# Geoscientific site characterization of the proposed Deep Geologic Repository, Tiverton, Ontario

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## Introduction

The Nuclear Waste Management Organization (NWMO) is conducting geoscientific site characterization studies on behalf of Ontario Power Generation into the proposed development of a Deep Geologic Repository (DGR) for Low and Intermediate Level Radioactive Waste at the Bruce nuclear 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 approximately 680 metres below ground surface (mBGS) within the argillaceous limestone of the Cobourg Formation.

The main objective the DGR site characterization work is the development of a Descriptive Geosphere Site Model (DGSM) that summarizes the subsurface geological, hydrogeological and geomechanical characteristics of the DGR site based on field and laboratory investigations. This paper provides an overview of the DGR site characterization program and presents a short summary of some key results presented in the form of site hydrostratigraphic units.

## Geoscientific Site Characterization Program and Methods

The site characterization program for the proposed DGR at the Bruce nuclear site is a surface-based, multi-year geoscientific characterization program focused on drilling, sampling, testing and monitoring of six continuously-cored deep boreholes (DGR series) and three shallow boreholes (US series) in three phases (1, 2A and 2B) of site investigation. Details of the activities that comprise the site investigation program are described in Geoscientific Site Characterization Plans (GSCPs) prepared in advance of undertaking the site characterization work. The Phase 1 GSCP, as well as a general overview of all planned DGR site characterization work are described by Intera Engineering Ltd. (2006). Phase 2A and 2B GSCP activity is described by Intera Engineering Ltd. (2008). GSCP work programs are divided into three principal program areas; geology, hydrogeology and geomechanics.

Phase 1 site characterization work, which started in fall 2006 included completion of 19.7 km of 2-D seismic reflection surveys, establishment of three micro-seismic monitoring stations, establishment of three shallow bedrock monitoring wells to 100-200 m depth (US-3, US-7 and US-8), and coring and testing of two deep vertical boreholes DGR-1 and DGR-2 at one drill site. Continuous core collected from these two initial DGR boreholes was photographed, geologically logged and field geomechanically tested. Preserved core specimens were distributed to national and international laboratories for a wide range of geoscientific testing. Laboratory testing included geological characterization (mineralogy, petrography and geochemistry), petrophysical characterization (permeability, porosity, fluid saturations and gas entry pressure), diffusion characterization (effective diffusion coefficients and porosity), porewater characterization (porosity, major ions, gases and environmental isotope chemistry) and geomechanical characterization (swelling, abrasivity and strength properties).

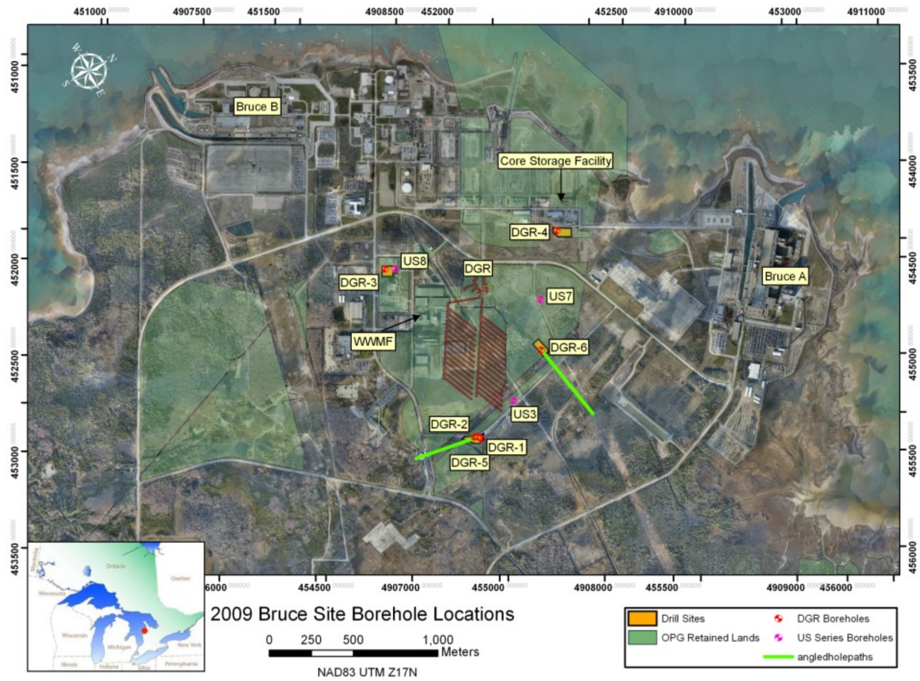


Figure 1: Location of deep DGR and shallow US bedrock boreholes and the proposed DGR footprint (reddish brown) at the Bruce nuclear site

