraphic Nomenclature	Stratigraphic Description	Primary Evidence for Pick	Geological Contact Description	Core Pick Rationale	BH Geophysical Pick Rationale	Armstrong and Carter (2006)	Difficulty of Pick
Cobourg Formation - Lower Member	Mottled light to dark grey to brownish grey, very fine- to coarse-grained (i.e. packstones and grainstones), very hard, fossiliferous (crinoids, brachiopods, shell fragments) argillaceous limestone. Petroliferous odour, and traces of hydrocarbons seep from rock in places. Irregular to wavy to diffuse shale interbeds found over bottom few metres.	core, natural gamma log, neutron log	relatively sharp	below lowest black shale calcareous shale bed and start of massive, non-disking brownish grey, argillaceous limestone	slight decrease in natural gamma and slight increase in neutron; gamma in the Lower Member is flatter compared to spikey gamma response of Collingwood	change to carbonates of Cobourg from calcareous shales of Collingwood, matched by slightly lower gamma response	core = easy geophysics = relatively easy
Sherman Fall Formation	Light grey to grey, medium- to coarse-grained, transitioning to fine- to medium-grained with depth, argillaceous limestone. Coarse-grained beds are bio- and intraclastic grainstones; fossils include brachiopods and other shell fragments. Grey-green, irregular shale laminae and beds are interbedded and interlaminated with the limestone and increase in abundance with depth to typically around 20% by volume. Formation is locally mottled with depth (nodular texture). Petroliferous odour over upper few metres.	core, natural gamma log	gradational	gradational contact from grey-brown argillaceous limestone to grey argillaceous limestone (shaly interbeds more well defined); top picked at first grainstone bed	grainstone bed presents in natural gamma as a trough that follows consistently higher gamma values of overlying Cobourg. Upper part of Sherman Fall has lower gamma values than Cobourg	transition from finer grain size of bluish grey Cobourg to tan or grey-brown of Sherman Fall	core = difficult, gradational geophysics = difficult (lower unit is similar to Cobourg)
Kirkfield Formation	Grey, fine- to medium-grained argillaceous, fossilliferous (brachiopods) limestone interbedded with dark grey-green irregular to planar bedded shale that locally constitutes up to 50% by volume of the rock. Some shale beds contain limestone clasts. Formation has petroliferous odour.	natural gamma log	gradational	very difficult pick as lower part of Sherman Fall is very similar to upper part of Kirkfield; the upper Kirkfield is generally less shalier than the overlying lower part of the Sherman Fall	decrease in natural gamma (corresponding to less shalier limestone) that marks the top of a shallow broad trough approximately 6-7 m below the largest gamma peak in the Sherman Fall	decrease in gamma log	core = very difficult geophysics = difficult
Coboconk Formation	Grey to tan-grey, mostly fine-grained with subordinate medium- and coarse-grained beds, fossiliferous, bioturbated limestone with irregular mottled bituminous shale laminae. Locally contains horizons of brown and black chert nodules and rare calcite-filled vugs. Formation is petroliferous with trace amounts of hydrocarbons.	core, natural gamma log	sharp	sharp transition from interbedded bluish-grey limestone and shale of Kirkfield to cleaner, light grey limestone of the Coboconk	base of plateau (elevated gamma of Kirkfield) and start of consistently low gamma values; located approximately 6 m above largest gamma peak in the Coboconk	decrease in gamma log and transition out of shaly limestones	core = easy geophysics = relatively easy
Gull River Formation	Light grey to grey, as well as tan-brown with depth, very fine-grained to medium-grained, locally bioturbated and fossiliferous limestone with brown to black bituminous shale laminae, beds and stringers. Limestone is locally arenaceous in middle of formation. Stylolites are locally common and the formation is commonly petroliferous with trace amounts of hydrocarbons.	core, natural gamma log	sharp	change in character of shale from distorted shale beds and blebs in the overlying Coboconk to more regualr shale beds in the Gull River. Gull River underlies oolitic beds in Coboconk	elevated and spikey gamma log	first shaly spike below low gamma response of Coboconk coinciding with transition from fine-grained bioclastic limestones of the Coboconk to the very fine-grained lithographic lime mudstones of the Gull River	core = moderate geophysics = relatively easy
Shadow Lake Formation	Interbedded grey to light green-grey-brown pyritic and gluaconitic siltstone and sandstone with subordinate grey-green sandy shale.	core	relatively sharp	top of first grey-green silty sandstone	not collected due to bridge plug in borehole to prevent flowing artesian conditions from Cambrian	top of largest shift in gamma log coinciding with change from carbonates (Gull River) to argillaceous silt/sandstone (Shadow Lake)	core = easy geophysics = not collected due to bridge plug in bottom of DGR-2 to prevent flowing artesian conditions.
Cambrian Sandstone	Grey, tan, brown, white, pinkish-orange, medium-grained sandstone that is locally abundantly pyritic and glauconitic, and is interbedded with brown to light grey dolostone and sandy dolostone in places. Fractures in-filled with quartz, calcite and pyrite.	core	sharp	first dolostone bed below overlying sand of Shadow Lake; bottom of Shadow Lake may contain clasts of the Cambrian Formation (as in DGR2)	not collected due to bridge plug in borehole to prevent flowing artesian conditions	transition from greenish, shaly clastics to clean quartzose sandstones, dolomitic sandstones or sandy dolostones	core = extremely easy geophysics = not collected due to bridge plug in bottom of DGR-2 to prevent flowing artesian conditions.
Precambrian basement	Pink to black, fine- to medium-grained felsic gneiss.	core	sharp	sharp contact from overlying tan-grey sandstone to granitic gneiss	not collected due to bridge plug in borehole to prevent flowing artesian conditions	increase in gamma response coincident with sharp contact with granitic gneiss	core = easy geophysics = not collected due to bridge plug in bottom of DGR-2 to prevent flowing artesian conditions

Table 2. Summary of Bedrock Formation Depths, Thicknesses and Elevations in DGR-1 to DGR-6

