Regional and site geological frameworks – proposed Deep Geologic Repository, Bruce County, Ontario

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ABSTRACT
Regional and site geological frameworks for the proposed Deep Geologic Repository at the Bruce site located near Tiverton Ontario have been defined based on comprehensive review of existing regional drilling and geological data and completion of on-site investigations including 2-D seismic reflection surveys and drilling and logging of four deep cored boreholes. The results of these studies show the depth, thickness, orientation and rock quality of the 34 formations, members or units that comprise the 840 m thick Paleozoic bedrock sequence at the Bruce site are remarkably uniform and predictable over distances of several kilometres.

RÉSUMÉ
Les cadres géologiques regionaux et locaux conçernant les installations de stockage de déchets radioactifs dans les couches géologiques profondes au site Bruce situé près de la ville de Tiverton, Ontario, ont été définis grâce à une revue détaillée des données de forage régional et les données géologiques, ainsi que par la tenue d'études sur le site, y compris le levés de sismique réflexion 2-D et le forage et la diagraphie de quatres puits de forages profonds. Les résultats des ces études nous disent que la profondeur, l'épaisseur, l'orientation et les qualités de roche des 34 formations, membres et strates comprenant les 860 m de la séquence de soubassement au site Bruce sont remarquablement uniformes et prévisibles sur une distance de plusieurs kilomètres.

1 INTRODUCTION

The Nuclear Waste Management Organization (NWMO) is conducting geoscientific studies on behalf of Ontario Power Generation into the proposed development of a Deep Geologic Repository (DGR) for Low and Intermediate Level Radioactive Waste (L&ILW) at the Bruce site, located near Tiverton, Ontario, Canada. The DGR is proposed to be constructed as an engineered facility comprising a series of underground emplacement rooms at depth of 680 metres below ground surface (mBGS) within the argillaceous limestone of the Cobourg Formation.

An important goal of these geoscientific studies is the development of a coherent and integrated understanding of the geological framework and setting at both regional and DGR site scales. Such understanding provides the basis for development of descriptive geological, hydrogeological and geomechanical models of the DGR site that will be central to environmental and safety assessments of the proposed Bruce DGR.

DGR project reports cited in this paper are available at www.nwmo.ca/dgr .

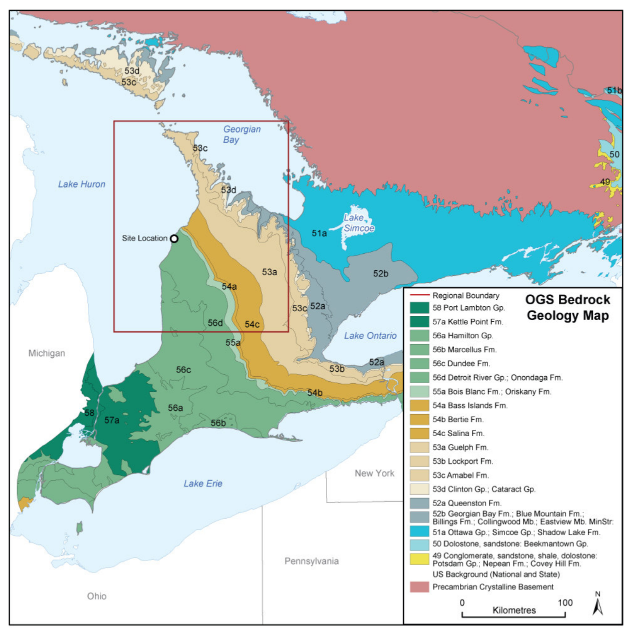

Figure 1. Geological map of southern Ontario showing DGR Regional Study Area and Bruce site.

2 REGIONAL GEOLOGICAL FRAMEWORK

The sedimentary rocks of Southern Ontario rest on the southern margin of the Canadian Shield. The crystalline basement is composed of metamorphic rocks of the Proterozoic Grenville Province. Figure 1 shows progressively younger Paleozoic sedimentary units outcropping/subcropping from the Canadian Shield margin in central Ontario towards southwestern Ontario.

These sedimentary units range in age from the upper Cambrian to Upper Devonian and were deposited in two paleo-sedimentary basins, the foreland Appalachian Basin (eastern Southern Ontario centered in the eastern US) and intra-cratonic Michigan Basin (western portions of southern Ontario and centered over Northern

Michigan). These Basins are separated in Ontario by a basement high known as the Algonquin Arch. Figure 1 shows the location of the DGR Regional Study Area (RSA) boundary, the area used to define and construct a detailed three-dimensional geological framework (3DGF) model as described below. The DGR site is located at the eastern margin of the Paleo-Michigan Basin.