During drilling, samples of groundwater were collected from permeable bedrock horizons and submitted for detailed analysis of major/minor ions, gases and environmental isotopes. Following the completion of drilling, boreholes DGR-1 and DGR-2 were geophysically logged (standard electrical, nuclear and borehole imaging) and profiled for hydraulic conductivity and formation pressure using custom-fabricated, straddle-packer hydraulic testing tool. Fluid electrical conductivity testing to identify permeable horizons was also completed in DGR-1. At the completion of field hydraulic testing, boreholes DGR-1 and DGR-2 were completed with multi-port/packer MP55 stainless steel/PVC monitoring casings manufactured by Westbay Instruments/Schlumberger Water Services to allow long-term monitoring of formation pressures using both dedicated MOSDAX transducer strings and conventional pressure profiling.

Phase 2A site characterization work, which started in spring 2008, focused on continuous core drilling, sampling, testing and monitoring of two deep vertical boreholes, DGR-3 and DGR-4, to the Cambrian sandstone. Together with DGR-1 and DGR-2, these four boreholes triangulate around the proposed DGR at well spacings of 1047 to 1318 m and provide detailed information on the strike/dip and thickness of the Paleozoic bedrock formations present at the Bruce nuclear site. Similar to Phase 1 work, opportunistic groundwater samples were collected from permeable formations (A1 Carbonate; Guelph; Cambrian sandstone) during drilling and core collected from boreholes DGR-3 and DGR-4 was photographed, logged, field geomechanically tested and submitted for comprehensive geological, petrophysical, diffusion, porewater and geomechanical testing. Boreholes DGR-3 and DGR-4 were also subject to borehole geophysical logging, continuous straddle-packer (30 m) hydraulic testing and completion with MP55 multi-level monitoring casings for long-term pressure monitoring.

Phase 2B site characterization work, which started in late 2008, involves the continuous oriented core drilling, logging and testing of boreholes DGR-5 and DGR-6 to the deep Ordovician limestones underlying the proposed DGR. DGR-5 and DGR-6 are inclined boreholes oriented at 60º and 65º, respectively, from the horizontal at ground surface to intersect apparent vertical structure identified by 2-D seismic surveys and to provide sampling of sub-vertical to vertical structure (fractures) present in the Paleozoic bedrock formations at the Bruce nuclear site near the proposed DGR.

## Results and Discussion

Drilling, logging and testing of DGR and US boreholes have identified 34 distinct bedrock formations, members or units at the Bruce nuclear site (Raven et al., 2009), which have been grouped based on hydrogeologic properties into 9 hydrostratigraphic (HS) units as illustrated in Figure 2. Each of these hydrostratigraphic units has been characterized as an aquifer (HS Units 2, 4A, 4B and 8), aquitard (HS Units 1, 3, 7 and 9) or aquiclude (HS Units 5 and 6) based on the results of field and laboratory testing.

