OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Three-Dimensional Geological Framework Model

March 2011

Prepared by: Itasca Consulting Canada, Inc. and
AECOM Canada Ltd.

NWMO DGR-TR-2011-42

OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Three-Dimensional Geological Framework Model

March 2011

Prepared by: Itasca Consulting Canada, Inc., and
AECOM Canada Ltd.

NWMO DGR-TR-2011-42

THIS PAGE HAS BEEN LEFT BLANK INTENTIONALLY

Document History

Title:	Three-Dimensional Geological Framework Model		
Report Number:	NWMO DGR-TR-2011-42		
Revision:	R000	**Date:**	March 2011
Itasca Consulting Canada, Inc. and AECOM Canada Ltd.			
Prepared by:	L. Cotesta (Itasca Consulting Canada, Inc.), R. Frizzell (AECOM Canada Ltd.)		
Reviewed by:	R. Brummer (Itasca Consulting Canada, Inc.)		
Approved by:	R.E.J. Leech (AECOM Canada Ltd.)		
Nuclear Waste Management Organization			
Reviewed by:	R. Crowe, A. Parmenter		
Accepted by:	M. Jensen		

THIS PAGE HAS BEEN LEFT BLANK INTENTIONALLY

EXECUTIVE SUMMARY

Ontario Power Generation (OPG) is proposing the development of a Deep Geologic Repository (DGR) for the long-term management of Low and Intermediate Level Waste (L&ILW) generated at OPG-owned or operated nuclear facillties. The proposed DGR is situated at the Bruce nuclear site located in the Municipality of Kincardine, Ontario. As envisioned, the shaft accessed DGR would be excavated into the Paleozoic age sedimentary sequence underlying the Bruce nuclear site to a depth of 680 m within the argillaeous limestone Cobourg Formation. The purpose of this report is to document the development of a regional scale (35,000 km^2) three-dimensional Geological Framework (3DGF) for the Bruce nuclear site and surrounding region. This model provides a reasoned basis to understand the stratigraphic and spatial continuity of sedimentary bedrock formations in which the DGR would be constructed.

The Regional Study Area (RSA) for the 3DGF extends from Collingwood, Ontario in the east to the midpoint of Lake Huron in the west, south to Goderich, Ontario, and north to the tip of the Bruce Peninsula. The framework model was designed using Gocad™, an earth modelling and scientific visualization technology capable of displaying 3-dimensional configurations of individual stratigraphic layers, as well as, partial or entire stratigraphic sequences. The 3DGF model generated is based on well logging observations and formation picks documented in Ontario Ministry of Natural Resources well records. The primary data source was the Oil, Gas, and Salt Resources Library (OGSR) Petroleum Wells Subsurface Database. This data set includes geological formation tops, logging records, and oil/gas/water intervals for tens of thousands of petroleum wells throughout Ontario. The RSA contained at total of 341 wells from which a data screening process verified 299 for inclusion in the 3DGF.

Development of the 3DGF with Gocad™ allowed for manual interpretation for representation of geologic structures (i.e. pinnacle reefs; erosional features). Further, the process included comparison of 3DGF generated models against published geologic cross-section to ensure that known stratigraphic relationships and structure were correctly honoured. The manual inclusion of geologic interpretation of stratigraphic relationships and knowledge of basin evolution and structure was required to assure that the model remained consistent with contemporary understanding.

Two independent model validation tests, at both regional and local scales, are presented. Test results were acceptable at both scales; particularly since the model was purpose-built for the regional scale. These results provide confidence in supporting the principle that the stratigraphy is continuous and predictable across the RSA.

Structural contour maps for the top of each geological unit were generated from the model along with oblique cut-away sections to illustrate spatial variability of formation elevations and thicknesses, and potential structural features. This report contains appendices that include a digital data release of the revised petroleum well database, and all modelled stratigraphic surface outputs. This report is a companion report to the Regional Geology of Southern Ontario (AECOM 2011).

THIS PAGE HAS BEEN LEFT BLANK INTENTIONALLY

TABLE OF CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

1. INTRODUCTION

The primary purpose of the 3D Geological Framework (3DGF) was to define the stratigraphic and spatial continuity of Paleozoic bedrock formations at the regional scale. This project was conducted for Ontario Power Generation's proposed Deep Geologic Repository (DGR) for the long-term management of Low and Intermediate Level Waste (L&ILW). The 3DGF was mainly constructed using Paradigm's Gocad™ software platform, an advanced 3D earth modelling and scientific visualization technology. GoCad™ is capable of displaying three-dimensional configurations of individual stratigraphic layers, as well as, partial or entire stratigraphic sequences. This report provides a description of the 3DGF model development process, including tools, data sources, data verification procedures, workflow, and results.

The 3DGF Regional Study Area (RSA) encompasses approximately 35,000 km^2 centred on the DGR site (Figure 1.1, Figure 1.2).

The 3DGF is intended to provide both context for the site-specific Bruce nuclear site investigations and to provide a rationale for extrapolation of site conditions (stratigraphic continuity) beyond the DGR site. Results derived from this work are included and discussed in Regional Geology, Southern Ontario (AECOM 2011), and in the OPG DGR Geosynthesis Report (NWMO, 2011).

