OPG's DEEP GEOLOGIC

REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

Phase 2 Geoscientific Site Characterization Plan

April 2008

Prepared by:

INTERA Engineering Limited

INTERA 06-219.50-Phase 2 GSCP-R0

OPG 00216-REP-03902-00006-R00

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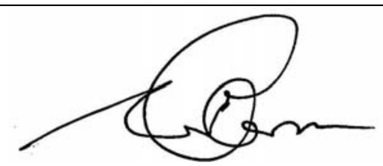
Approved by:	 Kenneth Raven	

EXECUTIVE SUMMARY

Ontario Power Generation Inc. is proposing the development of a Deep Geologic Repository (DGR) for low and intermediate level radioactive waste at the Bruce site, located near Tiverton, Ontario. The DGR will be constructed as an engineered facility approximately 680 m below ground surface within the Paleozoic argillaceous limestone of the Cobourg Formation.

A three-phase Geoscientific Site Characterization Plan (GSCP) was developed in 2006 to acquire the necessary geoscientific information to support the development of descriptive geosphere models of the Bruce site and the preparation of a DGR environmental assessment and site preparation/construction license application to the Canadian Nuclear Safety Commission. The GSCP is a multi-year program designed for iterative development, testing and refinement of site-specific descriptive geosphere models, including geologic, hydrogeologic and geomechanical models.

Phase 1 investigations, scheduled for completion in mid-2008, included coring, testing and instrumentation of two deep boreholes, 2-D seismic reflection surveys and shallow bedrock investigations and monitoring. Preliminary Phase 1 results are consistent with the previous understanding of the site's geology and hydrogeology.

This report describes the Phase 2 geoscientific site characterization activities recommended to acquire the necessary geoscientific information to characterize the Paleozoic geology at the Bruce site as it relates to long-term radioactive waste storage. Phase 2 work is to be completed between April 2008 and October 2010. Phase 2 is intended to complement Phase 1 results in obtaining additional detailed borehole information to test the understanding of site homogeneity and predictability as they relate to demonstrating long-term DGR Safety. Phase 2 activities will yield data and an integrated Descriptive Site Model to support Safety Assessment, Facility Engineering and Environmental Assessment.

Consistent with Phase 1, the Phase 2 GSCP work program is divided into the three principal program areas: Geology, Hydrogeology and Geomechanics. The selection of the methods and tools represents, in part, a re-examination of site-specific and off-site information needs necessary to assemble a comprehensive geoscientific understanding of the Bruce site relevant to the DGR safety case.

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1 INTRODUCTION

1.1 Background and Overview

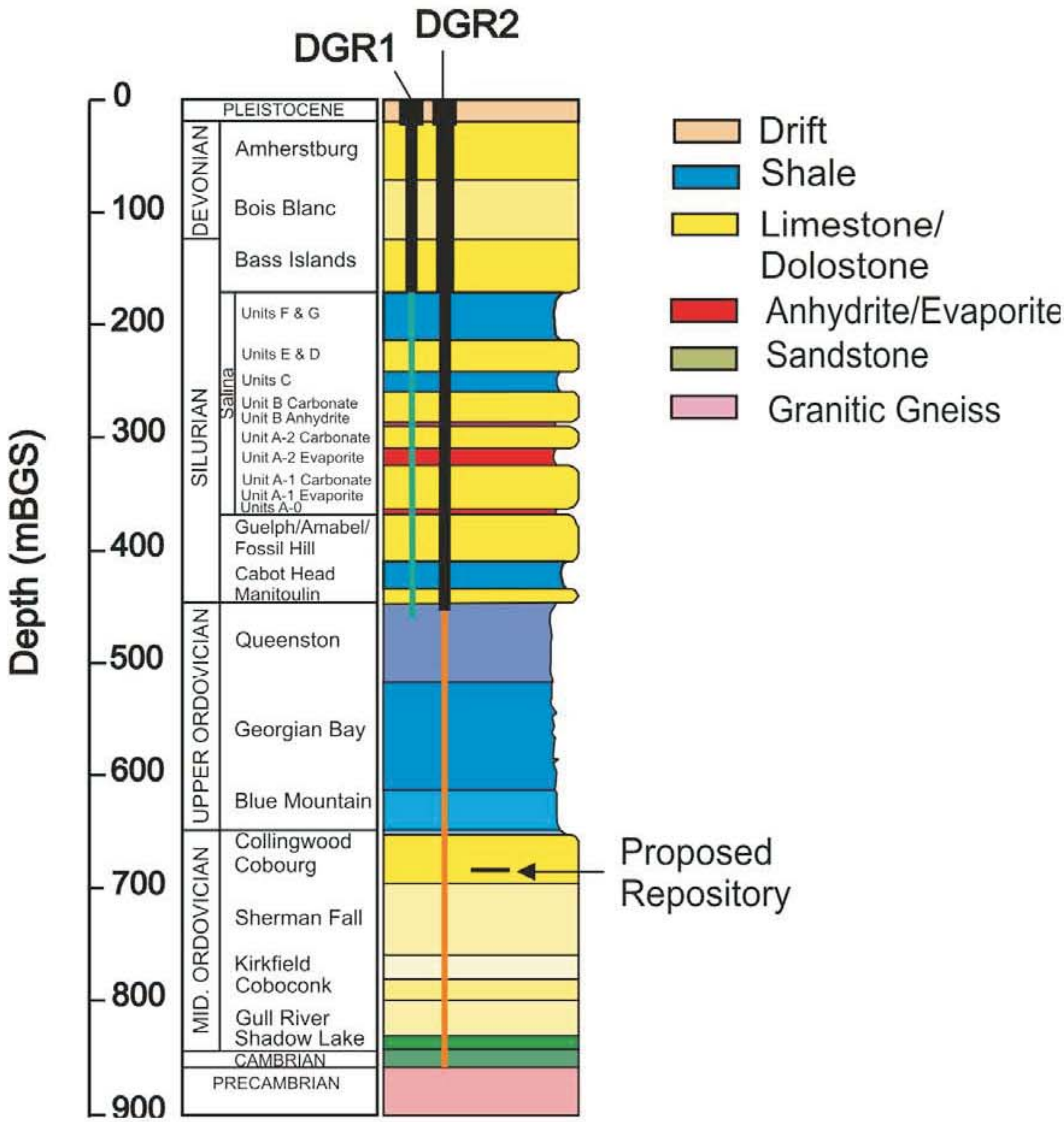
Intera Engineering Ltd. (Intera) has prepared this document to support the development of a site-specific Geoscientific Site Characterization Plan (GSCP) for the proposed Low and Intermediate Level Radioactive Waste Deep Geologic Repository (DGR) at the Bruce site. The GSCP (Intera Engineering Ltd, 2006) is designed for iterative development, testing and refinement of site-specific descriptive geosphere models, including geologic, hydrogeologic and geomechanical models. The GSCP, which began in 2006, is a multi-year investigative program. The Phase 1 investigations included a seismic survey of the proposed DGR location and the surrounding area, as well as coring of two deep boreholes used to improve the geosphere model of the site.