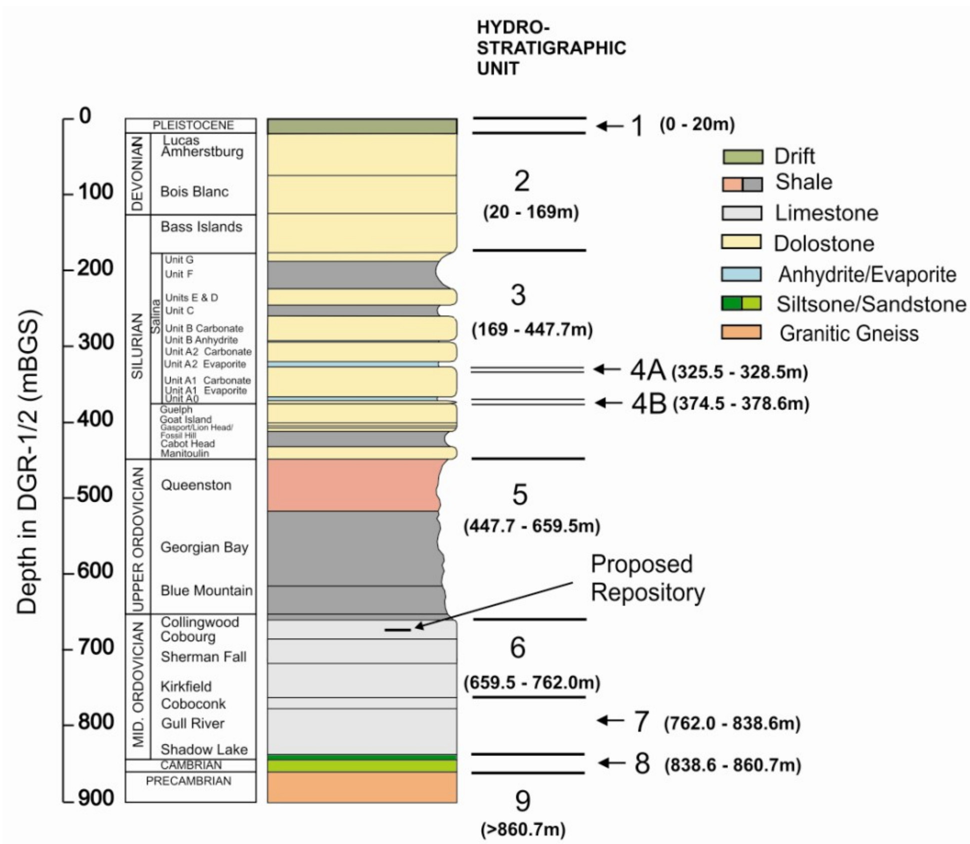


Figure 2: Reference stratigraphic column showing hydrostratigraphic units at the Bruce nuclear site.

Table 1 summarizes proposed estimates of hydraulic properties, diffusive properties and general groundwater/porewater chemistry for each of the hydrostratigraphic units identified at the Bruce nuclear site based on site characterisation activities thus far completed. Table 1 lists single estimates or ranges of estimates for HS units where changes with depth are apparent. This includes parameter values for specific storage ($S_s$), horizontal hydraulic conductivity ($K_h$), hydraulic conductivity anisotropy ratio ($K_h$:$K_v$), liquid porosity ($\phi_w$), vertical effective diffusion coefficient ($D_{e\text{-}v}$), diffusion coefficient anisotropy ratio ($D_{e\text{-}h}$:$D_{e\text{-}v}$), iodide accessible diffusion porosity ($\phi_I$) and major groundwater/ porewater chemistry. For the Ordovician shale aquiclude, two laboratory-derived estimates of liquid porosity, effective diffusion coefficient and iodide-accessible diffusion porosity are given – one for massive shale and one for limestone hard beds frequently found within the shale. For the Precambrian aquitard, two best estimates of horizontal hydraulic conductivity are noted – one for the upper weathered Precambrian and one for the deeper more competent bedrock.

Table 1: Summary of best estimates of hydrogeologic properties of hydrostratigraphic units