Contour maps of geological unit tops and oblique cut-away sections through the three dimensional surfaces are provided in Appendix A and B, respectively. The geological well picks, both original and revised, along with a listing of the wells that have been excluded from the original 341 wells may be found in Appendix C of this report

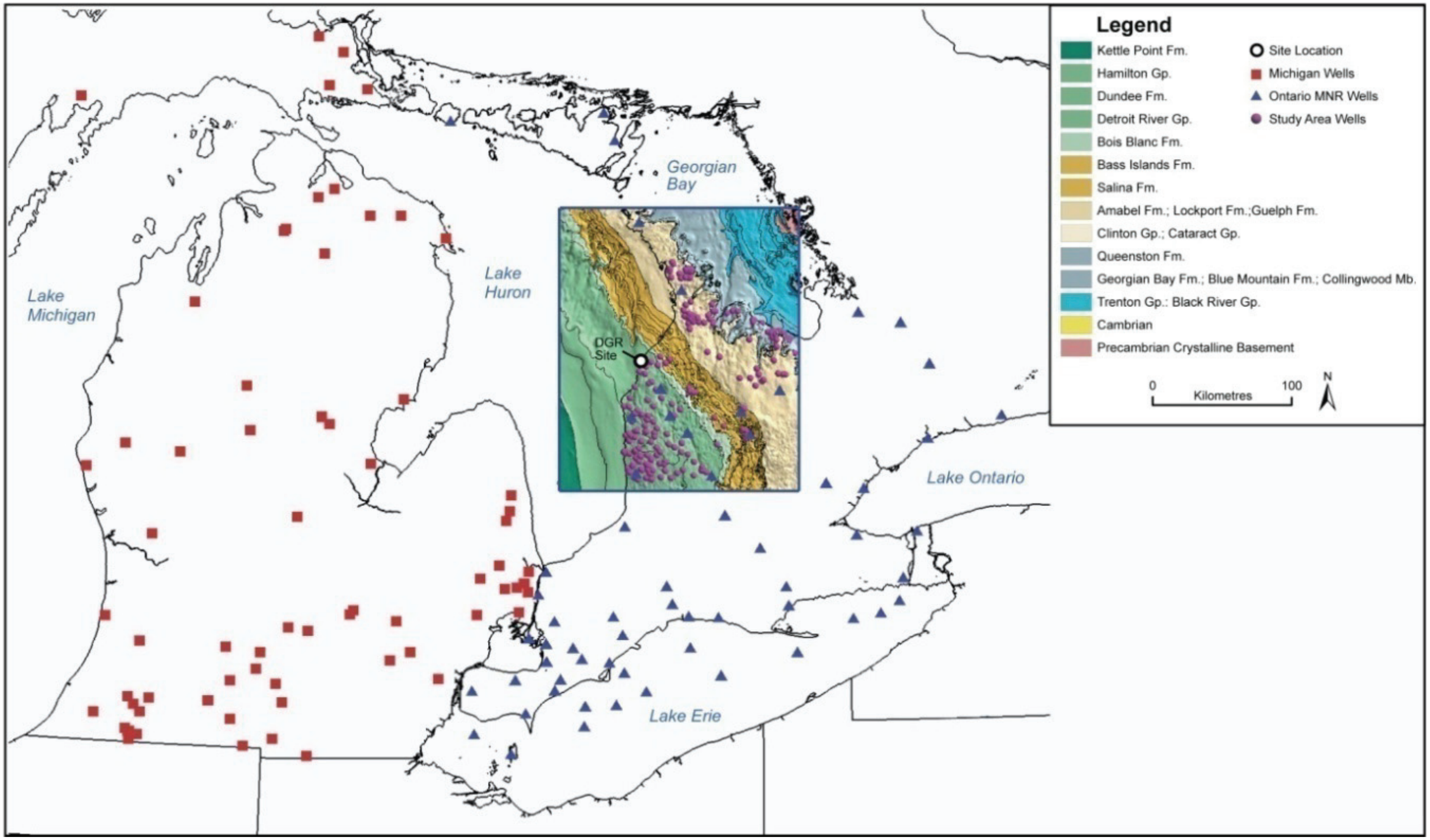


Figure 1.1: 3D Geological Framework Study Boundary with Paleozoic Geology and Well Locations