This report describes the Phase 2 geoscientific site characterization activities recommended to acquire the necessary geoscientific information to characterize the Paleozoic geology at the Bruce site as it relates to long-term radioactive waste storage. The methods and tools described in this work program have been designed with site-specific information and knowledge gained through the Phase 1 work program that is scheduled for completion in the summer 2008. The geoscientific information obtained from Phase 2 will be acquired in a manner consistent with the DGR Project Quality Plan (OPG, 2006) and Intera's project-specific Project Quality Plan (Intera Engineering Ltd, PQP, 2007) and will be used to support the preparation of a DGR Environmental Assessment and Site Preparation/Construction License application.

The proposed DGR will be constructed approximately 680 m below ground surface (BGS) within the argillaceous limestone of the Cobourg Formation. The DGR will be designed to receive low and intermediate level wastes produced by OPG-owned nuclear generating stations throughout their lifetime, as well as, similar wastes currently in interim storage at the Bruce site. OPG (2005) provides a detailed description of the DGR project, including the anticipated volumes, types and activities of the wastes to be placed in the DGR.

1.2 Favourable Site Characteristics

The current conceptual geosphere model of the Bruce site describes a sequence of layered sedimentary rocks, overlying the Precambrian basement, located at a depth of ~860 m. Figure 1.1 shows a schematic representation of the assumed bedrock stratigraphy based on results from Phase 1. The deeper intervals, specifically the Ordovician shales and argillaceous limestones are assumed to be homogenous and of extremely low permeability. The proposed DGR is to be located in argillaceous limestone at a depth of 680 m, about 50 m below the assumed shale/limestone contact.



Bedrock Stratigraphy at Bruce Site from DGR-1 & DGR-2 Phase 2 GSCP		Prepared by: NKP Reviewed by: JDA Date: May 2, 2008
FIGURE 1.1	Doc. No.: 06-219.50_Phase 2 GSCP_Fig 1.1.cdr	

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The sequence of sedimentary rocks at the Bruce site are assumed to posses the following favorable characteristics relevant to demonstrating repository safety:

- The horizontally-layered shale and argillaceous limestone sedimentary sequence that will overlie and host the DGR is geologically stable, geometrically simple and predictable, relatively undeformed and of large lateral extent.
- There is no known active faulting at or near the site and seismicity is very limited.
- The deep argillaceous formations that will host the DGR will provide stable and practically dry openings.
- The regional stress regime (horizontally compressive) is favourable with respect to sealing of any vertical fractures and faults.
- The 200 m thick argillaceous limestone that will host the DGR and the 200 m of argillaceous limestones and shales above and below the proposed repository horizon have very low permeabilities.
- Mass transport in the deep shales and limestones is diffusion dominated.
- The deep groundwater system in the shales and limestones is saline (about >200 g/L), stagnant, stable and ancient, not showing evidence of either glacial perturbations or cross formational flow or mixing.
- The shallow groundwater system is hydrologically isolated from the deeper groundwater system that will contain the DGR.

1.3 GSCP Purpose

The purpose of the GSCP, as described in part by the CNSC (2005), is to provide information necessary to develop a comprehensive descriptive geosphere site model (DGSM) that:

- provides a geoscientific understanding of the current condition of the site, its past evolution and likely future natural evolution over the period of interest for safety;
- establishes a baseline for detecting potential short-term and long-term environmental impacts caused by the construction, operation and closure of the facility; and
- provides the necessary geoscience information and data to design the facility and perform Safety Assessments and optimizations (i.e., for Environmental Assessment and/or licensing).

1.4 GSCP Scope – Phase 2

Phase 2 GSCP activities are surface-based investigations designed to complement the data obtained from Phase 1, with the intent of providing site-specific data that will be used to test the favourable site characteristics listed in Section 1.2, and to support DGR Geosynthesis and Environmental Assessment, and CNSC license application for site preparation and construction.

Phase 2 activities will focus on developing a complete 3-dimensional understanding of the Bruce site as it relates to DGR performance and long-term safety through the refinement of a descriptive geosphere site model. Phase 2 activities are focused on the drilling, testing and instrumentation of 4 deep boreholes (2 vertical; 2 inclined) that will also provide data to

Engineering Facilities and Safety Assessment functions. These Phase 2 work program activities will be conducted between April 2008 and October 2010.

The elements of the GSCP described within this report are considered consistent with the Canadian Nuclear Safety Commission (CNSC) Wastes and the Decommissioning Division discussion paper entitled "*Siting and Site Characterization for Long-Term Radioactive Waste Containment Facilities – Version 1.1, May 2005*". However, the GSCP only describes activities required for subsurface geoscientific characterization with the intent that this work would be integrated with surface based information during preparation of the DGR Environmental Assessment.