	Stratigraphic Nomenclature	Top of Formation Length Along Borehole Axis (mLBGS)					Core Run Containing Contact					Top of Formation True Vertical Depth (mBGS)					Top of Formation Elevation (mASL)					Elevation Difference Between DGR1/2 and DGR-3 to DGR-6 (m)				Interpreted Thickness (m)					Primary Formation Pick
		DGR-1/2*	DGR-3	DGR-4	DGR-5	DGR-6	DGR-1/2*	DGR-3	DGR-4	DGR-5	DGR-6	DGR-1/2*	DGR-3	DGR-4	DGR-5	DGR-6	DGR-1/2*	DGR-3	DGR-4	DGR-5	DGR-6	DGR-3	DGR-4	DGR-5	DGR-6	DGR-1/2*	DGR-3	DGR-4	DGR-5	DGR-6	Core or Geophysics
Late Devonian	Lucas Formation	20	7.9	7.5	22.2	16.9	--	--	--	--	--	20.0	7.9	7.5	20.0	14.4	165.7	179.5	174.1	165.7	169.1	--	--	--	--	10.4	46.6	30.1	10.4	16.9	Core
	Amherstburg Formation	30.4	54.5	37.6	33.8	37.0	3	11	3	--	--	30.4	54.5	37.6	30.4	31.3	155.3	132.9	144.0	155.3	152.2	22.4	11.3	0.0	3.1	44.6	39.4	38.6	44.6	42.5	Core
Early Devonian	Bois Blanc Formation	75	93.9	76.2	83.2	87.1	20	26	17	--	--	75.0	93.8	76.2	75.0	73.9	110.7	93.5	105.4	110.7	109.6	17.2	5.3	0.0	1.1	49.0	49.3	49.8	47.3	48.0	Core
Upper Silurian	Bass Islands Formation	124	143.3	126	134.8	142.3	39	44	33	--	--	124.0	143.1	126.0	122.2	121.9	61.7	44.2	55.6	63.5	61.6	17.5	6.1	-1.7	0.1	45.3	44.0	44.1	44.6	44.2	Core
	Salina Formation - G Unit	169.3	187.3	170.1	184.0	193.0	62	59	48	--	--	169.3	187.1	170.1	166.8	166.1	16.4	0.2	11.5	18.9	17.4	16.2	4.9	-2.5	-0.9	9.3	9.2	7.3	7.6	8.6	Core
	Salina Formation - F Unit	178.6	196.5	177.4	192.5	203.0	66	62	51	--	--	178.6	196.3	177.4	174.3	174.7	7.1	-8.9	4.2	11.4	8.8	16.1	2.9	-4.2	-1.6	44.4	43.0	43.6	38.7	40.0	Geophysics
	Salina Formation - E Unit	223	239.6	221	235.2	249.1	82	78	65	10	14	223.0	239.3	220.9	213.1	214.7	-37.2	-51.9	-39.3	-27.4	-31.2	14.7	2.1	-9.9	-6.0	20.0	23.8	24.4	19.4	17.2	Geophysics
	Salina Formation - D Unit	243	263.4	245.5	256.2	268.9	88	86	73	16	21	243.0	263.1	245.4	232.4	231.9	-57.2	-75.7	-63.8	-46.7	-48.4	18.5	6.5	-10.5	-8.9	1.6	2.6	1.8	1.0	1.0	Geophysics
	Salina Formation - C Unit	244.6	266	247.3	257.3	270.0	89	87	74	17	21	244.6	265.6	247.2	233.5	232.8	-58.8	-78.3	-65.6	-47.8	-49.3	19.5	6.8	-11.1	-9.5	15.7	11.9	14.7	12.8	33.3	Geophysics
	Salina Formation - B Unit	260.3	277.9	262	271.2	308.5	94	91	78	21	34	260.3	277.5	261.9	246.3	266.2	-74.5	-90.2	-80.3	-60.6	-82.7	15.6	5.7	-13.9	8.1	30.9	25.1	28.8	40.8	21.2	Geophysics
	B Unit Evaporite	291.2	303.0	290.8	315.5	333.0	104	99	88	38	42	291.2	302.6	290.7	287.1	287.4	-105.4	-115.2	-109.1	-101.4	-103.9	9.8	3.6	-4.1	-1.6	1.9	1.6	1.7	3.2	4.0	Geophysics
	Salina Formation - A2 Unit	293.1	304.6	292.5	319.0	337.7	105	99	88	39	43	293.1	304.2	292.4	290.3	291.4	-107.3	-116.8	-110.8	-104.6	-107.9	9.5	3.4	-2.8	0.6	26.6	28.8	28.4	27.9	25.8	Geophysics
	A2 Unit Evaporite	319.7	333.5	320.9	349.4	367.5	113	109	98	49	55	319.7	333.0	320.8	318.2	317.2	-133.9	-145.7	-139.2	-132.5	-133.7	11.7	5.2	-1.5	-0.3	5.8	5.1	5.2	5.6	3.7	Geophysics
	Salina Formation - A1 Unit	325.5	338.6	326.1	355.5	371.8	115	111	99	51	56	325.5	338.1	326.0	323.7	320.9	-139.7	-150.7	-144.4	-138.0	-137.4	11.0	4.6	-1.7	-2.4	41.5	41.1	40.7	41.5	40.4	Core
	A1 Unit Evaporite	367	379.8	366.8	400.4	418.0	129	125	113	66	74	367.0	379.2	366.7	365.2	361.2	-181.2	-191.9	-185.1	-179.5	-177.7	10.6	3.8	-1.7	-3.5	3.5	4.4	5.0	4.4	4.4	Geophysics
	Salina Formation - A0 Unit	370.5	384.2	371.8	405.0	423.0	130	126	114	68	75	370.5	383.6	371.7	369.6	365.7	-184.7	-196.3	-190.1	-183.9	-182.2	11.5	5.3	-0.9	-2.6	4.0	2.6	3.8	2.8	3.9	Geophysics
Middle Silurian	Guelph Formation	374.5	386.8	375.6	408.0	427.3	132	127	116	69	77	374.5	386.2	375.5	372.3	369.6	-188.7	-198.9	-193.9	-186.6	-186.1	10.1	5.1	-2.1	-2.7	4.1	5.4	4.9	5.4	3.7	Geophysics
	Goat Island Formation	378.6	392.2	380.5	413.7	431.5	133	129	117	71	78	378.6	391.6	380.4	377.7	373.3	-192.8	-204.3	-198.8	-192.0	-189.8	11.4	5.9	-0.8	-3.0	18.8	18.3	18.6	18.1	18.5	Geophysics
	Gasport Formation	397.4	410.5	399.1	433.0	452.2	139	135	123	77	85	397.4	409.9	399.0	395.8	391.8	-211.6	-222.6	-217.4	-210.1	-208.3	10.9	5.7	-1.6	-3.3	6.8	6.5	6.5	9.2	7.9	Geophysics
Lower Silurian	Lions Head Formation	404.25	417	405.6	442.8	461.0	141	137	126	80	88	404.2	416.4	405.5	405.0	399.7	-218.5	-229.1	-223.9	-219.3	-216.2	10.6	5.4	0.8	-2.3	4.4	4.5	4.4	2.3	3.6	Geophysics
	Fossil Hill Formation	408.7	421.5	410	445.3	465.0	143	139	127	81	89	408.7	420.9	409.9	407.3	403.3	-222.9	-233.6	-228.3	-221.6	-219.8	10.6	5.3	-1.4	-3.1	2.3	1.3	1.5	2.4	2.6	Geophysics
	Cabot Head Formation	411	422.8	411.5	447.8	467.9	143	139	127	82	90	411.0	422.2	411.4	409.7	405.9	-225.2	-234.8	-229.8	-224.0	-222.4	9.6	4.5	-1.2	-2.8	23.8	24.7	24.2	23.7	23.4	Geophysics
	Manitoulin Formation	434.8	447.5	435.7	473.0	493.6	151	147	136	92	100	434.8	446.9	435.6	433.4	429.3	-249.0	-259.5	-254.0	-247.7	-245.8	10.5	4.9	-1.4	-3.2	12.8	9.5	10.6	12.9	13.2	Geophysics
Upper Ordovician	Queenston Formation	447.65	457	446.3	486.6	507.9	156	150	140	96	105	447.6	456.4	446.2	446.2	442.6	-261.9	-269.0	-264.6	-260.5	-259.1	7.1	2.7	-1.4	-2.8	70.3	74.4	73.0	70.3	69.3	Core
	Georgian Bay Formation	518	531.4	519.3	560.6	583.1	DGR-2 23	175	164	121	133	518.0	530.7	519.2	516.6	511.9	-332.1	-343.4	-337.6	-330.9	-328.4	11.2	5.4	-1.3	-3.7	90.9	88.7	88.7	88.6	88.2	Core
	Blue Mountain Formation	608.9	620.1	608	653.3	684.7	52	205	195	151	172	608.9	619.4	607.9	605.2	600.1	-423.0	-432.1	-426.3	-419.5	-416.6	9.0	3.2	-3.6	-6.4	38.1	40.0	41.1	45.1	45.0	Geophysics
	Blue Mountain Formation - Lower Member	647	660.2	649.1	--	--	65	218	209	--	--	647.0	659.5	649.0	--	--	-461.1	-472.1	-467.4	--	--	11.0	6.2	--	--	4.6	4.1	4.0	--	--	Core
Middle Ordivician	Cobourg Formation - Collingwood Member	651.6	664.3	653.1	699.9	738.3	67	219	211	167	190	651.6	663.6	653.0	650.3	645.1	-465.7	-476.3	-471.4	-464.6	-461.6	10.5	5.6	-1.2	-4.2	7.9	8.7	8.4	8.6	6.5	Geophysics
	Cobourg Formation - Lower Member	659.5	673	661.5	708.7	746.1	70	222	214	170	192	659.5	672.3	661.4	658.9	651.6	-473.6	-485.0	-479.8	-473.2	-468.1	11.3	6.1	-0.5	-5.5	28.6	27.8	27.5	27.1	28.5	Core
	Sherman Fall Formation	688.1	700.8	689	736.5	780.2	79	232	223	179	203	688.1	700.1	688.8	686.0	680.2	-502.2	-512.7	-507.2	-500.3	-496.7	10.5	5.0	-1.9	-5.6	28.0	28.9	28.3	29.3	28.8	Geophysics
	Kirkfield Formation	716.1	729.8	717.3	766.5	814.7	89	243	233	189	215	716.1	729.0	717.1	715.3	709.0	-530.2	-541.7	-535.5	-529.6	-525.5	11.5	5.3	-0.7	-4.7	45.9	45.8	45.7	--	46.8	Geophysics
	Coboconk Formation	762	775.6	763	--	870.5	105	258	248	--	234	762.0	774.9	762.8	-	755.8	-576.1	-587.5	-581.2	--	-572.3	11.4	5.1	--	-3.9	23.0	23.7	23.8	--	22.4	Geophysics
	Gull River Formation	785	799.3	786.8	--	897.2	114	266	256	--	243	785.0	798.6	786.6	-	778.1	-599.1	-611.2	-605.0	--	-594.6	12.1	5.9	--	-4.5	53.6	51.7	52.2	--	--	Geophysics
	Shadow Lake Formation	838.6	851	839	--	--	132	283	273	--	--	838.6	850.3	838.8	-	-	-652.7	-662.9	-657.2	--	--	10.2	4.5	--	--	5.2	4.5	5.1	--	--	Core
	Cambrian Sandstone	843.8	855.5	844.1	--	--	133	284	274	--	--	843.8	854.8	843.9	-	-	-657.9	-667.4	-662.3	--	--	9.5	4.4	--	--	16.9	--	--	--	--	Core
	Precambrian basement	860.7	--	--	--	--	146	--	--	--	--	860.7	-	-	-	-	-674.8	--	--	--	--	--	--	--	--	--	--	--	--	--	Core