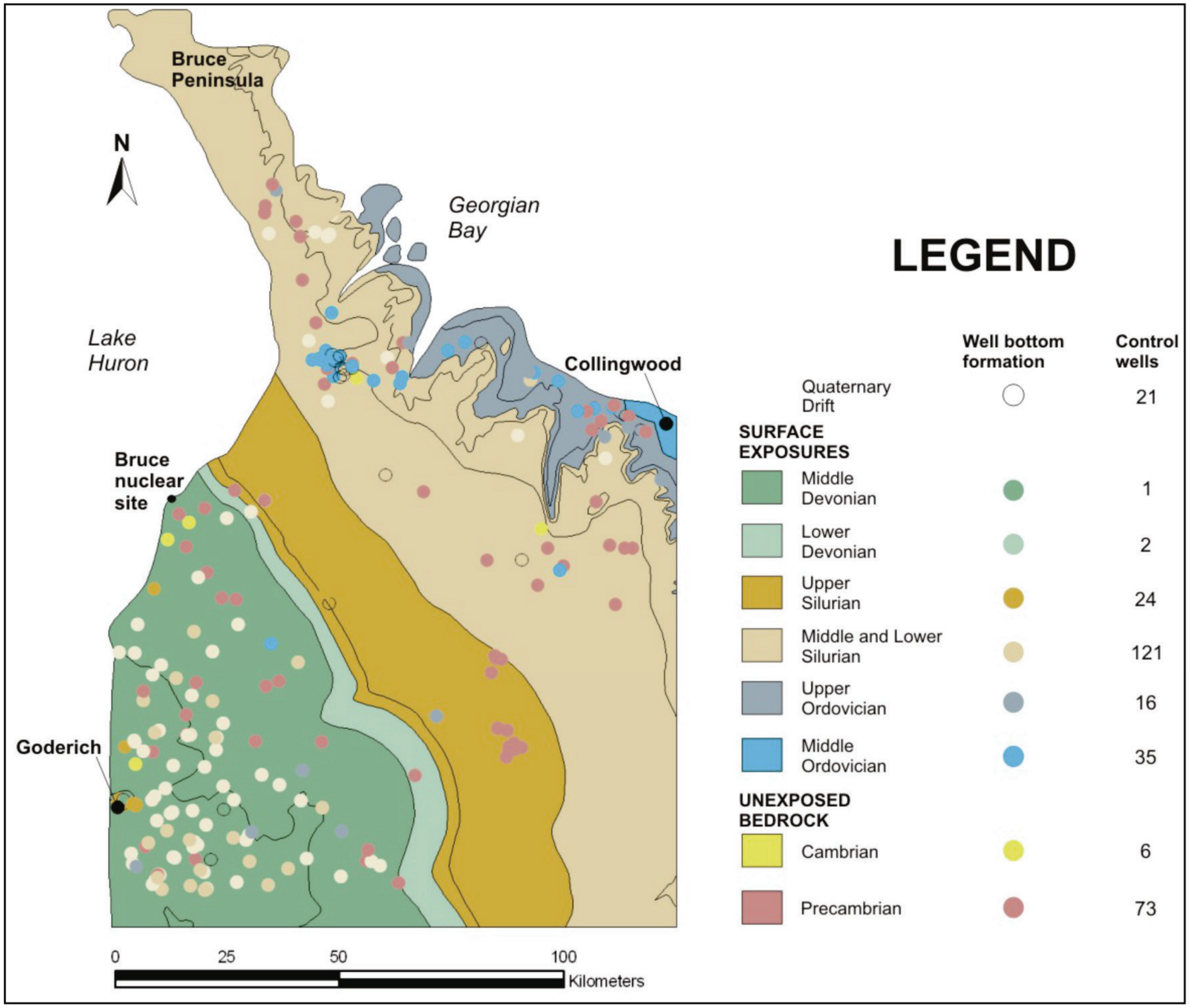


Figure 1.2: RSA Geology and Well-control (by Well Bottom Formation) for All Data Points in 3DGF Model

.

2. METHODOLOGY

The stratigraphic model generated for the RSA was based on observations and re-interpretation of Ministry of Natural Resources well records. The primary data source for the 3DGF construction was the Oil, Gas, and Salt Resources Library (OGSR) Petroleum Wells Subsurface Database, which represents all well data collected in Ontario from 1930 to the present. This data set includes 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 northern shore of Lake Erie extending towards Sarnia/Lambton County. At the time of model development, the RSA contained at total of 341 wells, from which 299 wells were determined useful through a data verification process. Site stratigraphy obtained from an early set of logs for DGR-1 and DGR-2 boreholes was also used to construct the 3DGF (Sterling 2010).

Other key sources of data used to construct the 3DGF included:

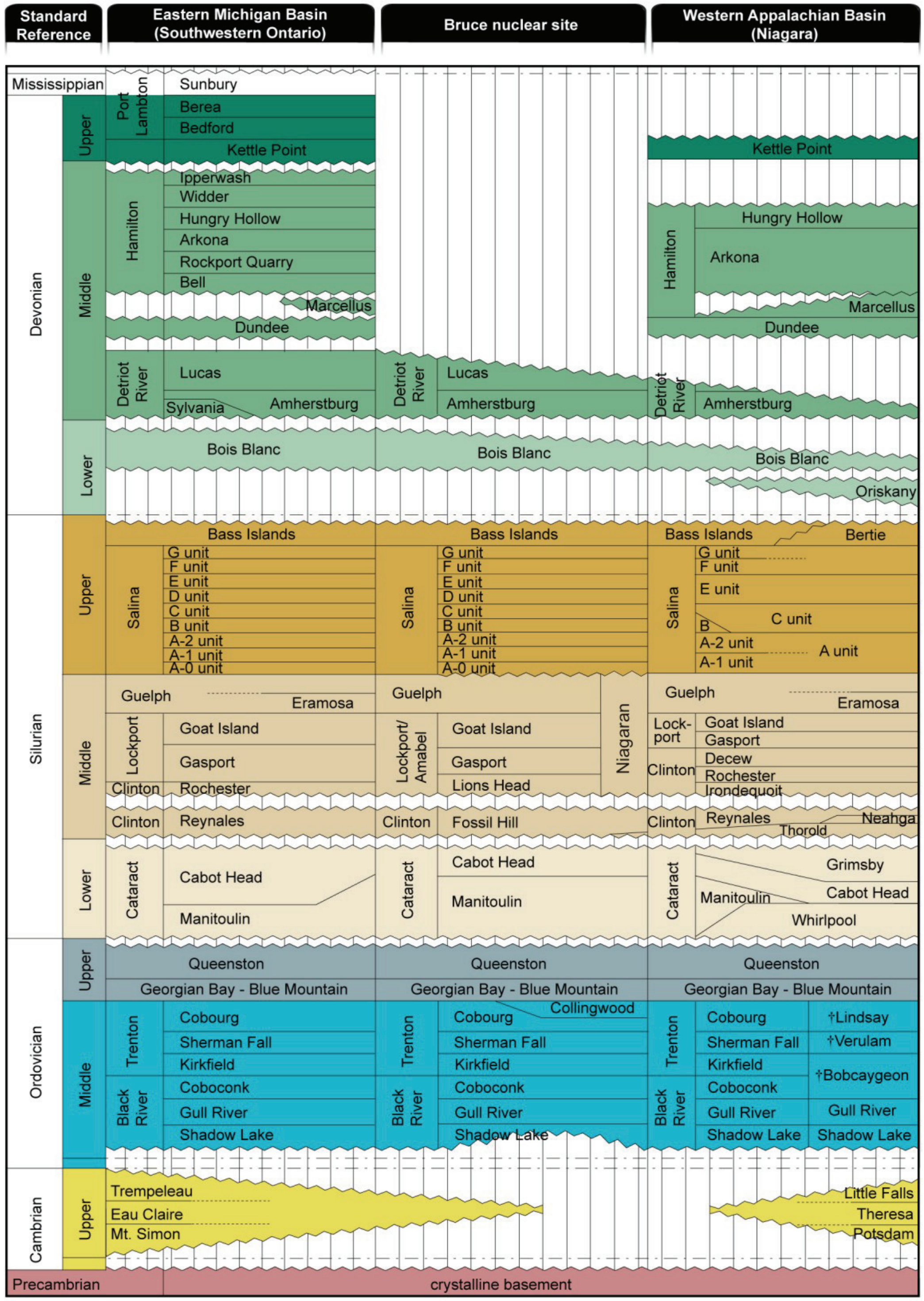
a) 1:50,000 OGS Digital Bedrock Geology of Ontario Seamless Coverage ERLIS Data Set 6;
b) Downhole geophysics (used to verify well contacts/picks), acquired from the OGSR for select wells within the RSA;
c) Ontario Geological Survey (OGS) Open File Report 6191, “An updated guide to the Paleozoic stratigraphy of southern Ontario” (Armstrong and Carter 2006).
d) Michigan Department of Natural Resources and Environment, Petroleum Well Database;
e) OGS Digital Bedrock topography and overburden thickness mapping, Southern Ontario – Miscellaneous Data Release no. 207 (Gao et al. 2006); and
f) National Oceanic and Atmospheric Administration (NOAA) digital bathymetry mapping of Lake Huron and Georgian Bay (Great Lakes Bathymetry Griding Project 2007).

The bathymetry mapping was used to correlate errosional scarp faces in Lake Huron with the stratigraphic data extrapolated from subsurface well data and bedrock maps. An assumption made during this process was that there are limited recent sediments draped over the bedrock surface beneath the lake. Assuming limited or no sediment cover within the lake also produced a discrepancy in elevation data in some locations between the bedrock surface digital elevation model and the lakebed bathymetry. The surfaces were stitched together using a qualitative best-fit interpretation.

Since no well data exist beneath Lake Huron, geological maps and selected petroleum well data from the State of Michigan (Figure 1.1) were used to provide guidance in extrapolation beneath Lake Huron. The remaining data sources include published literature, government reports (i.e., MNR and OGS), and consulting reports.

The stratigraphic nomenclature used for this project is derived from Armstrong and Carter (2006) (Figure 2.1).

Development of the 3DGF stratigraphic model allows manual interpretation to recognize possible geologic structures and enables an assessment of formation spatial variability and uncertainty. Manual changes to the model are sometimes required; these are documented within Appendix C.



*modified from Armstrong and Carter (2006) after Winder and Sanford (1972)
†outcrop nomenclature for Southern and Eastern Ontario

Note. Compiled from locations in the Michigan Basin, Algonquin Arch (DGR Site) and Appalachian Basin (modified from Armstrong and Carter 2006).