| ***HS Unit*** | ***Depth in DGR-1/2 (mBGS)*** | ***Hydraulic Properties*** | | | | ***Iodide Diffusive Properties*** | | | ***Groundwater/Porewater Properties*** | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | $S_s$ ($m^{-1}$) | $K_h$ (m/s) | $K_h$: $K_v$ (-) | $\Phi_w$ (%) | $D_{e-v}$ ($m^2$/s) | $D_{e-h}$: $D_{e-v}$ (-) | $\Phi_I$ (%) | TDS (mg/L) | Type |
| 1: Overburden Aquitard | 0-20 | $1x10^{-3}$ | $8x10^{-10}$ | 2:1 | 20 | $6x10^{-10}$ | 1:1 | 20 | <500 | $Ca,Na-HCO_3$ |
| 2: Dolostone Aquifer | 20-169.3 | $8x10^{-7}$ to $3x10^{-6}$ | $1x10^{-7}$ to $1x10^{-4}$ | 10:1 | 7 | $1x10^{-11}$ | 2:1 | 7 | 500 to 5000 | $Ca,Mg-HCO_3$ to $Ca-SO_4$ |
| 3: Silurian Aquitards | 169.3-447.7 | $4x10^{-7}$ to $3x10^{-5}$ | $5x10^{-14}$ to $7x10^{-11}$ | 10:1 | 3 to 15 | $1x10^{-12}$ | 2:1 | 1.5 to 6 | 10,000 to 350,000 | $Ca-SO_4$ to Na-Cl |
| 4A: Silurian Aquifer | 325.5-328.5: | $1x10^{-6}$ | $2x10^{-7}$ | 1:1 | 7 | $1x10^{-11}$ | 1:1 | 7 | 30,000 | Na-Cl |
| 4B: Silurian Aquifer | 374.5-380.0 | $1x10^{-6}$ | $3x10^{-8}$ | 1:1 | 7 | $1x10^{-11}$ | 1:1 | 7 | 370,000 | Na-Cl |
| 5: Ordovician Shale Aquiclude | 447.7-659.5 | $5x10^{-6}$ to $3x10^{-5}$ | $2x10^{-14}$ to $5x10^{-14}$ | 10:1 | 2.4 & 9.6 | $1x10^{-13}$ & $1x10^{-12}$ | 2:1 | 2 & 4.5 | 300,000 | Na-Cl |
| 6: Ordovician Lmst Aquiclude | 659.5-762.0 | $8x10^{-7}$ | $1x10^{-14}$ | 10:1 | 1.9 | $3x10^{-13}$ | 2:1 | 1.5 | 270,000 to 230,000 | Na-Cl |
| 7: Ordovician Lmst Aquitard | 762.0-838.6 | $8x10^{-7}$ | $5x10^{-12}$ | 10:1 | 2.5 | $3x10^{-13}$ | 2:1 | 1.5 | 230,000 to 200,000 | Na-Cl |
| 8: Cambrian Aquifer | 838.6-860.7 | $1x10^{-6}$ | $1x10^{-9}$ to $3x10^{-6}$ | 1:1 | 12 | $1x10^{-11}$ | 1:1 | 12 | 225,000 | Na,Ca-Cl |
| 9: Precambrian Aquitard | >860.7 | $1x10^{-6}$ | $1x10^{-10}$ & $1x10^{-12}$ | 1:1 | 0.5 | $3x10^{-13}$ | 1:1 | 0.5 | 50,000 to 350,000 | Ca,Na-Cl |

## Conclusions

Ongoing geoscientific site characterization work at the Bruce nuclear site is defining the geological, hydrogeological and geomechanical properties of the bedrock units that will overly, host and underlie the proposed DGR. The results of these investigations indicate subsurface conditions favourable for the long-term management of low and intermediate level radioactive waste. The available site characterization data demonstrate that the proposed host and surrounding rocks are competent, and of extremely low formation hydraulic properties ($K_h=10^{-14}$ m/s) and diffusion properties ($D_e=10^{-13}$ to $10^{-12}$ $m^2$/s), such that solute transport will be governed by diffusion and that the diffusion rate will be extremely slow.

## Acknowledgements

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## References

Intera Engineering Ltd., 2006. Geoscientific Site Characterization Plan, OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Report, OPG Report # 00216-REP-03902-00002-R00, April, www.nwmo.ca/dgr.

Intera Engineering Ltd., 2008. Phase 2 Geoscientific Site Characterization Plan, OPG's Deep Geologic Repository for Low and Intermediate Level Waste, Report, OPG Report # 00216-REP-03902-00006-R00, April, www.nwmo.ca/dgr.

Raven, K.., Sterling. S, Gaines, S. Wigston, A. and Frizzell, R., 2009. Regional and site geological frameworks – proposed Deep Geologic Repository , Bruce County Ontario. Proc. 62nd Canadian Geotechnical Conf. & 10th Joint CGS/IAH-CNC Groundwater Conf., Halifax, 1348-1355.