2 GEOLOGIC CHARACTERIZATION PLAN

2.1 Objectives and Scope

Geologic characterization will be undertaken to develop a descriptive geologic model of the Bruce site and surrounding area that will directly support hydrogeologic and geomechanical descriptive site models. The Phase 2 geologic work program is focused on the following eight major work elements and implementation issues, which are described in more detail in the following sections.

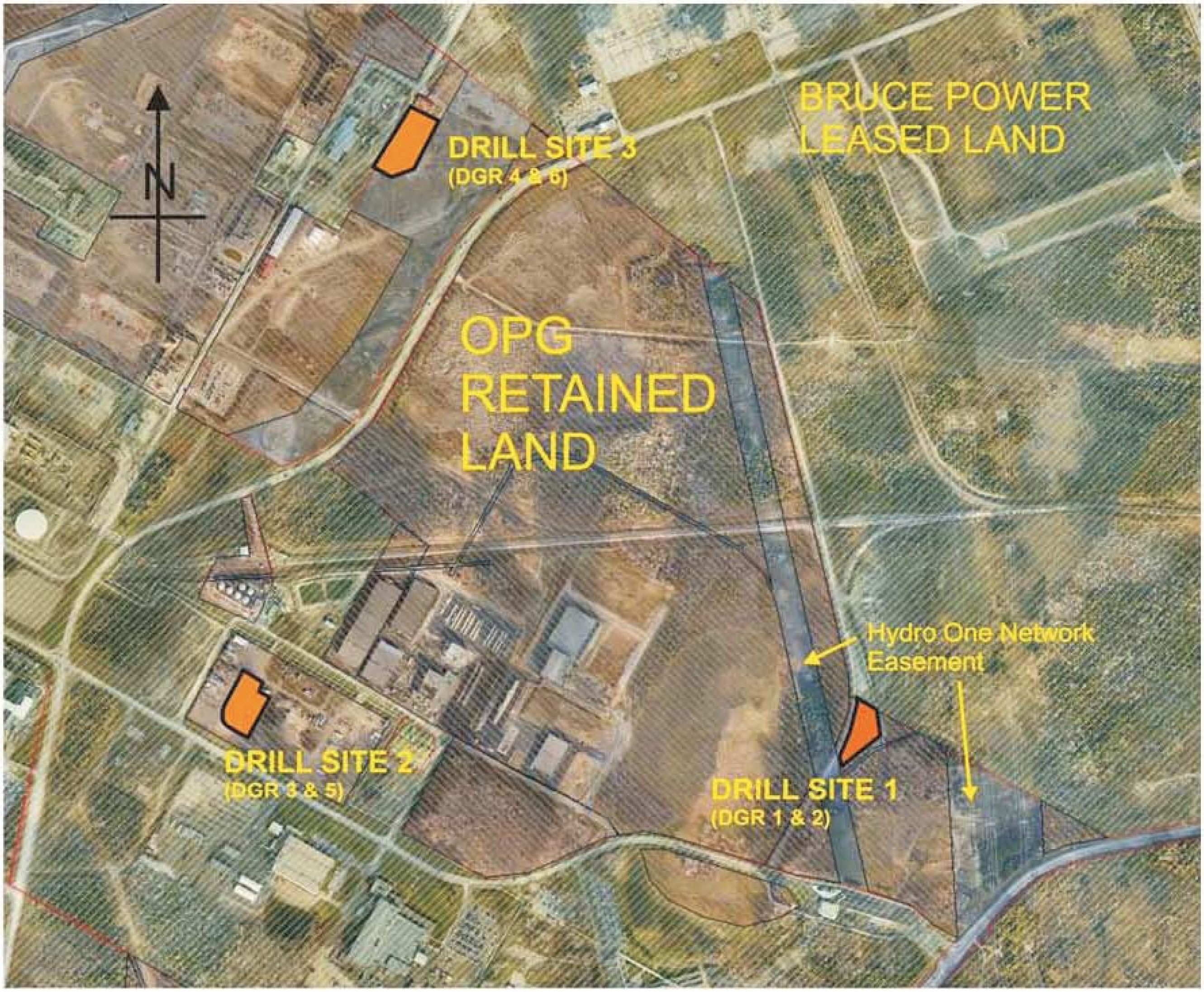
- Borehole Drilling
- Temporary Borehole Sealing Systems
- Drilling Fluids
- Borehole Orientation Surveys
- Geologic Core Logging
- Borehole Geophysical Logging
- Laboratory Petrography, Mineralogical and Geochemical Testing of Core
- Refinement of Descriptive Geologic Site Model
- Implementation Issues

2.2 Borehole Drilling

The Phase 2 drilling program will consist of the completion of two vertical boreholes in 2008 followed by two inclined (60^o-65^o plunge) boreholes in 2009. The data collected from this drilling program will be used to determine the three-dimensional continuity of the bedrock stratigraphy across the site and determine the strike and dip of various bedrock formations and stratigraphic units. In addition, the inclined boreholes are intended to investigate the characteristics (strike, dip, thickness) of sub-vertical structural discontinuities, with a focus on the Ordovician formations hosting and overlying the proposed DGR.

The locations of the four proposed boreholes are a sufficient distance (375 to 520 m) from the proposed DGR location to prevent the boreholes from penetrating the rock mass that would host the DGR and at a sufficient distance to minimize the role of the boreholes in future solute transport. Each borehole will be drilled under Ontario Ministry of Natural Resources License and will require blow-out protection and other standard drilling requirements as dictated by the Provincial Operating Standards mandated under the Oil, Gas and Salt Resources Act (MNR, 2002).