2.1 Structural Geology

The structure of the Proterozoic basement of southern Ontario has been characterized by surface mapping north of the Paleozoic/Precambrian contact, regional field geophysical data (aeromagnetics, gravity), seismic reflection surveys and analyses of samples recovered from boreholes. Figure 2 shows the structural subdivisions of Precambrian basement, updated locations of previously mapped major faults, and aeromagnetic lineaments. Two major structures can be followed from their surface exposure northwest and east of Georgian Bay beneath the Paleozoic cover to the southwest. The first is the Grenville Front Tectonic Zone (GFTZ), which marks the leading edge of the Grenville Orogen with the Southern and Superior shield provinces. The second is the Central Metasedimentary Belt Boundary Zone (CMBBZ), which defines the tectonic contact within the Grenville Province between the Central Gneiss Belt to the west and the Central Metasedimentary Belt.

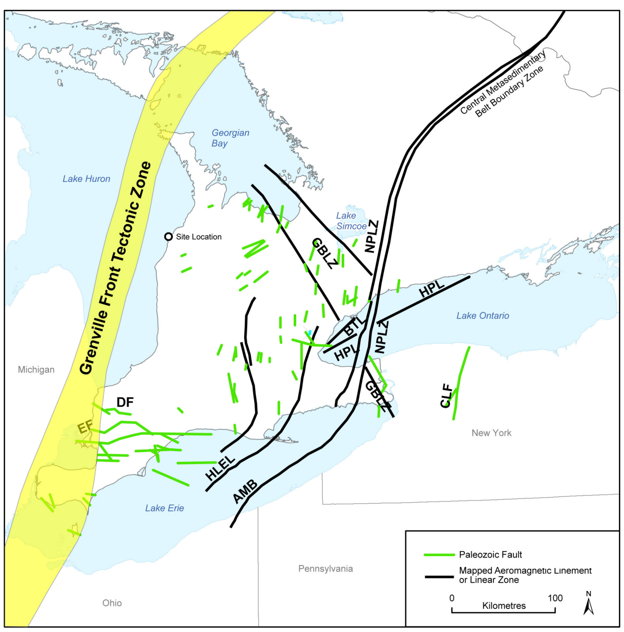

Figure 2. Structural subdivisions of the Precambrian basement, Paleozoic faults and mapped aeromagnetic lineaments of southern Ontario (Gartner Lee Limited, 2008a)

The study area can be characterized as one of the more structurally simple or undisturbed parts of southern Ontario. Paleozoic strata dip gently towards the centre of the Michigan Basin and contain two principle fracture (joint) sets in surface exposures whose orientations are consistent with those elsewhere in southern Ontario. Sanford *et al.* (1985) subdivided Southern Ontario south of the Canadian Shield into a number of tectonic blocks (megablocks) based upon the characteristics of basement structures, subsurface faults and surface lineaments. The two megablocks most relevant to the DGR are the Bruce Megablock where the RSA is located and the more fractured Niagara Megablock in southwestern Ontario. Sanford et al. (1985) indicate that Paleozoic units within the Bruce Megablock contain ENE- to EW-trending normal faults with ~10 km spacing and top to the south displacements. However, lack of evidence for the continuation of these faults to the basement or surface indicates that their significance requires further evaluation. The Paleozoic rocks rest unconformably on a crystalline basement of Proterozoic age. Available aeromagnetic and gravity data (Easton and Carter, 1995; Wallach et al., 1998) suggest that Proterozoic rocks underlying the majority of the study area are structurally simple with no major basement structural features. The Bruce site is located at the edge of the stable cratonic region of North America and therefore the likelihood of a large seismic event in the region is low. (Gartner Lee Limited, 2008b).

2.2 Paleozoic Stratigraphy and Sedimentology

The scientific understanding of regional facies models combined with field mapping, outcrop data and borehole data across the Ontario portions of the Michigan and Appalachian Basins provide a sound understanding of Paleozoic geology over large distances. In the case of southern Ontario, the Paleozoic stratigraphy is relatively simple, flat lying and continuous. This geometry was the result of deposition over broad carbonate and clastic shelf and platform settings that extended from the eastern margin of the Appalachian Basin to the centre of the continent. Deposition later in the Paleozoic within the relatively isolated Michigan Basin produced predictable basin-centred facies assemblages. Exceptions to the relatively predictable stratigraphy are the Cambrian deposits and Salina evaporites. Widespread erosion of the Cambrian units during a major unconformity makes predicting the distribution within the subsurface through most of southern Ontario, including the RSA, difficult. The Salina evaporite distributions are complicated by selective dissolution within the RSA that occurred during Paleozoic times.

The following descriptions of the main Paleozoic stratigraphic sequences found with the study area, and beneath the DGR site, are adapted from Armstrong and Carter (2006).