DGR Borehole	DGR-1*	DGR-2*	DGR-3	DGR-4	DGR-5	DGR-6
Ground Surface Elevation (mASL)	185.71	185.84	187.35	181.6	185.70	183.50
Total Drilled Depth (m)	462.87	862.12	869.17	856.98	807.15	903.16

Note: * DGR-1 and DGR-2 are both vertically cored boreholes situated approximately 50 m apart and therefore are considered to represent 1 stratigraphic borehole. As such, all top of formation depth information for bedrock units above and including the Queenston Formation are referenced to DGR-1 and all formation top information for bedrock units below and including the Georgian Bay Formation are referenced to DGR-2.



Reference Stratigraphic Column at the Bruce Site Based on DGR-1 and DGR-2 Borehole Data	Prepared by: SNG Reviewed by: SNS Date: 7-Apr-11
FIGURE 2 Doc. No.: TR-09-11_Figure 2_R0.cdr	

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Table 3 Stratigraphic Marker Beds in Boreholes DGR-1 to DGR-6

Formation	Marker Bed or Horizon	Depth (mLBGS)					Elevation (mASL)				
		DGR -1/2	DGR -3	DGR -4	DGR -5	DGR -6	DGR-1/2	DGR-3	DGR-4	DGR-5	DGR-6
Salina F Unit	brown dolostone bed in grey shale	182.0	200.7	181.5	--	--	3.7	-13.1	0.14	--	--
Queenston	limestone bed in shale	504.3	517.7	505.6	546.0	568.6	-318.5	-329.7	-323.9	-316.9	-315.0
Georgian Bay	fossiliferous limestone bed in shale	576.5	589.2	577.9	622.3	649.6	-390.6	-401.2	-396.2	-389.7	-387.1
Coboconk	volcanic ash bed in limestone	768.8	781.0	769.0	--	876.7	-582.9	-592.9	-587.2	--	-577.5
Coboconk	tan dolostone bed in grey limestone	778.7	790.5	778.3	--	888.0	-592.8	-602.4	-596.5	--	-586.9

6.2 Formation Thicknesses

Intersection of bedrock formations by boreholes DGR-1 to DGR-6 allows assessment of the uniformity of bedrock formation thickness in the area of the proposed DGR. Table 2 shows that the formation thicknesses in DGR boreholes are remarkably uniform (generally within two to three metres) with separation distances between DGR drilling sites ranging from of approximately 600 (between Drill Sites 1 and 4) to 1300 m (between Drill Sites 1 and 3). The thicknesses of formations are somewhat more variable above the Salina B Unit and more uniform below the B Unit.

