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Evidence for the Long-term Barrier Integrity of Ordovician Rocks - The Deep Geologic Repository Project, Ontario, Canada

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SUMMARY

The Nuclear Waste Management Organization in late 2006 initiated geoscientific investigations at the Bruce Nuclear site near Tiverton, Ontario, Canada, to verify suitability for development of a Deep Geologic Repository for long-term management of Low & Intermediate Level Radioactive Waste generated at Ontario Power Generation owned facilities. The Bruce Nuclear site, located on the eastern flank of the Michigan Basin, is underlain by ca. 840 m of Cambrian to Devonian age sediments that lie unconformably on the crystalline Shield. The DGR, as envisioned, would be excavated at a depth of 680 m within the massive Cobourg Formation, an Ordovician argillaceous limestone that is overlain by ca. 200 m of Ordovician shale. Field and laboratory studies conducted as part of a deep borehole drilling, coring, testing and instrumentation program are yielding evidence of an ancient, diffusion dominant groundwater regime that is resilient to repeated glacial perturbations. This evidence includes measurements of extraordinarily low rock mass hydraulic conductivities(≤10-12 m sec-1), matrix porosities (0.01-0.08) and diffusivities (Dp≤10-11 m2 sec-1), and observation of anomalously depressed environmental heads (ca. 250 m) and vertical environmental tracer distributions within the Ordovician sediments. This presentation describes program results relevant to understanding groundwater regime stability and DGR safety.

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 Nuclear Waste (L&ILW) at the Bruce Nuclear site, located near Tiverton, Ontario, Canada. The Bruce site is situated on the eastern flank of the Michigan Basin, a Paleozoic age intra-cratonic marine sedimentary basin. Beneath the Bruce site the sedimentary sequence is approximately 840 m thick, comprised of Devonian to Cambrian age sediments including near horizontally layered carbonates, shales, evaporites and minor clastics (Figure 1). As envisioned the vertical shaft accessed DGR would be excavated at a depth of 680 m within the argillaceous limestone Cobourg Formation, capped by 200 m of Ordovician shale. Geoscientific studies to verify the suitability of the Bruce site for safe implementation of the DGR concept were initiated in 2006. These studies are yielding useful insight into the long-term stability and barrier integrity of the deep seated argillaceous sediments and groundwater system. This paper describes interim results and numerical simulations from the Bruce site investigation as relevant to evaluating the properties and long-term barrier function of the Ordovician sediments that host and immediately enclose the DGR.

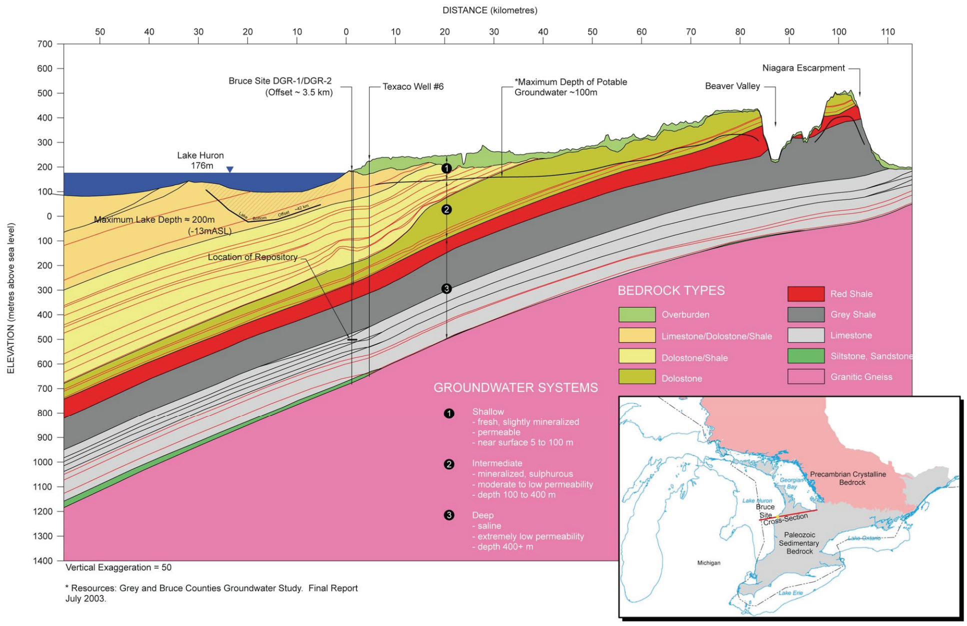

Figure 1 *Proposed DGR and Conceptual Geologic/Hydrogeologic Model for Bruce Nuclear Site and Surrounding Region.*