The basal Cambrian deposits were deposited directly over the Precambrian basement, and although these deposits extend from the Appalachian Basin to the Michigan Basin, they have largely been eroded over most of southern Ontario. The lithology of the Cambrian units ranges from dolostone, sandy dolostone, argillaceous dolostone to quartzose sandstone, which are often described as porous and permeable.

Overlying the Cambrian deposits or basement in the subsurface of southern Ontario are the Middle Ordovician Carbonates. These rocks include the Shadow Lake, Gull River, Coboconk Formations of the Black River Group and the Kirkfield, Sherman Fall, Cobourg Formations (DGR host rock) of the Trenton Group. These rocks are generally characterized as limestones to argillaceous limestones and have a uniform and extensive distribution from the Appalachian Basin in New York, into the Michigan Basin of Ontario and Michigan. Capping the Ordovician limestones are the extensive Upper Ordovician shale sequences of the Blue Mountain, Georgian Bay and Queenston Formations. These tight shale units are generally composed of non-calcareous to calcareous shales with minor siltstone and carbonate interbeds.

The Lower and Middle Silurian rocks beneath the DGR consist of the Manitoulin Formation dolostones, Cabot Head Formation shales and the dolostones of the Fossil Hill, Lions Head, Gasport, Goat Island and Guelph Formations. The Guelph Formation is highly variable in thickness across the study area due to its depositional environment, where pinnacle, patch and barrier reefs occurred in separate zones within the Michigan Basin. The Upper Silurian Formations are comprised of the Salina Group and the Bass Islands Formations. Repeating deposition of carbonate, evaporites (halite, anhydrite and gypsum) and argillaceous sediments within both the Appalachian Basin and Michigan Basin characterize the Salina Group.

The youngest rocks in the regional study area include the lower Devonian Bois Blanc Formation dolostones, which are disconformably overlain by Middle Devonian mixed limestones and dolostones of the Detroit River Group (Amherstburg and Lucas Formations). The Lucas Formation subcrops beneath the overburden at the DGR Bruce and outcrops along the shoreline.

2.3 3-D Geological Framework Model

The 3DGF model covers an area of approximately 35,000-km^2 around the DGR site and was developed to capture and present the current geological understanding of the Paleozoic sedimentary formations and their stratigraphy around the DGR. This understanding was required to provide context to the geology at the DGR site. The 3DGF was also used as the basis for the regional hydrogeological modelling hydrostratigraphy, providing the geometric framework for numerical simulations of groundwater migration and mass transport. A cut away view of the 3DGF illustrating the stratigraphy and the DGR repository horizon at depth is shown in Figure 3.

The primary data source for the geologic framework construction was the Oil, Gas, and Salt Resources Library (OGSR) Petroleum Wells Subsurface Database. These data sets include geological formation tops, logging records, and oil/gas/water intervals for tens of thousands of petroleum wells throughout Ontario. The vast majority of these wells are located in southwestern Ontario along the shore of Lake Erie extending towards Sarnia/Lambton County. The Regional Study Area (RSA) contained a total of 341 wells, which were reduced to 302 wells through a data validation process described in the Regional Geology Supporting Technical Report (Gartner Lee Ltd., 2008a). The process of verifying data used for development of the 3DGF involved both geological software modelling methods and the application of "expert" knowledge. The resulting framework was constructed using a unique process, and is essentially a hybrid geological model where software was used to develop a model or best fit of the source data that was then manually edited, where required, to reflect knowledge of the stratigraphy. The geological model software honoured all of the subsurface geological contacts that were deemed to be reliable as determined by the verification procedures.

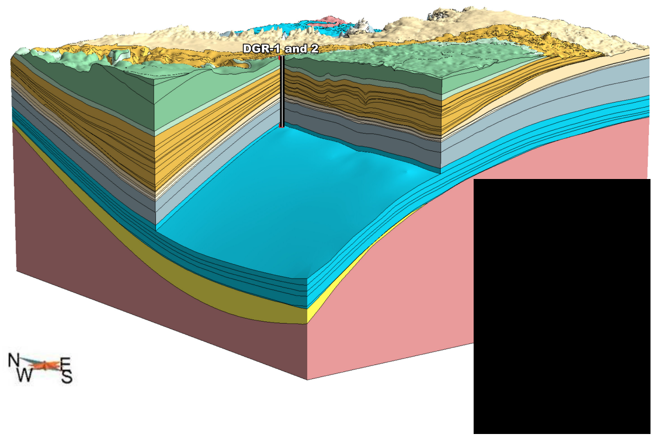

Figure 3. 3-D Regional Geological Framework model cut-away looking NE showing the location of the DGR beneath the Bruce site at boreholes DGR-1 and DGR-2 with about 40X vertical exaggeration

In addition to the wells within the RSA, a further 57 petroleum Reference Wells (Armstrong and Carter, 2006) and 76 petroleum wells from the Michigan State Geological Survey Digital Well Database located outside of the RSA were used. These additional wells were required to constrain the geometry of the basin, and subsequent geological layers within RSA. Other important data included published geological maps, and bedrock topography, drift thickness and lake bathymetry mapping.