The drilling program will be conducted at two new drill sites on Ontario Power Generation retained lands selected to allow triangulation to determine the strike and dip of the bedding at the proposed DGR site (Figure 2.1). The two new drill sites and the first drill site from Phase 1 are located approximately 1.0 km apart. Specific drill site diagrams showing surface wellhead locations for DGR-3 and -5 and DGR4 and -6 are shown in Figure 2.2 and Figure 2.3, respectively. The vertical holes, DGR-3 and DGR-4, will be continuously cored from bedrock



Proposed Borehole Drilling Sites Phase 2 GSCP		Prepared by: NKP Reviewed by: JDA Date: May 2, 2008
FIGURE 2.1	Doc. No.: 06-219.50_Phase 2 GSCP_Fig 2.1.cdr	

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Legend

Borehole

Site boundary

Scale

0 5 10 20 30 40 Metres

Drill Site #2 Proposed Layout Phase 2 GSCP		Prepared by: NKP Reviewed by: JDA Date: May 2, 2008
FIGURE 2.2	Doc. No.: 06-219.50_Phase 2 GSCP_Fig 2.2.cdr	

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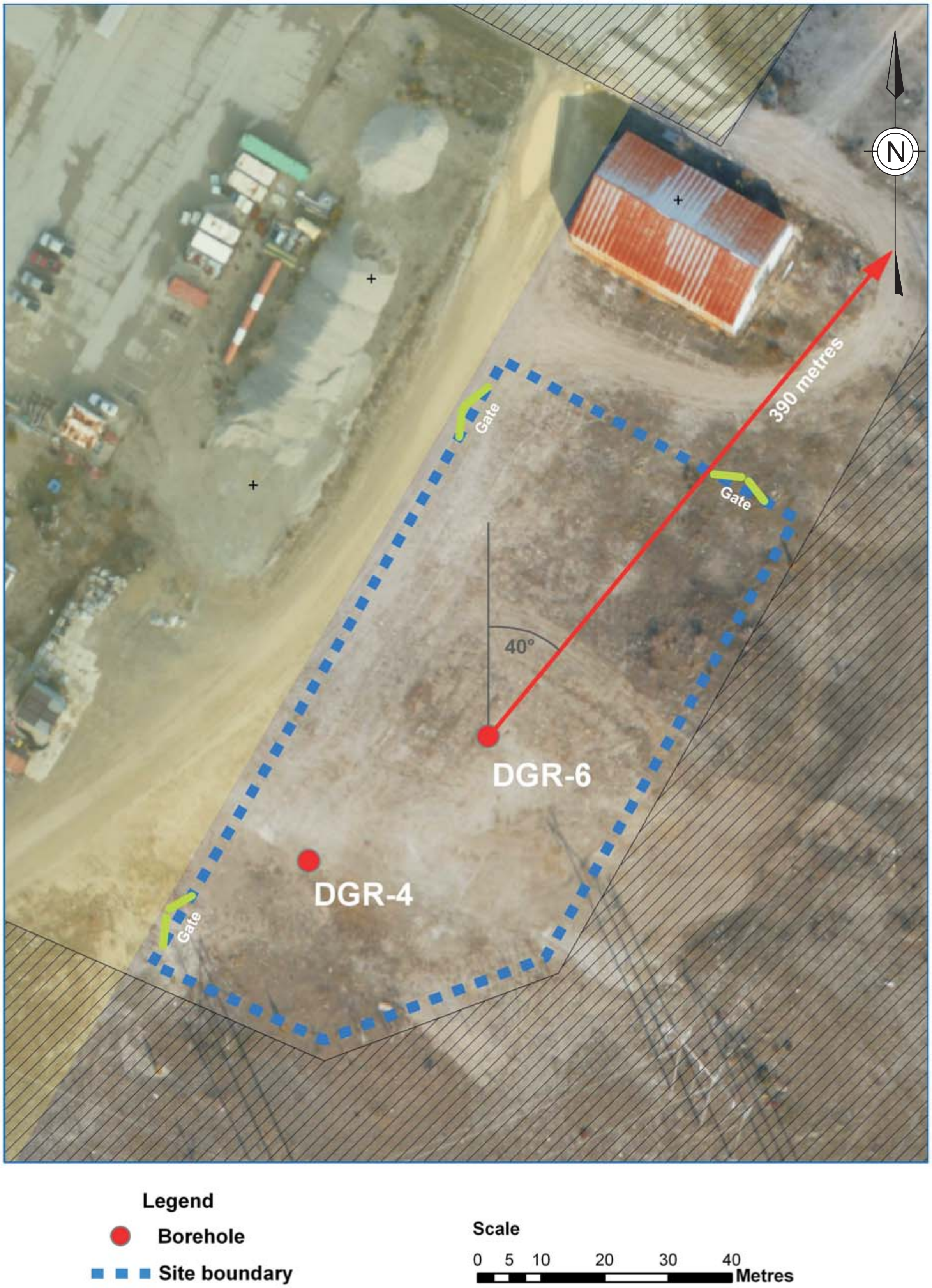

Drill Site #3 Proposed Layout **Phase 2 GSCP**		Prepared by: NKP Reviewed by: JDA Date: May 2, 2008
FIGURE 2.3	Doc. No.: 06-219.50_Phase 2 GSCP_Fig 2.3.cdr	