Figure 2.1: Paleozoic Stratigraphic Nomenclature of Southwestern Ontario

Such examples may include the following.

- Separation of bedrock formations that were grouped together in the database (e.g., Trenton Formation).
- Errors on inspection of the database in which formation contacts and/or elevations were incorrectly reported. Identification of such errors was typically made possible by adjacent borehole data and/or well established regional stratigraphic relationships.
- Corrections applied for known geologic features such as pinnacle or barrier reef geometry.
- The location of erosional features and stratigraphic pinch-outs, particularly in association with the Cambrian sediments in the RSA.

Where formation contacts were not reliably or consistently identified, the formations were grouped together within the 3DGF. The groupings observed are as follows: 1) the Salina B Unit and the C Unit were combined; 2) the A0 Unit was not identified in the regional database; 3) the Guelph, Amabel/Lockport (Goat Island, Gasport and Lions Head) formations were combined as the Niagaran (Middle Silurian on Figure 2.1); and 4) the Georgian Bay, Blue Mountain and Collingwood formations were combined. The revised classification is presented in Table 2.1 below.

Table 2.1: Standard Geological Fields from the OGSR Database and the Revised Geological Framework Classification

OGSR Nomenclature	Revised Classification	Notes
Drift	Drift	No change
Antrim	Antrim	Equivalent to Kettle Point Formation
Traverse Group	Traverse Group	Equivalent to Hamilton Group
Dundee	Dundee	No change
Columbus	Detroit River Gp	Lateral equivalent (Armstrong and Carter 2006)
Lucas	Detroit River Gp	The contact between these units cannot be consistently picked on a regional basis (Carter and Armstrong 2006)
Amherstburg	Detroit River Gp	The contact between these units cannot be consistently picked on a regional basis (Armstrong and Carter 2006)
Bois Blanc	Bois Blanc	No change
Bass Islands/Bertie	Bass Islands	Bertie Formation (Fm.) is the Appalachian Basin lateral equivalent of Bass Islands (Map 2582, Johnson et al. 1992)
G Unit	G Unit	No change
F Unit	F Unit	No change
F Salt	F Salt	No change
E Unit	E Unit	No change

OGSR Nomenclature	Revised Classification	Notes
D Unit	D Unit	No change
C Unit	B and C units	These units are largely dolomitic shales, shaley dolomite (Armstrong and Carter 2006)
B Equivalent	B and C units	
B Unit	B and C units	
B Salt	B Anhydrite/Salt	Represents a common sequence of anhydrite overlain by salt. The lateral distribution of this Salina sequence is restricted to the southwest portion of the study area.
B Anhydrite	B Anhydrite/Salt	Represents a common sequence of anhydrite overlain by salt. The lateral distribution of this Salina sequence is restricted to the southwest portion of the study area.
A-2 Carbonate	A-2 Carbonate	No change
A-2 Shale	A-2 Carbonate	Only recognized as a distinct unit in 2 holes. These shales are commonly found at the base of the A-2 carbonate unit.
A-2 Anhydrite	A-2 Anhydrite/Salt	Represents a common sequence of anhydrite overlain by salt. The lateral distribution of this Salina sequence is restricted to the southwest portion of the study area.
A-2 Salt	A-2 Anhydrite/Salt	Represents a common sequence of anhydrite overlain by salt. The lateral distribution of this Salina sequence is restricted to the southwest portion of the study area.
A-1 Carbonate	A-1 Carbonate	No change
A-1 Evaporite	A-1 Evaporite	No change
Guelph	Niagaran	Niagaran contacts were not consistently picked in the well logs. This may be partly owing to the distinct differences displayed in Niagaran reef and inter-reef wells.
Eramosa	Niagaran	
Goat Island	Niagaran	
Gasport	Niagaran	
Irondequoit	Niagaran	
Lions Head	Niagaran	
Wiarton/Colpoy Bay (Amabel)	Niagaran	
Rochester	Niagaran	

OGSR Nomenclature	Revised Classification	Notes
Reynales/Fossil Hill	Reynales/Fossil Hill	No change
Thorold	Reynales/Fossil Hill	Lateral equivalent to Fossil Hill in the Michigan Basin (Map 2582, Johnson et al. 1992)
Cabot Head	Cabot Head	No change
Dyer Bay	Cabot Head	Lateral equivalent south of Manitoulin Island (Map 2582, Johnson et al. 1992)
Grimsby	Cabot Head	Lateral equivalent in Michigan Basin (Map 2582, Johnson et al. 1992)
Wingfield	Cabot Head	Lateral equivalent south of Manitoulin Island (Map 2582, Johnson et al. 1992)
Manitoulin	Manitoulin	No change
Whirlpool	Manitoulin	Lateral equivalent in Michigan Basin (Map 2582, Johnson et al. 1992)
Queenston	Queenston	No change
Georgian Bay/Blue Mtn	Georgian Bay/Blue Mtn	No change
Collingwood	Georgian Bay/Blue Mtn	Although considered a member of the Cobourg Fm., this shale was more likely to have been logged as a member of Blue Mtn Fm.
Cobourg	Cobourg	No change
Sherman Fall	Sherman Fall	No change
Kirkfield	Kirkfield	No change
Coboconk	Coboconk	No change
Gull River	Gull River	No change
Shadow Lake	Shadow Lake	No change
Cambrian	Cambrian	No change
Mount Simon/Potsdam	Cambrian	Mount Simon and Potsdam are lateral equivalents from the Michigan Basin and Appalachian Basin respectively (Map 2582, Johnson et al. 1992)
Precambrian	Precambrian	No change