3 DGR GEOLOGICAL SITE MODEL

The descriptive geological model of the Bruce DGR site has been developed based on implementation of Phase 1 and Phase 2A Geoscientific Site Characterization Plans (GSCP - Intera Engineering Ltd., 2006; 2008) and integration of these on-site results with geological information from the 3DGF, in particular Texaco #6 (MNR #T002636) located 2.9 km southeast of borehole DGR-2 .

3.1 Geoscientific Site Characterization Program

Characterization activities at the Bruce site are ongoing and are being performed to meet the requirements specified in the GSCP. The GSCP is a multi-phase 4-year program of deep drilling and testing that also has included completion of about 20 km of 2-D seismic reflection surveys to map bedrock stratigraphy and possible presence of vertical fault structure.

Phase 1 GSCP work (Raven et al., 2007) included the continuous coring and testing of vertical boreholes DGR-1 and DGR-2 drilled into the top of the Queenston shale at 447.7 mBGS and into the Precambrian basement at 860.7 mBGS, respectively. Phase 2A GSCP activity has included continuous coring and testing of vertical boreholes DGR-3 and DGR-4 to depths of 869.2 and 857.0 mBGS, respectively within the Cambrian sandstone. Avis et al. (2009) describes the results of hydraulic testing of Phase 2A boreholes.

In combination, boreholes DGR-1 through DGR-4 triangulate the footprint of the proposed DGR and allow for re-construction of the 3-D geometry of the bedrock formations surrounding the DGR. Phase 2B, which is currently underway, includes the continuous coring and testing of two inclined boreholes DGR-5 and DGR-6, targeted to investigate possible sub-vertical structure mapped with 2-D seismic surveys.

Figure 4 shows the location of the 6 deep DGR-series boreholes, the proposed DGR footprint, and the locations of 8 US-series boreholes that provide geological and hydrogeological information for the permeable upper 200 m of Devonian and Upper Silurian dolostones at the Bruce site.

Figure 4. Location of DGR- and US-series boreholes and the proposed DGR footprint (orange) at the Bruce site.

3.2 Bedrock Stratigraphy

The drilling and testing of boreholes DGR-1 to DGR-4 has resulted in the identification of 34 distinct Paleozoic bedrock formations, members or units at the Bruce site. These bedrock formations, members or units are logged in accordance with the stratigraphic nomenclature of Armstrong and Carter (2006). Formation contacts in boreholes DGR-1 through DGR-4 were determined in two core workshops held in September 2007 and November 2008, that were attended by senior geologists from the Ontario Geological Survey, Ministry of Natural Resources and the Geological Survey of Canada, as well as DGR project staff.

Figure 5 illustrates the stratigraphic column at the Bruce site referenced to boreholes DGR-1 and DGR-2. In descending order the uppermost site stratigraphy includes: 20 m of Pleistocene overburden and fill, 104 m of Devonian Lucas, Amherstburg and Bois Blanc dolostone and 45.3 m of Upper Silurian Bass Islands dolostone. The remaining Upper Silurian bedrock of the Salina Formation is a 205.2 m thick sequence of brecciated dolostones and shales, argillaceous dolostones, carbonates, shales, anhydrites and evaporites that is mapped as 12 distinctive units or beds ranging from G to A0 Units. Healed and gypsum/ anhydrite infilled brecciation, which is extensive within the F Unit shale, E Unit dolostone and shale, D Unit anhydritic dolostone, C Unit shale and the upper part of the B Unit dolostone, is thought to be the result of formation collapse caused by ancient paleo-dissolution of the salt beds of Units D and B.