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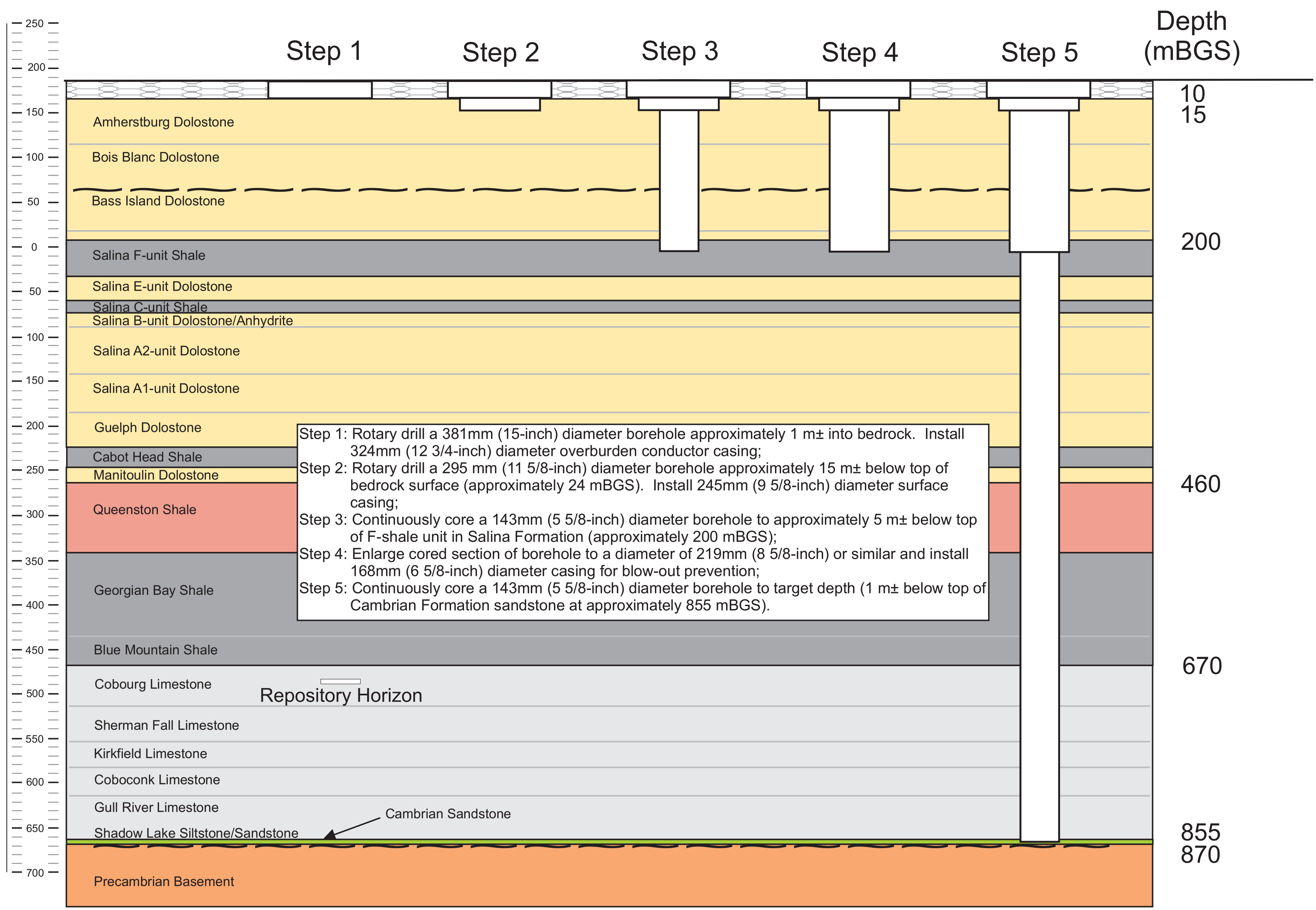
surface into the upper surface of the Cambrian Formation sandstone at an estimated depth of approximately 855 metres below ground surface (mBGS).

Flowing groundwater under high pressure is expected in the Cambrian Formation, as encountered in drilling DGR-2 in Phase 1. In the unlikely event that such groundwater is not encountered, drilling would continue into the Cambrian Formation until such conditions are encountered. Should flowing pressurized groundwater not be encountered anywhere in the Cambrian Formation, then drilling would continue to about 10 m into the Precambrian. The inclined boreholes, DGR-5 and DGR-6, will have plunges of approximately 65º and be oriented to maximize opportunity for intersection with vertical and sub-vertical discontinuities as understood from regional scale geologic mapping. These holes will be continuously cored through the Silurian and Ordovician sediments. Unlike the vertical boreholes, the inclined boreholes will not be advanced into the over-pressurized Cambrian Formation primarily as a means to avoid complications during borehole testing. As shown in Figures 2.2 and 2.3, DGR-5 (Site 2) is proposed to have an azimuth of 130º and DGR-6 (Site 3) an azimuth of 40º. These borehole azimuths will be re-assessed and justified following completion and incorporation of information gathered during the 2008 field season and from finalization of the 2-D seismic reflection survey report.