Exceptions to uniform thicknesses are the Salina Formation B Unit in DGR-5 which appears to be approximately 10 m thicker compared to other DGR boreholes, and the Salina Formation C Unit in DGR-6 which appears to be approximately 18 m thicker compared to other DGR boreholes. A possible explanation for these increased thicknesses include dissolution of the B salt unit causing the collapse of overlying B Unit allowing for additional sediment deposition into this collapsed zone. A possible reason for variable thicknesses between DGR-5 and DGR-6 is that the B salt unit dissolved at different times due to presence of local embayments.

6.3 Strike and Dip Calculations

Borehole coordinates and relative distances are listed in Table 4. True strike and dip values were calculated using the elevation data (corrected for true vertical depth as discussed in Section 5) for the tops of formations and marker beds in the three vertical borehole locations (DGR-1/2, DGR-3, and DGR-4). These calculations followed the analytical three-point problem method of Groshong (2006, p 52). Strike values are reported in azimuth degrees using the right-hand rule convention in which the direction of dip is 90° in a clockwise direction from the strike.

Table 4 Borehole Coordinates and Relative Distances Between DGR Boreholes

Borehole	UTM Coordinates (NAD83, Zone 17)		Horizontal Distance Between Borehole Collar Locations (m)				
	Easting	Northing	DGR-2	DGR-3	DGR-4	DGR-5	DGR-6
DGR-1	454240	4907755	47	1159	1312	22	631
DGR-2	454209	4907720	-	1129	1318	25	649
DGR-3	453081	4907740	-	-	1047	1141	1046
DGR-4	453378	4908744	-	-	-	1310	716
DGR-5	454222	4907742	-	-			635
DGR-6	453953	4909317					

Table 5 lists the updated true strike and dip values along with the dip direction in azimuth degrees for each bedrock formation. The updated strike and dip directions (azimuth degrees) were generally less than 0.6 degrees smaller compared to those presented in TR-08-12 (Intera Engineering Ltd., 2010a) which did not take into account TVD. One exception to this general trend is the Queenston Formation attitude which was 2.5 degrees smaller after accounting for TVD. These calculations assume that the top surface of each bedrock formation is a linear plane and although geologically this is inaccurate, this assumption is sufficient for the purpose of this exercise when discussing boreholes separated by less than 1500 metres.

Generally, marker bed and formation top elevations were highest at Drill Site 4 (DGR-6), similar but lower at Drill Site 1 (DGR-1, DGR-2, and DGR-5) and Drill Site 3 (DGR-4), and lowest at Drill Site 2 (DGR-3). Therefore, true dips are from the northeast towards the southwest. Exceptions to this general trend are several bedrock units in the Salina Formation (above the A2 Unit) as well as the Lucas Formation.

The Lucas Formation is the uppermost bedrock formation at the site, in which the elevation of its top was highest at DGR-3 and lowest at DGR-1/-2. The dip direction of the Lucas Formation is reflective of erosion that has occurred subsequent to its deposition (and the deposition of any overlying strata that has been eroded) since the end of the Devonian 360 million years ago. Because top of the Lucas Formation is an erosional discontinuity, it does not reflect the orientation of the bedding or the orientation of the formation. The Salina Formations above the A2 Unit are subject to salt dissolution and structural collapse, therefore the predictability and uniformity of formation thicknesses and elevations is considered to be lower for these bedrock units.

As shown in Table 5 the dip direction of all formation tops and marker beds, with the exception of the Lucas Formation, were to the southwest and ranged between 235° (Salina Formation – E Unit) and 257° (Cobourg Formation) azimuth degrees, although the majority were between 243° and 258°. The Lucas Formation dip direction was 81° which reflects the attitude of the erosional surface. Dip angles were between 0.41° (Queenston Formation) and 1.15° (Amherstburg Formation) (7 to 20 m/km, respectively). Formations above and including the Salina C Unit all had dip angles equal to or greater than 0.90°; whereas formations below the Salina C – Unit had dip angles that were generally between 0.55° and 0.65°. The steeper dip angles of between 0.9° and 1.15° calculated for formations above and including the Salina Formation – C Unit are attributable to post-depositional dissolution of evaporate beds (Unit B and Unit D salts) in the Salina succession (Sanford, 1977) and collapse of overlying bedrock formations.

Table 5. Summary of True Strike and Dip Values for Bedrock Formations/Marker Beds and Difference Between Measured and Predicted Bedrock Elevations in DGR-5 and DGR-6