A key element of the Bruce site field investigations has been the implementation of a deep drilling program. At present 4 of 6 planned boreholes drilled from 3 locations triangularly positioned around the DGR footprint (0.3 km^2) have been diamond cored through the entire sedimentary sequence to a depth of ca. 860 m. The bedrock stratigraphy is consistent with regional trends indicating remarkably consistent formation thickness and dip (0.6^o SW) within the Ordovician sediments. Core petrophysics, coupled with efforts to characterize pore fluid chemistry and diffusive rock capacity factors, are estimating low porosities for the cap Ordovician Shales (Queenston, Georgian Bay, Blue Mountain Formations) of 0.06 to 0.08 and extremely low porosities for underlying carbonates of 0.01 to 0.02. Pore matrix fluid chemistry is a dominantly NaCl brine with Total Dissolved Solids ranging between 250 to 350 gm l^{-1}. In-situ hydraulic pulse testing is yielding extremely low rock mass hydraulic conductivities within the Ordovician shales of $\leq 10^{-12}$ m sec^{-1} and the underlying carbonates of $\leq 10^{-13}$ m sec^{-1}. Estimated specific storage for the formations is estimated from laboratory testing to be 10^{-6} m^{-1}. Laboratory determination of effective diffusion coefficients using through diffusion and micro-computed tomography techniques are consistent with Archies Law, on the order of 10^{-12} m^2 sec^{-1} for the shales and 10^{-13} m^2 sec^{-1} for the carbonates.

Efforts beyond the field and laboratory have involved the integration of field data at local and regional scale into 3-dimensional numerical simulations of the regional and site-specific groundwater system. While interim in nature these simulations, performed with the code FRAC3DVS-OPG, have explored uncertainty in bedrock hydrostratigraphy and boundary conditions, the influence of variably salinity of near-surface fresh to deep seated brine waters and the effect of glacial events on groundwater hydrodynamics and mass transport. Illustrative numerical simulations of the groundwater system predict a sluggish deep seated groundwater system resilient to glacial perturbations and one in which mass transport is dominantly governed by diffusive processes. Computed Mean Life Expectancies (time to system discharge) that incorporate advective, dispersive and diffusive transport processes, for solute at the repository horizon are 8 million years or greater.

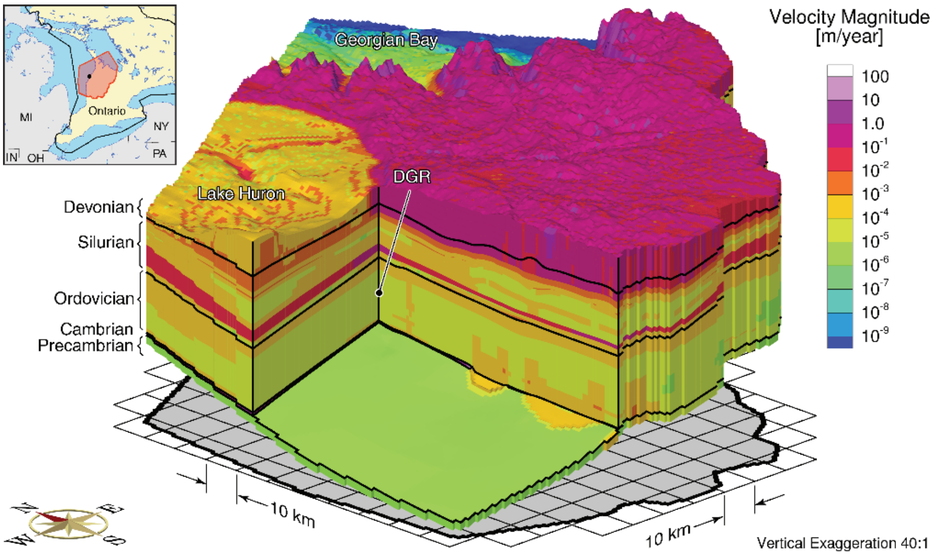

Figure 2 *Numerical Simulation of Regional (18,000 km^2) Groundwater System With FRAC3DVS-OPG Within Paleozoic Sediments in Vicinity of the Proposed DGR.*

The numerical simulations further examined long-term field observations of non-hydrostatic or abnormal hydraulic head conditions within the sediments as observed in a multi-level Westbay (MP-55) monitoring system. Particularly of note are the depressed environmental heads in the Ordovician sediments that while still equilibrating after a year are currently ca. 250 m below ground surface. These sediments lie unconformably above a thin (17 m), laterally extensive, permeable (K≈10^{-7} m sec^{-1}), and low storage (S_s≈10^{-6} m^{-1}) Cambrian sandstone within an abnormal overpressure of 150 m above ground surface. The resultant vertical hydraulic gradients sustained across the sediments are high, on the order of 2 and appear convergent on the repository horizon. Studies examining the origin and longevity of the abnormal heads are continuing with respect to understanding Ordovician properties and barrier function time and space scales relevant to repository safety. Interim model results imply that formation hydraulic conductivities must be of the order of 10^{-14} m sec^{-1} or less to preserve the observed hydraulic heads. Further, the simulations suggest that hydro-mechanical coupling associated with repeated glacial ice-sheet advance-retreat is an unlikely cause of the abnormal heads. The apparent transient disequilibrium of the Ordovician heads coupled with on-going work to explore the migration of environmental tracers (i.e., Cl, Br, ^{18}O, ^{2}H) in the same sediments is leading to an improved understanding of barrier function, role of connected local and regional scale vertical pathways (faulting/ fault zones), and effectiveness of the barrier formations to safely contain and isolate the L&ILW.