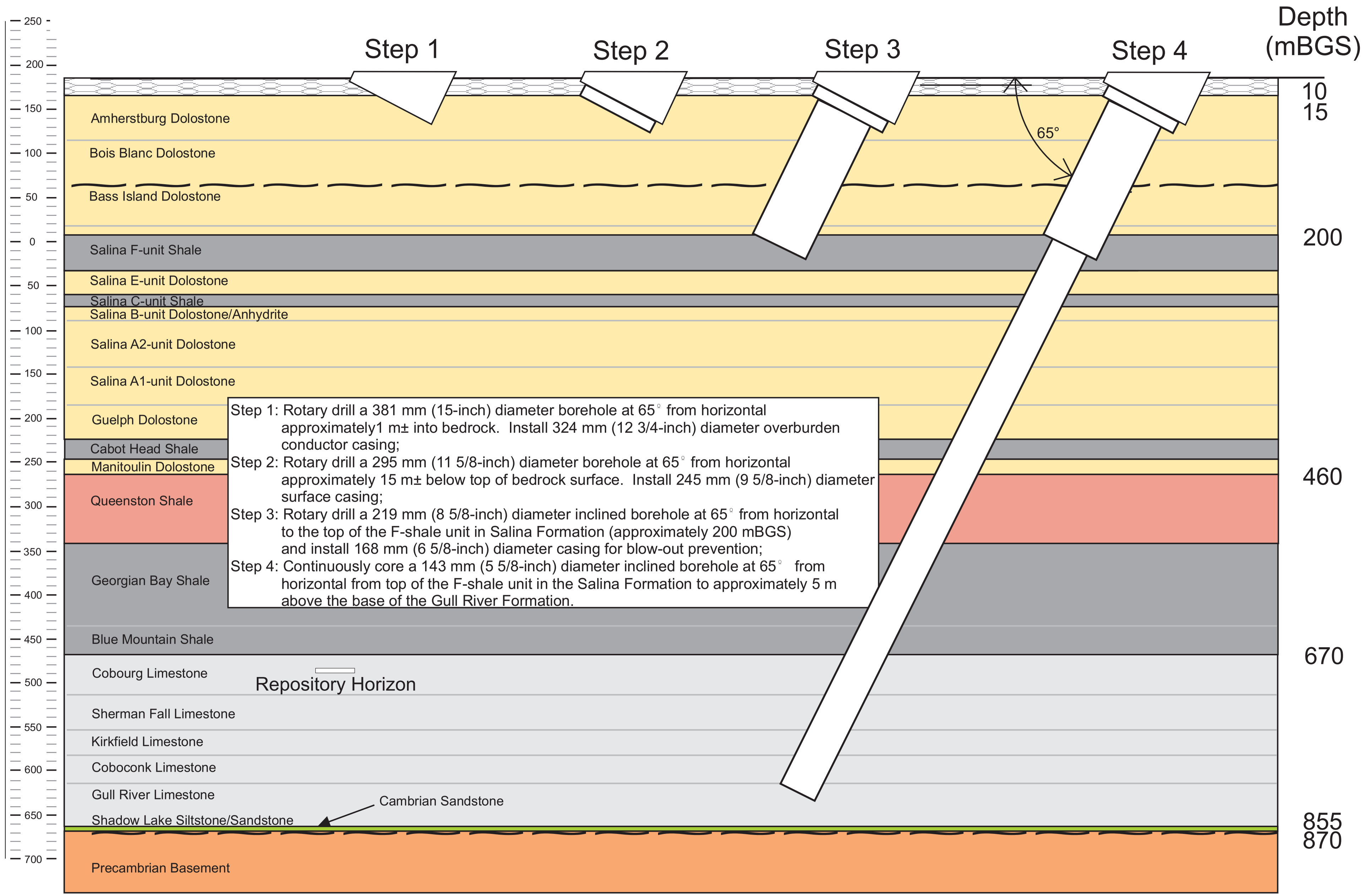
The experience gained during Phase 1 drilling activities indicated that large diameter bores (160 mm) were not necessary to avoid borehole collapse or failure. As such, the boreholes in the Phase 2 program will be slightly smaller diameter of 143 mm. Coring will be completed using a double-tube wireline coring system with a split inner barrel (Christensen) that produces a 76mm diameter high quality core in 3.05 m lengths. On occasion it may be necessary to core shorter lengths to accommodate difficult drilling conditions.

The proposed drilling and casing installation sequences for boreholes DGR-3 to DGR-6 are shown on Figures 2.4 and 2.5. Each vertical borehole will be initiated by rotary drilling a 381 mm diameter borehole through the overburden and 1m into the bedrock, and cementing a 324 mm diameter conductor casing in the borehole. This casing is cemented in place in order to prevent the overburden from interfering with subsequent drilling and data acquisition from the boreholes. A 295 mm diameter borehole will be rotary drilled into the bedrock at a depth of approximately 20 to 30 mBGS, and a 245 mm diameter casing will be cemented in the borehole. The additional casing is required because blowout prevention equipment is not installed until the borehole reaches approximately 200 mBGS. Continuous rock coring will follow in a 143 mm diameter borehole to about 5 m into the top of the Salina F Unit shale approximately 200 m BGS. Once the Salina F Unit shale is reached the borehole will be enlarged to a diameter of 219 mm and a 168 mm diameter casing will be installed, cemented and fitted with blowout prevention equipment. The remainder of the borehole will then be cored to a total depth as described previously. This section of the borehole will not be cased in order to allow for geophysical and hydrogeological testing in the borehole, followed by the installation of multilevel groundwater monitoring equipment.



Proposed Drilling and Casing Installation Sequence - Vertical Boreholes DGR-3 & DGR-4

FIGURE 2.4	Doc. No.: 06-219.50_Phase 2 GSCP_R0.cdr	Prepared by: NKP Reviewed by: KGR Date: May 1, 2008



Proposed Drilling and Casing Installation Sequence - Inclined Boreholes DGR-5 & DGR-6

FIGURE 2.5	Doc. No.: 06-219.50_Phase 2 GSCP_R0.cdr	Prepared by: NKP Reviewed by: KGR Date: May 1, 2008

The procedure for the inclined boreholes will be the same, except that the inclined boreholes will be terminated at about 5 above the base of the Gull River Formation in order to avoid pressurized and flowing conditions that most likely extend from the Cambrian Formation up into the Shadow Lake Formation. However, the procedure for inclined coring may be subject to modification depending on the results of the vertical boreholes and other considerations.

2.3 Temporary Borehole Sealing Systems

Permeable zones in the boreholes will be sealed to isolate flow zones and minimize cross formation fluid flow in the open boreholes. Sections of each borehole may be sealed with bridge plugs and/or Production-Injection Packers (PIPs) following drilling and prior to the installation of Westbay multilevel systems as described in the Phase 1 GSCP and Section 3.8 of this report. If zones of significant gas, water flow, or borehole instability are encountered, these zones could be cemented and re-drilled although precautions are required to avoid or minimize impact on groundwater chemistry.

Phase 1 results indicated that rock from the top of the Salina Formation to the top of the Cambrian Formation sandstone was, with few exceptions, of very low permeability. This entire section will be cored as noted above and the use of temporary borehole seals will probably not be required, except at the more permeable Cambrian Formation sandstone, where flowing artesian conditions are expected, and possible local borehole sloughing conditions in the shales in the inclined boreholes. No large occurrences of natural gas are expected.