	Stratigraphic Nomenclature	True Strike and Dip (DGR-1/2, DGR-3 & DGR-4)				DGR-5			DGR-6		
		Strike (Azimuth Degrees)	Dip Gradient (m/km)	True Dip (Degrees from Horizontal)	Dip Direction (Azimuth Degrees)	Predicted Elevation from Plane (mASL)	Table 2 Measured Elevation in Core (mASL)	Vertical Offset (m)	Predicted Elevation from Plane (mASL)	Table 2 Measured Elevation in Core (mASL)	Vertical Offset (m)
Late Devonian	Lucas Formation	351.1	11.9717	0.69	81.1	165.98	165.70	0.28	168.0	169.1	-1.13
Late Devonian	Amherstburg Formation	164.4	20.0392	1.15	254.4	154.77	155.32	-0.55	153.2	152.2	1.00
Early Devonian	Bois Blanc Formation	153.1	16.5899	0.95	243.1	109.98	110.71	-0.74	111.4	109.6	1.77
Upper Silurian	Bass Islands Formation	155.2	16.6433	0.95	245.2	60.77	63.46	-2.69	62.5	61.6	0.85
Upper Silurian	Salina Formation - G Unit	152.7	15.7796	0.90	242.7	15.24	18.90	-3.67	17.9	17.4	0.50
Upper Silurian	Salina Formation - F Unit	146.6	16.6581	0.95	236.6	5.72	11.35	-5.64	9.8	8.8	1.00
Upper Silurian	Salina Formation - E Unit	144.8	15.6397	0.90	234.8	-38.86	-27.37	-11.49	-34.2	-31.2	-3.00
Upper Silurian	Salina Formation - D Unit	155.4	17.6979	1.01	245.4	-58.94	-46.72	-12.22	-55.5	-48.4	-7.09
Upper Silurian	Salina Formation - C Unit	155.1	18.6819	1.07	245.1	-60.65	-47.77	-12.88	-56.9	-49.3	-7.57
Upper Silurian	Salina Formation - B Unit	156.2	14.9651	0.86	246.2	-76.03	-60.60	-15.43	-73.0	-82.7	9.68
Upper Silurian	B Unit Evaporite	156.2	9.5330	0.55	246.2	-106.52	-101.37	-5.15	-104.3	-103.9	-0.44
Upper Silurian	Salina Formation - A2 Unit	155.6	9.3093	0.53	245.6	-108.42	-104.58	-3.84	-106.2	-107.9	1.72
Upper Silurian	A2 Unit Evaporite	160.4	11.0853	0.64	250.4	-135.21	-132.46	-2.74	-132.9	-133.7	0.76
Upper Silurian	Salina Formation - A1 Unit	158.8	10.5462	0.60	248.8	-141.00	-138.02	-2.98	-138.6	-137.4	-1.25
Upper Silurian	A1 Unit Evaporite	155.4	10.5251	0.60	245.4	-182.70	-179.52	-3.18	-179.5	-177.7	-1.79
Upper Silurian	Salina Formation - A0 Unit	161.1	10.9485	0.63	251.1	-186.13	-183.87	-2.26	-183.5	-182.2	-1.38
Middle Silurian	Guelph Formation	163.6	9.5321	0.55	253.6	-189.91	-186.63	-3.28	-187.9	-186.1	-1.85
Middle Silurian	Goat Island Formation	164.4	10.6741	0.61	254.4	-194.13	-192.01	-2.13	-192.0	-189.8	-2.19
Middle Silurian	Gasport Formation	164.6	10.2149	0.59	254.6	-212.92	-210.08	-2.83	-210.8	-208.3	-2.43
Lower Silurian	Lions Head Formation	163.7	9.9478	0.57	253.7	-219.78	-219.33	-0.46	-217.5	-216.2	-1.31
Lower Silurian	Fossil Hill Formation	163.3	10.0129	0.57	253.3	-224.26	-221.59	-2.67	-221.9	-219.8	-2.07
Lower Silurian	Cabot Head Formation	161.4	9.21	0.53	251.4	-226.50	-224.02	-2.49	-224.1	-222.4	-1.69
Lower Silurian	Manitoulin Formation	161.3	10.03	0.57	251.3	-250.47	-247.67	-2.80	-247.7	-245.8	-1.88
Upper Ordovician	Queenston Formation	155.8	7.25	0.42	245.8	-263.07	-260.54	-2.52	-260.5	-259.1	-1.45
Upper Ordovician	Georgian Bay Formation	163.3	11.06	0.63	253.3	-333.38	-330.87	-2.52	-330.0	-328.4	-1.61
Upper Ordovician	Blue Mountain Formation	156.5	9.43	0.54	246.5	-424.45	-419.46	-4.99	-420.1	-416.6	-3.54
Upper Ordovician	Blue Mountain Formation - Lower Member	168.0	10.59	0.61	258.0	--	--	--	--	--	--
Middle Ordivician	Cobourg Formation - Collingwood Member	166.0	10.26	0.59	256.0	-467.05	-464.56	-2.49	-463.2	-461.6	-1.67
Middle Ordivician	Cobourg Formation - Lower Member	166.5	10.97	0.63	256.5	-475.04	-473.19	-1.85	-471.0	-468.1	-2.86
Middle Ordivician	Sherman Fall Formation	162.9	10.43	0.60	252.9	-503.74	-500.29	-3.45	-499.1	-496.7	-2.48
Middle Ordivician	Kirkfield Formation	162.2	11.36	0.65	252.2	--	-529.57	--	-526.6	-525.5	-1.09
Middle Ordivician	Coboconk Formation	161.4	11.37	0.65	251.4	--	--	--	-572.0	-572.3	0.25
Middle Ordivician	Gull River Formation	163.6	11.87	0.68	253.6	--	--	--	--	-594.6	
Middle Ordivician	Shadow Lake Formation	161.0	10.27	0.59	251.0	--	--	--	--	--	--
	Cambrian Sandstone	162.1	9.54	0.55	252.1	--	--	--	--	--	--
	Precambrian basement	--	--	--	--	--	--	--	--	--	--

Marker Beds	Salina F Unit (brown dolostone bed in shale)	149.9	17.66	1.01	239.86	--	--	--	--	--	--
Marker Beds	Queenston Formation (limestone bed below shale)	163.6	11.08	0.63	253.62	-319.59	-316.91	-2.68	-316.4	-315.0	-1.33
Marker Beds	Georgian Bay Formation (6 cm fossiliferous limestone bed)	165.5	10.31	0.59	255.46	-391.85	-389.74	-2.12	-388.6	-387.1	-1.46
Marker Beds	Coboconk (ash bed in limestone)	160.4	10.12	0.58	250.38	--	--	--	-579.2	-577.5	-1.68
Marker Beds	Coboconk (tan bed in grey limestone)	158.8	9.75	0.56	248.79	--	--	--	-589.1	-586.9	-2.15

These strike and dip values are based on three borehole locations that are within 1.32 km of each other and therefore local geological characteristics (e.g. variations in local formation thicknesses from regional thicknesses) may produce results that vary slightly from regional values. Nonetheless, calculated strike and dip values of marker beds and bedrock formation tops, with the exception of the Lucas Formation, are consistent with reported general regional bedrock strata dips. Winder and Sanford (1972) report regional dips of 0.31° to 0.50° to the west into the Michigan Basin. Gartner Lee Limited (2008) report regional dip angles as averaging approximately 0.5 degrees in the vicinity of the Bruce site and increasing from the Michigan Basin margin towards the basin centre (westwards). Armstrong and Carter (2010) also describe the regional dip angles of sedimentary bedrock in Southern Ontario to range from 3 to 6 m/km (0.17 to 0.34 degrees) south-westwards from the Algonquin Arch to the Chatham Sag which steepens to approximately 3.5 to 12 m/km (0.20 to 0.69 degrees) down the flanks of the Algonquin Arch and westwards into the Michigan Basin.

6.4 Prediction of Formations in DGR-5 and DGR-6

The top elevation of bedrock formations encountered in DGR-5 and DGR-6, as presented in Table 2, were compared to the predicted formation top elevations based on the equation of a plane using data from the vertical DGR boreholes (DGR-1/2, DGR-3, and DGR-4) as described in Section 5. This comparison provides an assessment of the predictability of formation occurrence at the Bruce DGR site. Table 5 lists the measured top of bedrock formation elevations based on core data, the predicted elevations based on the equation for a plane, and the difference between measured and predicted values for each bedrock formation. These data indicate that measured bedrock formation top elevations in DGR-5 are generally above their predicted elevations and measured elevations in DGR-6 are generally below their predicted elevations.

For DGR-5, stratigraphy above the Salina Formation - B Unit Evaporite appears up to 15.4 m above (i.e., -15.4 m) their predicted elevations (Salina Formation - B Unit). Conversely, stratigraphy below the Salina B Unit shows bedrock formation elevations that range from 0.05 m above (Lions Head Formation) to 5.0 m above (Blue Mountain Formation) predicted values but mostly are approximately 2.0 to 3.0 m above predicted values. DGR-5 is located adjacent to DGR-1 and DGR-2, therefore these minor, yet consistent differences above the predicted bedrock formation elevations suggest a consistent error or bias in the determination of the tops of formation in DGR-5. This error may be due to overestimation of the plunge of DGR-5 as measured by ATV logging. An error of 0.3°-0.4° in borehole plunge measurement would account for the observed difference of 2.0 to 3.0 m in DGR-5.