The addition of contacts was completed primarily for the Ordovician Trenton and Black River Groups. Well logs consistently used the “Group” name rather than the individual formation names. Some wells used the formation name to describe the whole group. Seven wells had minor unit additions other than Trenton and Black River changes. In all cases, these edits were informed and guided with logging data from nearby reference well(s). Twenty-seven wells were edited to include units not identified in the OGSR logs within the Trenton/Black River Groups. These database edits were conducted using two different methods. The first and primary method used was interpolation to predict the elevation of missing layers. This was done by generating a surface based on surrounding well data and extending this surface through the well with the missing contact to generate an elevation. The second method used mean unit thickness from surrounding wells, with preference always given to reference wells (Armstrong and Carter 2006).

It should be noted that the 3DGF developed as part of this work program is derived from data acquired from third party sources. As a result, there is some reliance on QA/QC procedures employed by the organizations that have compiled the primary data.

The geological modelling software is capable of honouring all of the subsurface geological contacts that were deemed to be reliable as determined though the verification procedure. Prior to importing well picks into the model, wells were screened to remove those that contained no data, or contained obvious errors such as units not in stratigraphic sequence. Further verification checks were conducted within the model to help identify geological or stratigraphic anomalies within the geological framework. These verifications included:

a) If an anomalous well pick was indentified in the model, geophysical logs from the well were compared with standard geophysics recorded in the OGS reference wells (Armstrong and Carter, 2006);
b) Verifying that the stratigraphic relationships, as recorded in the data, are correct;
c) Verifying if offsets in adjacent formation elevations provided evidence of geological structure such as faulting or reefs;
d) Comparing whether the logged geological units coincide with outcrop mapping; and
e) Verifying that the geological model layers reflect the current scientific understanding of the subsurface stratigraphy as presented in published literature.

Further to these tests, a simple test, which compared well collar elevation to the Digital Elevation model, was also conducted. This test was used to verify whether geological contacts consistently offset from neighbouring wells were related to errors in the recording of well collar elevations. A comparison with the DEM model could be used when the difference between the two elevation data points was greater than the standard measurement error of the DEM, typically ±5 to 10 m.

The final test revised or added well picks and deleted wells from the OGSR database along with the final 3D stratigraphic surfaces are provided in Appendix C (digital CD copy). A description of the geology and discussion of 3DGF model results is provided in AECOM 2011 and NWMO 2011.

Surface contour maps and oblique cut-away geological sections (Appendix A and B) were generated from the 3DGF to illustrate spatial variability of formation elevations and thicknesses. Structural interpretations, however, are not included in the mapping. The limited well control and distance between well points does not allow a well constrained interpretation of structure within the 3DGF. A discussion of structural geology in the Regional Study Area is provided NWMO 2011.

2.1 Stratigraphic Modelling Workflow

One of the key elements in the development of the 3DGF was to devise a workflow to ensure a consistent approach to modelling each of the "formation top" surfaces (Appendix C). While workflows are excellent tools to help implement consistency, it should be noted that there are instances when manual intervention is required during construction of the model. The aim of this section is to provide a brief overview of the stratigraphic modelling workflow that was devised for this study.

The first step in the workflow requires that source data is verified by geologist and modeller as described in the previous section. Once stratigraphic data is validated, the construction of each individual "formation top" begins, starting from the bottom (Precambrian) and building each subsequent surface, unit by unit all the way to the top of the stratigraphic column. The main goal is to create geologically valid wireframe surfaces to represent each of the formation tops in the 3DGF. This constitutes what is referred to as a topographical modelling approach, i.e., the units themselves are made up of the material between subsequent formation tops.

To better explain the process as it relates to the 3DGF, the Queenston unit will be singled out to provide an illustrative example. To create a representative surface for the top of the Queenston unit, a wireframe is first created by connecting all of the Queenston top markers from the validated wells within the well database. Once created, hard constraints are imposed on the wireframe (through the software) to ensure that well picks are always honoured. More precisely, the constraint is one that restricts any movement from occurring at the nodes on the wireframe that are co-located with the well marker locations in question. This is done to ensure that the wireframe will always honour the validated well picks regardless of any subsequent geometrical operations, i.e. interpolation and mesh improvement that may occur on that surface as part of the modelling process.