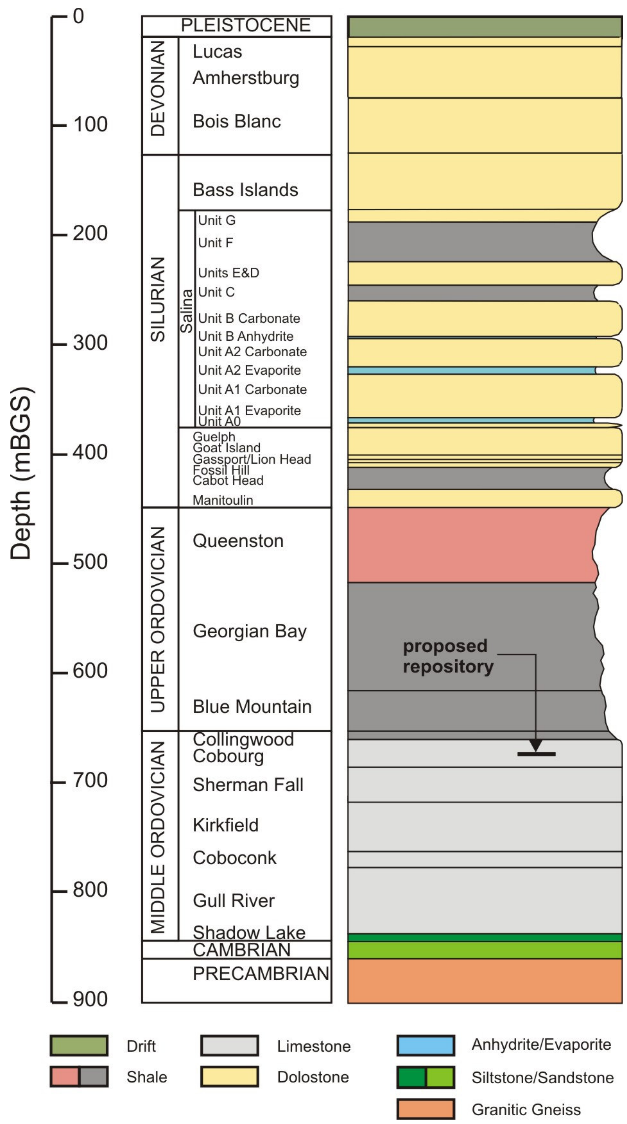

Figure 5. Bedrock stratigraphy at DGR-1 and DGR-2

The Middle Silurian bedrock at DGR-1includes 36.5 m of vuggy to argillaceous dolostones and dolomitic limestones of the Guelph, Goat Island, Gasport, Lions Head and Fossil Hill Formations. The Lower Silurian bedrock is comprised of 23.8 m of Cabot Head Formation non-calcareous shale and 12.9 of cherty dolostone and shale of the Manitoulin Formation.

The Upper Ordovician shales, which form the principal overlying barrier rocks to the DGR, are comprised of 70.4 m of Queenston Formation red shale, 90.9 m of Georgian Bay Formation grey shale and 42.7 m of Blue Mountain Formation dark grey shale at DGR-2. Within both the Queenston and Georgian Bay Formations, there are carbonate-rich hard beds of siltstone and limestone.

Immediately overlying the proposed repository horizon is 7.9 m thick sequence of black calcareous shale that is the Collingwood Member of the Middle Ordovician Cobourg Formation. The Lower Member of the Cobourg Formation is the proposed DGR host formation and is a 28.6 m thick bed of argillaceous limestone in DGR-2.

Underlying the Cobourg Formation in DGR-2 is a sequence of argillaceous, bioturbated and lithographic limestones comprising the Sherman Fall Formation (28.0 m), Kirkfield Formation (45.9 m), Coboconk Formation (23.0 m) and Gull River Formation (53.6 m). The 5.2 m thick Shadow Lake siltstone and sandstone and the 16.9 m thick Cambrian sandstone lie between the Gull River Formation and the Precambrian basement in DGR-2. The upper half of the Cambrian sequence is tight silty to sandy dolostone; the lower half is permeable quartzose sandstone.

3.3 Marker Beds

For many of the formations identified in DGR boreholes, the contacts are abrupt and easily discernable from inspection of core and review of borehole geophysical logs. For example, selection of the contacts for the Salina F Unit shale, the Guelph Formation vuggy dolostone, the Cabot Head Formation shale, the Cobourg Formation limestone and the Shadow Lake Formation siltstone and sandstone is unambiguous. However, for many of the other formations, the contacts are gradational and require some judgment.

To assist in assessment of formation orientation, several thin diagnostic maker beds have been identified in DGR core. Noteworthy marker beds identified to date include 10 to 20 cm thick tan dolostone beds in the top of Salina F Unit shale and the bottom of the Coboconk Formation limestone, and a 20 cm thick, high porosity, volcanic ash bed within the middle of the Coboconk Formation limestone.

Figure 6 shows the occurrence of the volcanic ash marker bed of the Coboconk Formation in core recovered from boreholes DGR-2, DGR-3 and DGR-4. The ash marker bed is evident in the bottom third of the DGR-1 core photograph, the middle of the DGR-2 core photograph and the very bottom of the DGR-4 core photograph. Arrows on core photographs of Figure 6 point to the bottom of the core run.