For DGR-6, stratigraphy above the Salina Formation – B Unit Evaporite ranges between 7.6 m above (Salina Formation – C Unit) to 9.7 m below (Salina Formation – B Unit) their predicted elevations. These variable offsets are most likely due to the difficulty in making formation picks in a section of bedrock with increased brecciation as discussed in Section 5. For example, anhydrite and tan dolostone marker beds, that have been evident in the Salina B, C and E Units and have been relied on to help establish these formation tops in DGR-1 through DGR-5, are brecciated in DGR-6. Therefore selection of formation contacts is difficult at best and may not correspond to more obvious marker beds in other DGR boreholes. Conversely, stratigraphy below the Salina B Unit show bedrock formation elevations that range from 1.7 m below (Salina Formation – A2 Unit) to 3.5 m above (Blue Mountain Formation), but mostly are 1.5 to 2.5 m above the predicted values. This consistent under prediction of the elevation of the top of the formation in DGR-6 may be due to overestimation of the borehole plunge of DGR-6 as measured by gyroscopic surveys.

DGR-5 and DGR-6 were drilled at target inclinations of 25 and 30 degrees from vertical to better assess vertical structure and to help identify any vertical movement (i.e. fault offsets). The orientation of DGR-6 was selected to investigate a potential seismic feature as identified in TR-07-15 – 2D Seismic Survey of the Bruce Site (Intera Engineering Ltd., 2009d). The minor differences in predicted versus measured elevation of formations in DGR-5 and DGR-6 appear to be in the range of expected values given uncertainty in measured borehole plunges, formation picks and the formation planarity. Consequently, these data do not indicate any significant formation offsets in the vicinity of DGR-5 or DGR-6.

7 Data Quality and Use

Data on bedrock formation nomenclature and identification in this Technical Report are based on expert geological review of the geology and geophysical properties observed in boreholes DGR-1 to DGR-6 at the Bruce site. Many contacts between individual bedrock formations are gradational and the selected contacts reflect the consensus opinion of the geological experts.

The data presented in this Technical Report are suitable for providing the framework for development of geological, hydrogeological and geomechanical descriptive site models of the Bruce DGR site.

Future research may result in changes to the stratigraphic nomenclature used to describe the rock record of the DGR boreholes; however, hydrogeological and geomechanical descriptive site models are based on the properties of the bedrock, irrespective of their nomenclature, and therefore, it is not anticipated that changes in nomenclature will affect these models.

8 Acknowledgments

The vast experience on logging sedimentary bedrock formations in Ontario shared by the list of geology experts who attended the Geosynthesis Core Workshops is greatly appreciated.

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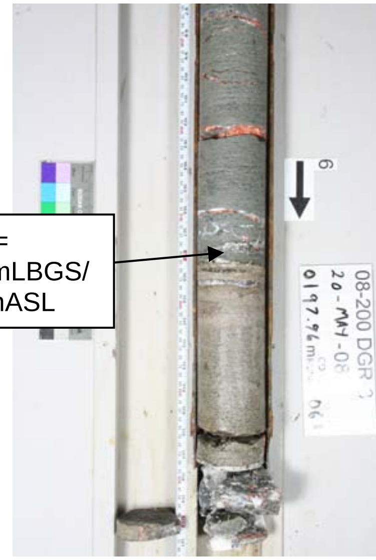
APPENDIX A