2.4 Drilling Fluids

Drilling fluids will be used as established during Phase 1. A freshwater drilling fluid will be used to drill the upper bedrock sequence above the Salina Formation where pore water is relatively fresh to brackish. Brine-based drilling fluid will be used to drill the Salina Formation and all bedrock units below this formation where saline to brine pore-water fluids were encountered in Phase 1. Drilling with brine-based drilling fluids will minimize dissolution and wash-out of bedrock with anhydrite and halite zones, and should minimize weathering/deterioration of some of the softer the Ordovician shale units (e.g., Collingwood Member and Blue Mountain Formation shales). All drilling fluids will be tagged with drill water tracers (Section 3.2).

Samples of drill fluids will be collected for field and lab determination of drill water tracer concentrations and for characterization of general drill water major ion, metals and environmental isotope contents. Na Fluorescein and electrical conductivity will be regularly measured (four times per day) in the field on drill water samples to both ensure maintenance of drill water tracer levels and for detection of production of formation fluids that may trigger opportunistic groundwater sampling. Drill water samples for tritium analyses will be regularly collected.

Detailed records will be kept during drilling activities concerning the borehole water levels, density, funnel viscosity, tracer concentrations, conductivity and temperature of drilling fluid in the hole to allow for future quantification of and compensation for drilling impacts on natural formation conditions. Additionally, the gas content (e.g., methane and H_2S) will be monitored for worker health and safety and for qualitative interpretation of geochemical conditions.

2.5 Borehole Orientation Surveys

The borehole orientation shall be measured after each 50 m interval of borehole length drilled during drilling using a gyroscopic survey, or comparable device, to measure the azimuth and plunge of the borehole as it is advanced. Orientation monitoring allows for tracking the precise location of the borehole, which is important for interpreting the data retrieved from Phase 2 activities. Based on the results of DGR-2 (deviation of less than 1^{o} by the end of the borehole), borehole deviation is not expected to be significant. A deviation of up to 2^{o}/50 m or up to 5^{o} for the entire borehole length is considered as tolerable. Should this be exceeded, discussion and re-evaluation would be required to determine acceptability and the type of corrective action available (if any).

2.6 Geologic Core Logging, Photography and Preservation

Core logging will follow the guidelines of Armstrong and Carter (2006) for stratigraphic nomenclature and ISRM (1978) for geomechanical nomenclature as established during Phase 1. Core logging for geological characterization will be conducted immediately upon recovery of core. Logging will be continuous and will detail the rock lithology, stratigraphy and sedimentological features, including the depth of recovery, fracture and bedding patterns, rock type, texture, colour and quality, any evidence of weathering or alteration, as well as the location, frequency, orientation and characteristics of discontinuities (infilling, openness, roughness, planarity, staining or other evidence of water flow) and any other structural or deformation features, and core recovery including Rock Quality Designation (RQD). The core will be digitally photographed immediately after the core is recovered. Photography will be conducted in a consistent manner to provide a high-quality visual catalogue of the core.

The cores need to be preserved as soon after recovery as possible in order to obtain high quality core samples for subsequent hydrogeological and geomechanical testing. The preservation of rock core samples should be completed within 45 minutes of core barrel retrieval, based on Phase 1 experience. In Phase 1, the shortest achievable preservation time was about 15 to 20 minutes.

2.7 Borehole Geophysical Logging

Geophysical logging of each borehole will be carried out as established during Phase 1. Geophysical logging is conducted to define stratigraphic contacts, as well as to obtain data on fracture orientations, spacing, apertures and filling materials. Additionally, the core logs and geophysical logs will be used to select intervals for detailed hydraulic testing, the design of the Westbay multilevel casing configuration, and to improve the descriptive geologic model for the site.

The logging speeds used will depend on the individual probes and will generally follow the methods used in Phase 1. For example, for those probes intended to target fine features such as discrete fractures, the probe sampling frequency would be approximately every 5 to 6 mm with emphasis on quantification of depth accuracy.

Table 2.1 summarizes the borehole geophysical logs intended to provide geological, hydrogeological and geomechanical information proposed for Phase 2 investigations. All of the geophysical logs listed on Table 2.1 are recommended to be used in each open borehole section immediately following drilling and flushing of drill fluid and cuttings from the borehole, following placement of any seals necessary to seal off flowing conditions in the Cambrian Formation, and prior to commencement of borehole hydraulic testing.

Table 2.1 Summary of Recommended Borehole Geophysical Logs in Phase 2

Borehole Geophysical Log	***Geoscience Data Need***	
	Discipline	***Target Information***
Gamma/Spectral Gamma	Geological	Lithology, Stratigraphy
Gamma-Gamma	Geological	Lithology, Stratigraphy, Density
Neutron	Geological Hydrogeological	Lithology, Stratigraphy Rock Porosity
Resistivity/Conductivity	Geological Hydrogeological	Lithology, Stratigraphy Salinity
Sonic/Full Wave Form Sonic	Geological Geomechanical	Lithology, Stratigraphy, Structure Bulk Modulus, Rock Competence, Sonic Velocities
Caliper	Geological	Borehole Diameter and Zones of Instability
Acoustic Televiewer	Geological Geomechanical	Borehole Diameter & Orientation, Fracture Occurrence & Orientation, Borehole Breakouts
Video	Geological Hydrogeological	Stratigraphy, Discontinuities, Borehole Wall geometry Flowing Zones, Gas
Temperature	Hydrogeological	Relative Inflow and migration in borehole, Porosity
Fluid Resistivity	Hydrogeological	Groundwater Salinity, Vertical Water Movement in Borehole

2.8 Laboratory Petrography, Mineralogical and Geochemical Testing of Core

The two primary goals of the laboratory testing of recovered bedrock core are:

1. demonstrate the pore waters within the Ordovician shales and argillaceous limestones beneath the Bruce site are ancient, i.e., > 1 million years, and

2. to understand the transport mechanisms controlling solute transport within these sedimentary units.