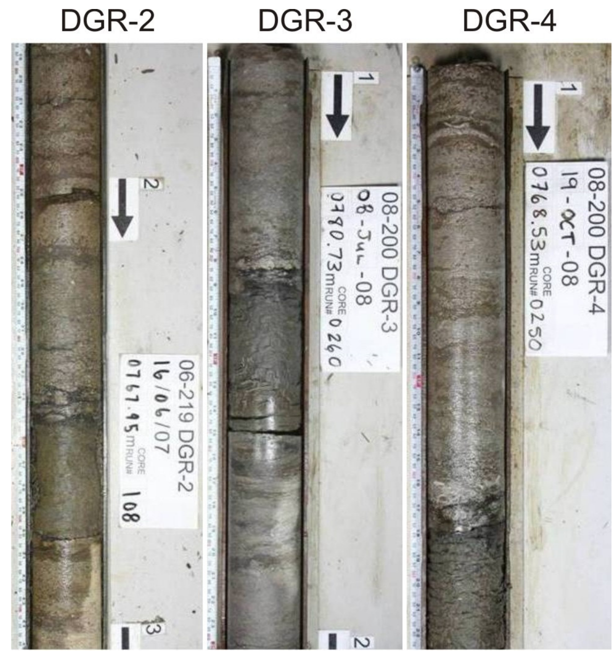

Figure 6. Volcanic ash marker bed within Coboconk Formation bioturbated limestone in DGR boreholes

3.4 Formation Thickness and Orientation

Intersection of bedrock formations by boreholes DGR-1, DGR-2, DGR-3 and DGR-4 allows assessment of the uniformity of bedrock formation thicknesses and the calculation of formation strike and dip in the area of the proposed DGR. Tables 1 and 2 summarize the formation thicknesses and calculated strike and dip of bedrock formations at the Bruce site.

Table 1. Summary of bedrock formation thicknesses (m) in DGR boreholes

Bedrock Formation	DGR-1/2	DGR-3	DGR-4
Amherstburg to Bass Islands	138.9	133.0	132.5
Salina G Unit to B Unit	121.9	117.3	122.4
Salina A2 Unit to A0 Unit	81.4	82.2	83.1
Guelph + Goat Island	22.9	23.7	23.5
Gasport to Fossil Hill	13.6	12.3	12.4
Cabot Head + Manitoulin	36.7	34.2	34.8
Queenston	70.4	74.4	73.0
Georgian Bay	90.9	88.7	88.7
Blue Mountain	42.7	44.2	45.1
Collingwood Member	7.9	8.7	8.4
Cobourg	28.6	27.8	27.5
Sherman Fall + Kirkfield	73.9	74.5	74.0
Coboconk + Gull River	76.6	75.4	76.0
Shadow Lake	5.2	4.5	5.1

Table 2. Orientation of bedrock formations and marker beds in DGR boreholes

Bedrock Formation/Marker Bed	Strike	Dip
Amherstburg	N16°W	1.15°SW
Bois Blanc	N27°W	0.95°SW
Salina F Unit Dolostone Marker Bed	N32°W	0.98°SW
Salina C Unit	N25°W	1.07°SW
Salina A0 Unit	N19°W	0.63°SW
Cabot Head	N19°W	0.53°SW
Queenston	N24°W	0.63°SW
Georgian Bay	N17°W	0.63°SW
Blue Mountain	N23°W	0.54°SW
Cobourg	N14°W	0.63°SW
Kirkfield	N16°W	0.65°SW
Coboconk Ash Marker Bed	N20°W	0.58°SW
Coboconk Dolostone Marker Bed	N16°W	0.56°SW
Shadow Lake	N19°W	0.59°SW

Table 1 shows the formation thicknesses and orientations in DGR boreholes are remarkably uniform over the DGR borehole separation distances of 1047 to 1318 m. The thickness and orientation of formations are somewhat more variable above the Salina B Unit and more uniform below the B Unit. This is most likely due to collapse and minor rotation of the overlying bedrock following paleo dissolution of the Salina B and D Unit salt beds. Below the Salina B Unit, formation thicknesses in DGR boreholes are within 1-2 m of each other in different holes, and the formation strikes are within 5-10° and formation dips are within 0.10° for each formation. The average strike and dip of the deeper Silurian and the Ordovician Formations of N20°W/0.6°SW at the Bruce site is consistent with results of the 3DGF model.

3.5 Core Quality and Natural Fracture Frequency

The Rock Quality Designation (RQD in %) and natural fracture frequency (m^{-1}) determined from continuous logging of 76 mm diameter core recovered from boreholes DGR-1 and DGR-2, DGR-3 and DGR-4 in 3.05 m length core runs are illustrated in Figures 7 and 8. Because of the larger diameter of core collected in DGR boreholes, RQD is defined as the modified core recovery for all core lengths greater than 15 cm (i.e., twice the core diameter) excluding drilling-induced breaks.