Core Photographs of Selected Marker Beds

DGR-1

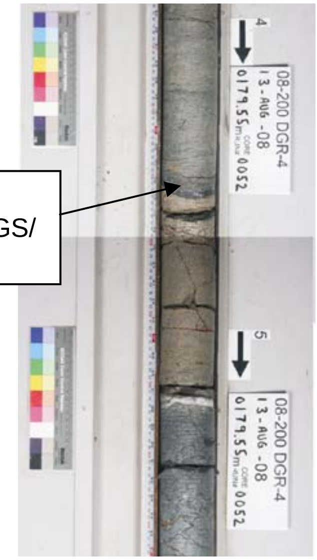
Depth =
182.0 mLBGS/
3.7 mASL

DGR-3



Depth =
200.7 mLBGS/
-13.4 mASL

DGR-4

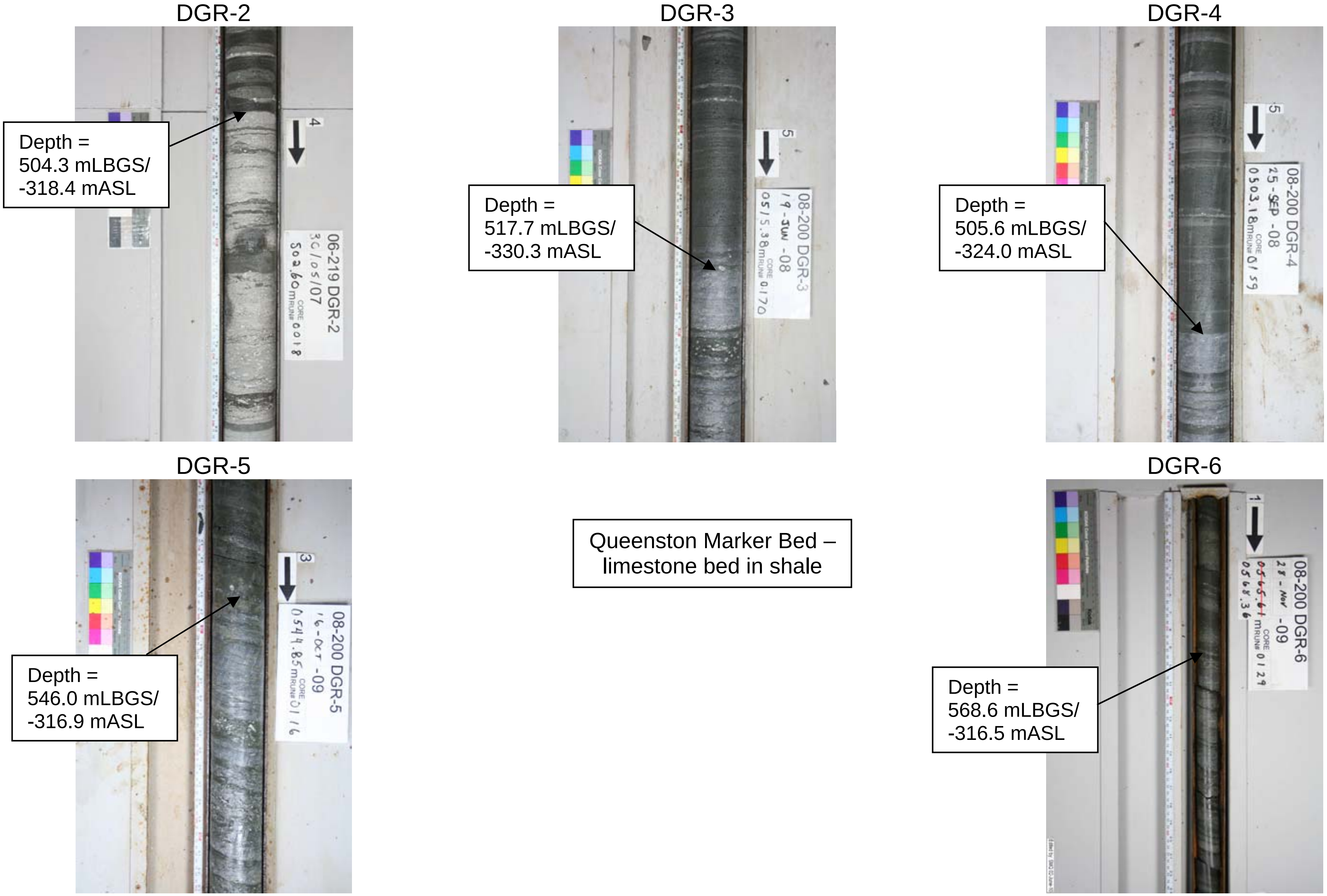


Depth =
181.5 mLBGS/
0.1 mASL

Salina F Unit Marker Bed –
brown dolostone bed in grey shale

Salina Formation - F Unit Tan Dolostone Marker Bed in DGR-1, DGR-3, and DGR-4		Prepared by: SNS Reviewed by: KGR Date: 7-Apr-11
FIGURE A.1	TR-09-11_Fig A.1 Salina F Unit_R0.doc	

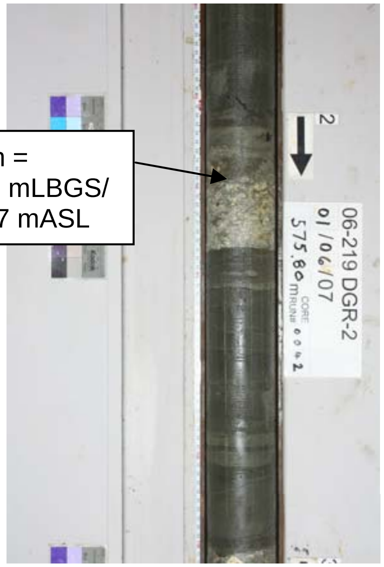
Geofirma Engineering Ltd



Queenston Formation Limestone Marker Bed in DGR-2, DGR-3, DGR-4, DGR-5, and DGR-6	Prepared by: SNS Reviewed by: KGR Date: 7-Apr-11
FIGURE A.2 TR-09-11_Fig A.2 Queenston_R0.doc	

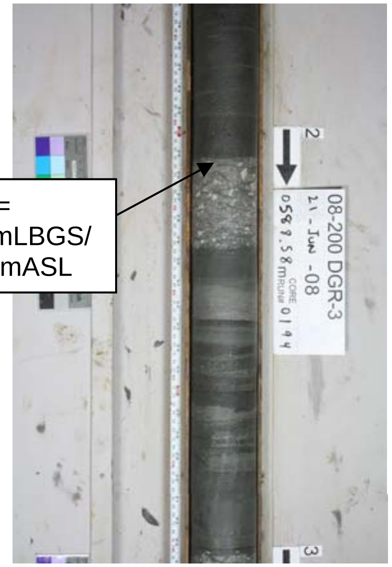
Geofirma Engineering Ltd

DGR-2



Depth =
576.5 mLBGS/
-390.7 mASL

DGR-3



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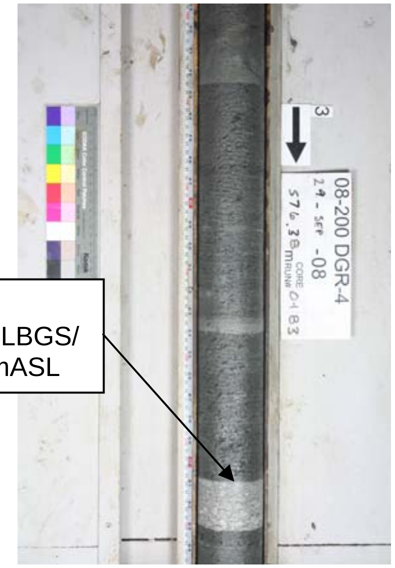
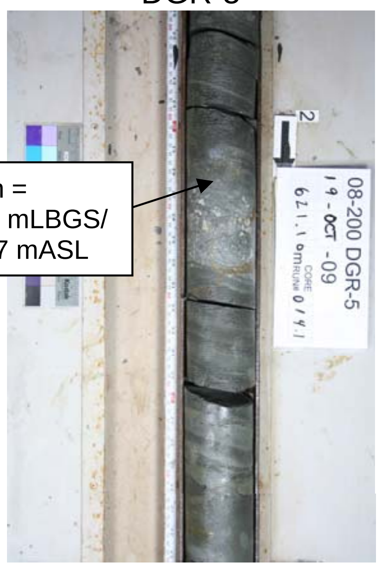
589.2 mLBGS/
-401.9 mASL

DGR-4



Depth =
577.9 mLBGS/
-396.2 mASL

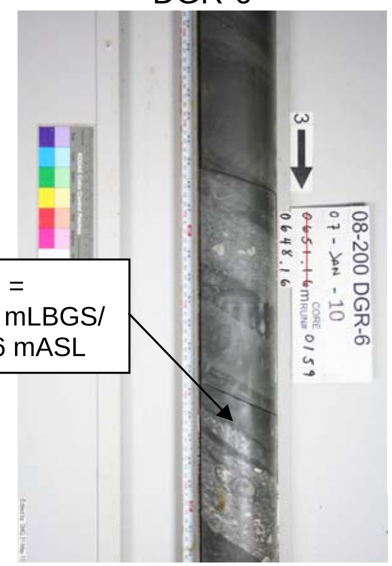
DGR-5



Depth =
622.3 mLBGS/
-389.7 mASL

Georgian Bay Marker Bed – fossiliferous limestone bed in shale

DGR-6

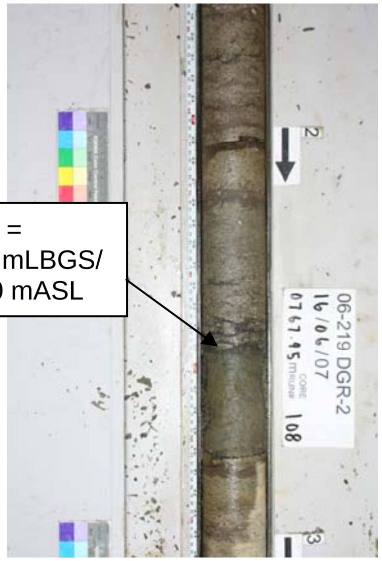


Depth =
649.6 mLBGS/
-388.6 mASL

Georgian Bay Formation Limestone Marker Bed in DGR-2, DGR-3, DGR-4, DGR-5, and DGR-6	Prepared by: SNS Reviewed by: KGR Date: 7-Apr-11
FIGURE A.3 TR-09-11_Fig A.3 Georgian Bay_R0.doc	