The thickness of the unit in question is defined by the difference in elevation between the tops of two subsequent units (as defined in Figure 2.1), in this case the Georgian Bay/Blue Mountain well picks and the tops of the Queenston unit picks. Hence, when two subsequent formation tops exist, discrete formation thicknesses at each of the well locations are computed. These formation thickness values are then contoured on the previously modelled formation top (Georgian Bay/Blue Mountain in this case) and in essence a "thickness map" is created. The thickness maps allow for a comparison to see where and how changes in thickness occur (if any) between wells where no data exists. The thickness map is then used to constrain the upper surface (Queenston). In simple terms, the surface in question may be either "pushed up" or "pulled down" at any given location between boreholes in an attempt to honour the thickness map created for the unit in question while retaining the hard constraints imposed on the surface (at the known well marker locations).

In some cases where the artificial crossing of surfaces may occur e.g., very thin units. An interpretation was carried out by a geologist and the surfaces were manually corrected. Further manual intervention by a geologist was undertaken where required, e.g., to reflect published realizations of sedimentary structure (pinnacle reefs, patch reefs and pinch-outs).

This procedure is repeated for each unit until a complete three-dimensional model is reconstructed. The end result is a set of assembled stratigraphic formation tops that honour the validated OGSR database well picks within the RSA, and capture, within reason considering the scale of the model, a number sedimentary structures contained within the literature.

2.2 Model Validation Tests

Validation of the modelled stratigraphic layers was completed by two separate tests. The goal of these tests was to determine how well the 3DGF represents the stratigraphy in locations without borehole data. The first method used a statistical analysis as described in AECOM 2011. For this test, 67% of wells intersecting the Ordovician Sherman Fall Formation were isolated and used to generate a surface through the other the 33% which were removed from the dataset. When the actual and predicted data for these 33% of wells was compared, the trend line was nearly 1 to 1 with an R^2 value of 0.99. This analysis was a useful tool to illustrate the predictability of the Ordovician units, particularly at the regional scale. A more complete discussion of the predictability and traceability of stratigraphic units at the regional scale are provided in NWMO (2011).

The second test consisted of using the 3DGF in a blind test to predict at what depth to expect the various formation tops to occur in DGR-4 (Sterling 2010) prior to drilling. This was possible because the 3DGF was built using only DGR-2 well picks. In this test, a fictional well was placed into the 3DGF at the known location for DGR-4. The depths at which the 3DGF formation picks intersected the fictional well were recorded and a comparison between predicted and actual formation tops was undertaken once logging for DGR-4 was complete. The differences between the actual and predicted depths (absolute) were computed and the results are presented in Table 2.2 below.

Table 2.2: Results from Blind Test Using the 3DGF to Predict Formation Depths in DGR-4

Formation	3DGF - Depth of Formation (mBGS)	DGR-4 - Depth of Formation (mBGS)	Absolute Error - 3DGF vs DGR-4 (m)
Detroit River Gp	1.1	7.5	6.5
Bois Blanc Fm	86.0	76.2	9.8
Bass Islands Fm	124.1	126.0	1.9
Salina G Unit	171.7	170.1	1.6
Salina F Unit	180.3	177.4	2.9
Salina E Unit	220.4	221.0	0.6
Salina D Unit	244.4	245.5	1.0
Salina B and C Units	246.5	247.3	0.8
Salina B Anhydrite Salt	285.2	290.8	5.6
Salina A2 Carbonate	293.4	292.5	0.9
Salina A2 Anhydrite Salt	319.4	320.9	1.5
Salina A1 Carbonate	326.8	325.1	1.7
Salina A1 Evaporite	364.6	366.8	2.2
Niagaran	369.0	375.6	6.6

Formation	3DGF - Depth of Formation (mBGS)	DGR-4 - Depth of Formation (mBGS)	Absolute Error - 3DGF vs DGR-4 (m)
Reynales Fossil Hill Fm	409.7	410.0	0.3
Cabot Head Fm	414.4	411.5	2.9
Manitoulin Fm	434.9	435.7	0.8
Queenston Fm	451.1	446.3	4.8
Georgian Bay/Blue Mtn Fm	521.9	519.3	2.6
Cobourg Fm	656.5	653.1	3.4
Sherman Fall Fm	689.0	689.0	0.0
Kirkfield Fm	733.3	717.3	16.0
Coboconk Fm	764.1	763.0	1.1
Gull River Fm	781.3	786.8	5.5
Shadow Lake Fm	838.4	839.0	0.6
Cambrian	845.9	844.1	1.8

The results in Table 2.2 illustrate that predicted stratigraphic contacts and total thickness of the sedimentary sequence are within meters. In several instances difference in predicted and actual formation contacts are relatively large, notably the Kirkfield formation. While formation contacts above and below the Kirkfield are predicted within a metre or less, the variance for the Kirkfield formation occurred as a result of a change in the logged formation contact. This was associated with core logging workshops that were attended by the Ontario Ministry of Natural Resources, the Ontario Geological Survey, the Geological Survey of Canada and the University of Waterloo. Results for the core logging are discussed in detail in Sterling (2010) and NWMO (2011). These latter reports also provide a detailed summary of the lateral continuity and orientation of the sedimentary bedrock formations beneath the Bruce nuclear site.