Figures 7 and 8 show that the Devonian and Upper Silurian dolostones are moderately to highly fractured with poor to fair RQD, whereas the deeper Silurian formations below the Salina G Unit and the Ordovician shales and argillaceous limestones are very sparsely fractured to unfractured with excellent RQD. Many of the low core recoveries and RQDs recorded for the Bois Blanc and Bass Islands Formations were attributed to difficult drilling conditions created in part by alternating hard and soft beds within these formations. Occasional joints/natural fractures were also identified within the deeper Silurian and Ordovician formations from core and borehole geophysical logging. These core quality and fracture frequency characteristics are very similar in all DGR boreholes.

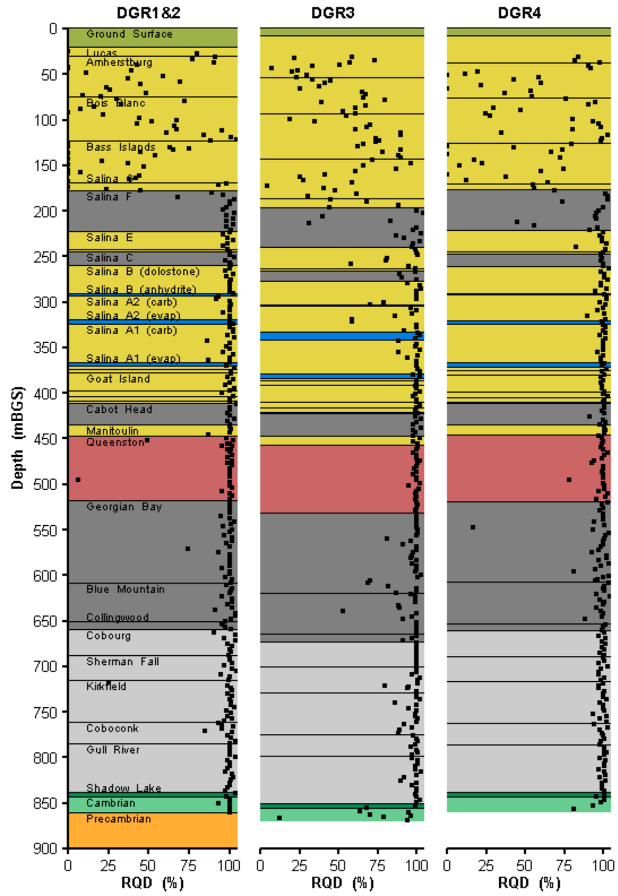

Figure 7. Rock Quality Designation in DGR boreholes.

3.6 Formation Predictability and Cross Section

Prior to the start of DGR drilling, the depth and thickness of bedrock formations at the Bruce site were estimated (Golder Associates Ltd., 2003) based on the results of chip and geophysical logging of the Texaco #6 oil and gas well and identification of the top of the Bois Blanc Formation in US-4. The comparison of estimated and actual formation depths and thicknesses in DGR-1 and DGR-2 are summarized in Table 3. The estimated formation depths for DGR-1 and DGR-2 are corrected for the dip of the Bois Blanc Formation (Table 2).

Table 3 shows that the predictions of formation thickness in DGR-1 and DGR-2 from the Texaco #6 well located 2900 m away were generally quite good (within 10 m) considering the gradational nature of many formation contacts, the changes in stratigraphic nomenclature since drilling of Texaco #6 in 1969, and the lack of coring in that well to allow for more reliable formation identification. Table 3 also shows that most of the formation depths were under-predicted by about 30 m. This common under-prediction is likely due to an erroneous identification of the top of the Bois Blanc Formation (~20 m offset) in US-4 and underestimation of the thickness of this formation at the Bruce site by about

10 m. Correcting for this combined 30 m offset, brings actual formation depths in DGR-1 and DGR-2 remarkably close to predictions based on Texaco #6 stratigraphy.