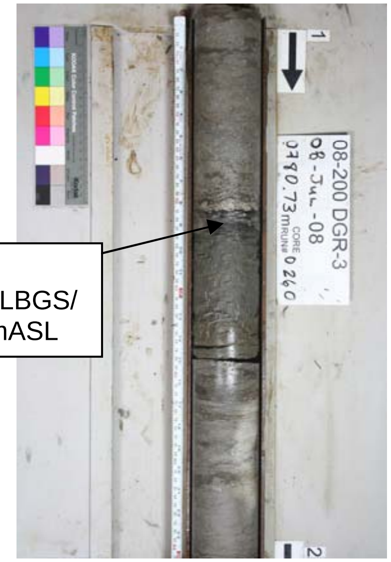
Geofirma Engineering Ltd

DGR-2



Depth =
768.8 mLBGS/
-583.0 mASL

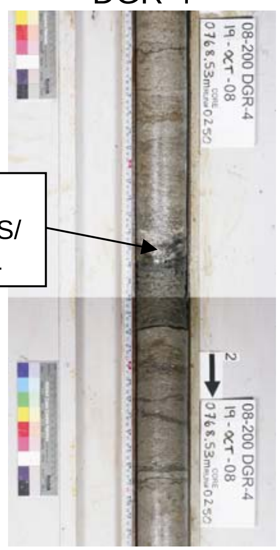
DGR-3



Depth =
781.0 mLBGS/
-593.7 mASL

Coboconk Marker Bed – volcanic ash bed in limestone

DGR-4



Depth =
769.0 mLBGS/
-587.4 mASL

DGR-6

Depth =
876.7 mLBGS/
-579.3 mASL

Coboconk Formation Ash Layer Marker Bed in DGR-2, DGR-3, DGR-4, and DGR-6		Prepared by: SNS Reviewed by: KGR Date: 7-Apr-11
FIGURE A.4	TR-09-11_Fig A.4 Coboconk Shallow_R0.doc	

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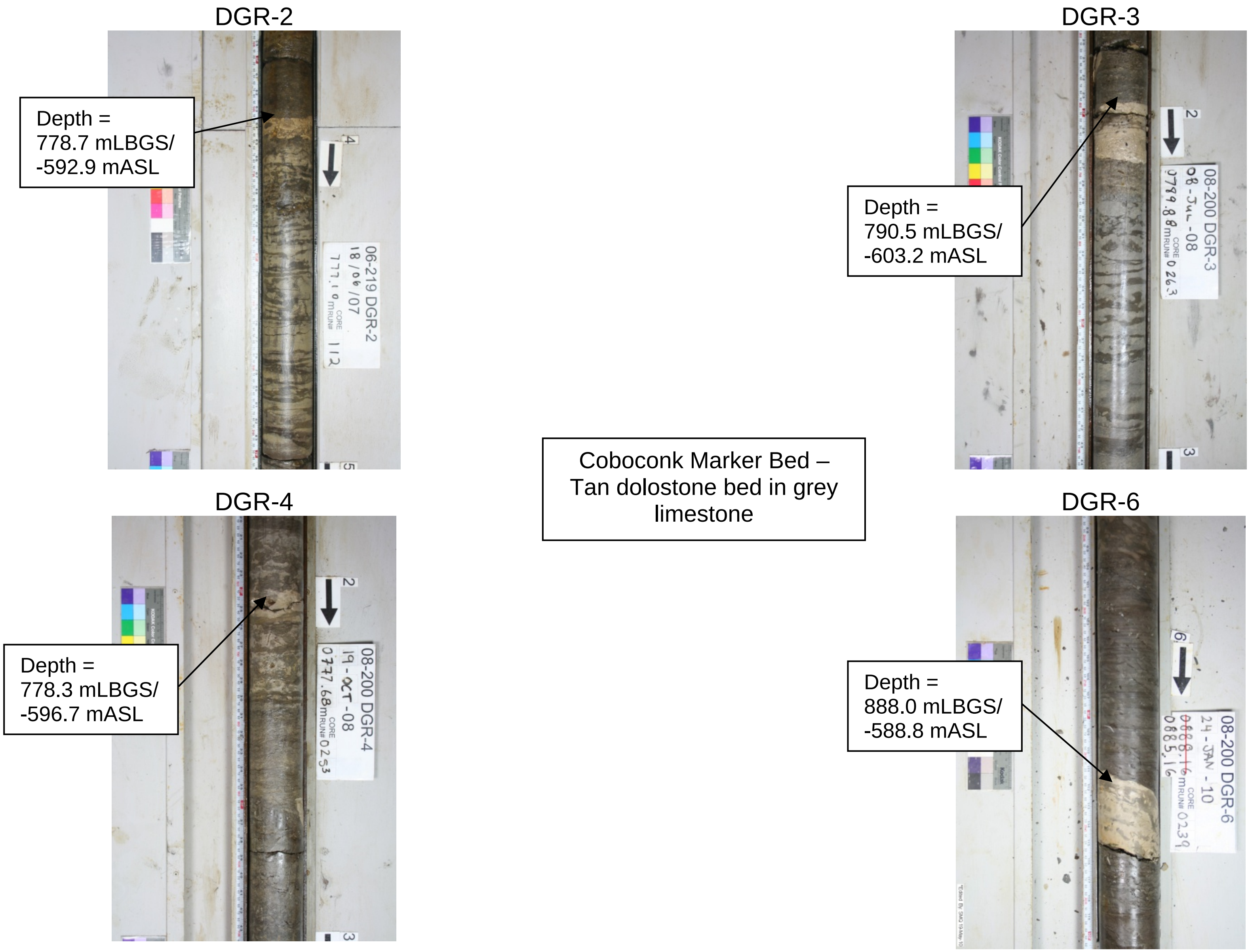

Coboconk Formation Tan Dolostone Marker Bed in DGR-2, DGR-3, DGR-4, and DGR-6		Prepared by: SNS Reviewed by: KGR Date: 7-Apr-11
FIGURE A.5	TR-09-11_Fig A.5 Coboconk Deep_R0.doc	

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