3. SUMMARY

The Three-Dimensional Geological Framework (3DGF) model presents an interpretation of the stratigraphy found within a Regional Study Area, with boundaries defined by Collingwood, Ontario in the east to the midpoint of Lake Huron in the west, south to Goderich, Ontario, and north to the tip of the Bruce Peninsula, encompassing an area covering approximately 35,000 km^2. The construction of the 3DGF was facilitated using Gocad^{TM}, an advanced 3D earth modelling and scientific visualization technology. The primary data source for model construction was the Oil, Gas, and Salt resources Library (OGSR) Petroleum Wells Subsurface Database.

Data screening using the historic OGSR dataset was used to reveal inconsistencies in the model, which was subsequently adjusted to compensate. The well data was augmented with topographic, geologic and bathymetric maps, as well as, petroleum well data from the state of Michigan. The approach used to develop the stratigraphic surfaces accommodated both numerical and manual interpretation able to reproduce geological structures that are consistent with geological understanding as presented in the published literature (Armstrong and Carter 2006, 2010).

Confidence in the model was increased with a series of checks that included: well collar elevation data, stratigraphic correlation and consistency with the published understanding of regional geology. Model validation in the form of predictability tests were performed at both the regional and local scales. Tests results were acceptable at both scales; particularly given the model was purpose-built for the regional scale.

Additional credence is given to the methodology given that the model produced acceptable results at the local scale. These results provide confidence in supporting the principle that the stratigraphy is continuous and predictable across the Regional Study Area.

Published data from this report is in the form of surface contour maps of formation tops for each geological unit (presented in Appendix A) and oblique cut-away sections of the three dimensional formation top surfaces (Appendix B). Appendix C of this report contains digital data as a data CD with; 1) the original OGSR wells used (unchanged); 2) revised wells database containing the well picks used to generate the stratigraphic surfaces; 3) a table showing the deleted wells with justification; and 4) revised formation picks associated with core logging workshops attended by the Ontario Ministry of Natural Resources, the Ontario Geological Survey, the Geological Survey of Canada and the University of Waterloo.

4. REFERENCES

AECOM and ITASCA CANADA. 2011. Regional Geology - Southern Ontario. AECOM Canada Ltd. and Itasca Consulting Canada Ltd. report prepared for the Nuclear Waste Management Organization NWMO DGR-TR-2011-15 R000. Toronto, Canada.

NWMO. 2011 Geosynthesis. Nuclear Waste Management Organization Report NWMO DGR-TR-2011-11 R000. Toronto, Canada.

Armstrong, D.K. and T.R. Carter. 2006. An updated guide to the subsurface Paleozoic stratigraphy of southern Ontario. Ontario Geological Survey, Open File Report 6191.

Armstrong, D.K. and T.R. Carter. 2010. The subsurface Paleozoic stratigraphy of Southern Ontario. Ontario Geological Survey, Special Volume 7.

Gao, C., J. Shirota, R.I. Kelly, F.R. Brunton and S. van Haaften. 2006. Bedrock topography and overburden thickness mapping, southern Ontario. Ontario Geological Survey, Miscellaneous Release—Data 207.

Great Lakes Bathymetry Griding Project. 2007. NOAA/National Geophysical Data Center, NOAA/National Ocean Service, NOAA/Great Lakes Environmental Research Laboratory, Canadian Hydrographic Service. http://www.ngdc.noaa.gov/mgg/greatlakes/greatlakes.html (accessed August, 20 2009).

Johnson, M.D., D.K. Armstrong, B.V. Sanford, P.G. Telford and M.A. Rutka. 1992. Paleozoic and Mesozoic geology of Ontario; in Geology of Ontario. Ontario Geological Survey, Special Volume 4, Part 2, 907-1008.

Michigan Department of Natural Resources and Environment. 2009. Oil and Gas Well Formation Tops & Elevations Download. http://www.michigan.gov/deq/0,1607,7-135-3311_4111_4231-143855--,00.html (accessed August 20, 2009).

Ontario Geological Survey. 1993. Bedrock geology, seamless coverage of the province of Ontario. Ontario Geological Survey, Data Set 6.

Ontario Oil Gas Salt Resources (OGSR) Library. 2009. Subsurface Geology and Petroleum Well Data. http://www.ogsrlibrary.com/ (accessed 20th August 2009).

Sterling, S. 2010. Bedrock Formations in DGR-1 and DGR-2. Intera Engineering Ltd.[1] Report TR-07-05 Rev.3. Ottawa, Canada.

[1] Currently known as Geofirma Engineering Ltd.

APPENDICES

THIS PAGE HAS BEEN LEFT BLANK INTENTIONALLY

APPENDIX A: SURFACE CONTOUR MAPPING

(see enclosed CD)

THIS PAGE HAS BEEN LEFT BLANK INTENTIONALLY

APPENDIX B: OBLIQUE GEOLOGICAL CUT-AWAY SECTIONS

(see enclosed CD)

THIS PAGE HAS BEEN LEFT BLANK INTENTIONALLY

APPENDIX C: DIGITAL DATA RELEASE

(see enclosed CD)