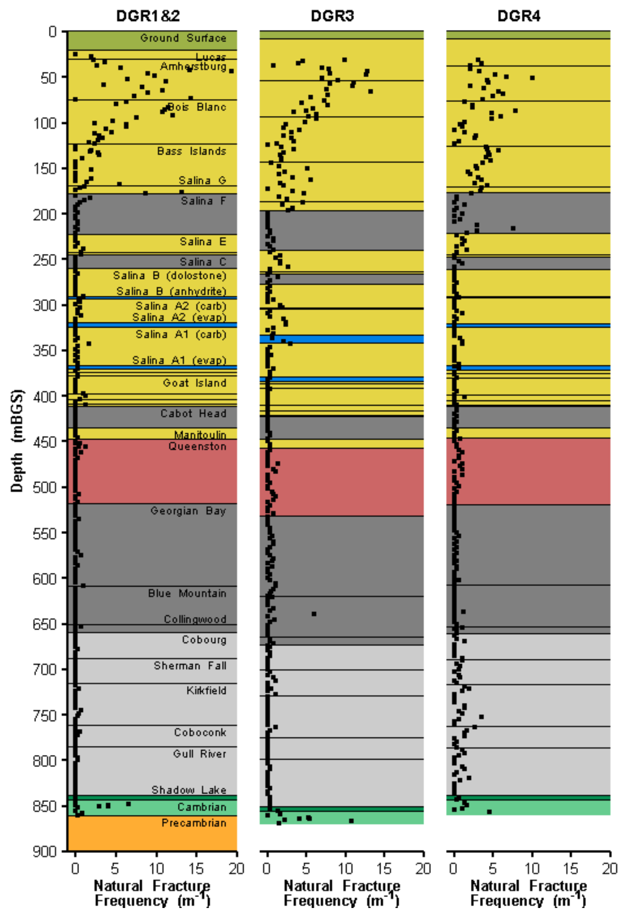

Figure 8. Natural fracture frequency in DGR boreholes

Table 3. Summary of estimated and actual bedrock formation occurrences in DGR-1 and DGR-2

Bedrock Formation	Actual-Estimated Top Depth (m)	Actual-Estimated Thickness (m)
Amherstburg	+22.6	-1.6
Bois Blanc	+21.0	+10.8
Salina G+F Units	+34.8	+7.4
Salina C+B Units	+31.2	-1.3
Salina A1+A0 Units	+30.0	+5.5
Guelph-Fossil Hill	+35.5	-5.6
Cabot Head + Manitoulin	+29.9	+1.1
Queenston	+31.0	-8.9
Georgian Bay	+22.0	-4.2
Blue Mountain	+17.8	+10.1
Cobourg	+27.9	-12.0
Sherman Fall - Coboconk	+28.7	-11.0
Gull River	+17.7	+9.7
Shadow Lake	+27.4	+0.4

Figure 9 shows the interpreted stratigraphic cross section constructed between Texaco #6 and DGR-1, DGR-2 and DGR-3 on the Bruce site. Figure 9 shows apparent dips of about 0.8 to 1.0° for the Devonian dolostones and about 0.4° for the Ordovician shales and limestones on the Bruce site. Lower apparent dips are evident from Texaco #6 to the Bruce site because that part of the cross section is oriented closer to the strike direction than the dip direction. Figure 9 illustrates the continuity and predictability of the Paleozoic formation depths, thicknesses and orientations over distances of 3 to 4 km in the vicinity of the proposed Bruce DRG.

The lack of apparent offsets in formation depths between boreholes DGR-1 to DGR-4 and with the off-site Texaco #6 well infers limited evidence for the presence of vertical faults within the Paleozoic bedrock near the Bruce DGR site. This inference will be tested in 2009 with inclined drilling of boreholes DGR-5 and DGR-6 purposefully oriented to intersect and verify interpreted vertical structure identified from 2-D seismic reflection surveys.

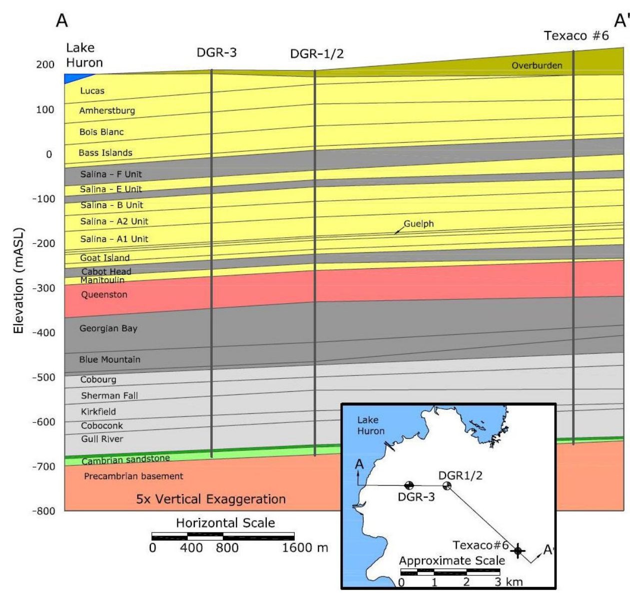

Figure 9. Stratigraphic cross section - Texaco #6 to Bruce site with 5X vertical exaggeration

4 CONCLUSIONS

The results of work described in this paper support the conclusions that the Paleozoic bedrock formations below the Bruce site have predictable depth, thickness, orientation, RQD and natural fracture frequency over distances of at least a few kilometres. Furthermore, the uniformity of formation depths, thicknesses and orientations infers limited evidence for the presence of vertical offsetting faults in the vicinity of the proposed DGR, particularly within the Ordovician shales and limestones that will host and overly/underlie the DGR.

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