The laboratory testing program is designed to meet these objectives and includes petrography, mineralogical and lithogeochemical testing of core described here, as well as laboratory testing of groundwater (Section 3.4.2), characterization of the rock matrix (Section 3.5) including diffusion properties, organic matter, fracture coatings or infillings, and petrophysical properties.

Table 2.2 summarizes the estimated petrography, mineralogical and geochemical testing program for core recovered from vertical boreholes in Phase 2. Core sampling to support this testing program will be coordinated with that required for geomechanical characterization.

Table 2.2 Summary of Core Geochemical Testing Program for Each Vertical Borehole Drilled in Phase 2

Method	***Targeted Formation***	***Estimated Number of Tests***
Mineralogy of Cores	Devonian and Silurian Formations	12 (Optical Microscopy & XRD)
	Upper Ordovician Formations	10 (Optical Microscopy & XRD)
	Middle Ordovician Formations	18 (Optical Microscopy & XRD)
	Vein or fracture coatings or infillings	6 (Optical Microscopy & XRD)
Geochemistry of Cores	Upper Ordovician Formations	10 (Fusion ICP-OES, ICP-MS)
	Middle Ordovician Formations	10 (Fusion ICP-OES, ICP-MS)
Cation Exchange	Upper Ordovician Formations	5 (Cation Exchange Capacity)
	Middle Ordovician Formations	5 (Cation Exchange Capacity)
Pore Structure	Upper Ordovician Formations	10 SEM (+ petrophysical tests)
	Middle Ordovician Formations	10 SEM (+ petrophysical tests)

Geochemical analyses of the whole-rock matrix including measurement of oxides using ICP-optical emission spectrometry (ICP-OES) and trace elements using ICP-mass spectrometry (ICP-MS) will be conducted on core samples from the Ordovician formations.

Core samples from the Ordovician shale and argillaceous limestones, vein or fracture infillings or coatings (if observed) and select core samples from the Devonian and Silurian formations will also be analyzed in thin-section using optical microscopy, electron microprobe analysis, and by X-ray diffraction to quantify the principal minerals (e.g., calcite, quartz, and illite). Trace minerals such as pyrite or soluble salts (e.g. halite, gypsum) may also be identified using optical microscopy. In addition, scanning electron microscopy (SEM) coupled with an energy dispersive spectrometer (EDS) is employed to detect trace minerals such as pyrite, and soluble salt minerals such as halite, gypsum or anhydrite, hexahydrite, epsomite or celestite.

In Phase 2, elemental mapping using analytical electron microscopy techniques may also be considered to identify trace minerals to provide additional constraints on porewater composition (see also Section 3.6). SEM analysis is also employed to examine pore fabric including pore structure and shape. Additional information on the pore space is provided by the petrophysical tests described in Section 3.5.2.

2.9 Refinement of the Descriptive Geologic Site Model

The descriptive geologic model of the DGR site developed during Phase 1 will be updated during Phase 2. Additionally, the descriptive hydrogeologic and geomechanical site models that depend on the geologic model will also be updated as new geological information becomes available.

2.10 Implementation Issues

One principal implementation issue for the geologic characterization plan is the completion of the final interpretation of the 2-D seismic survey after the development of this Phase 2 GSCP. As a result, this Phase 2 plan may require modification at a later date, depending on the results of the 2-D seismic survey.

The knowledge gained through the drilling of boreholes DGR-1 and -2 has solved many of the implementation issues related to drilling and borehole stability in the completion of deep boreholes at the Bruce site. However, the drilling of two inclined boreholes may present new issues, such as the effect of caving on an inclined hole that would affect drilling and hydraulic testing.

As encountered in DGR-2, flowing groundwater conditions will most likely be present in the Cambrian Formation sandstone, should it be decided to advance below the Gull River Formation. Such flowing conditions would require control, collection and disposal of any produced fluids during the drilling and testing activities. Control of such conditions can be readily achieved with the blow-out prevention equipment during drilling and with the installation of temporary bridge plugs or PIPs following drilling and prior to multi-level casing installation.

3 HYDROGEOLOGIC CHARACTERIZATION PLAN

3.1 Objectives and Scope

Hydrogeological site characterization activities for Phase 2 are designed to improve the understanding of the physical and geochemical hydrogeological systems, which will be used to refine the current descriptive hydrogeologic model of the Bruce site. A combination of field and laboratory activities will be conducted during Phase 2 to meet this objective. These are described in the following sections under eight major work elements.

- Drill Water Tracing
- Borehole Hydraulic Testing
- Groundwater Geochemistry
- Physical and Transport Properties of the Intact Rock Matrix
- Pore Fluid Geochemistry
- Characterization of Organic Matter
- Formation Pressures and Hydraulic Heads
- Refinement of Descriptive Hydrogeologic Site Model

3.2 Drill Water Tracing

Drill water tracers will be used in the borehole drilling program to provide identification of drill water contamination in subsequent analyses of groundwater and porewater samples for chemical and isotopic analyses. As per Phase 1, two types of drill water tracers are proposed – one that is readily detected in the field with a reduced level of accuracy and confidence and one that is detected in the laboratory with a higher level of accuracy and confidence.

The proposed field tracer will be Na Fluorescein, a yellow-green fluorescent organic dye. This tracer was readily detectable in the field using a field fluorometer during Phase 1 and provided a wide range of detection to determine drill water contamination at sub percent levels. The Na Fluorescein tracer will be added to drill water at a target concentration of 1 mg/L and will be tested on a regular basis to determine the tracer concentrations throughout all drilling phases.

The drill water tracer proposed for laboratory testing will be naturally occurring tritium (HTO). For all bedrock drilling, water from Lake Huron opposite the Bruce site will be used as the basic drilling fluid. Testing of drill water as part of the Phase 1 investigations showed that tritium levels in drill water ranged from 100 to 500 TU with average values of about 200 TU. These results confirm that tritium is an appropriate drill water tracer for use in Phase 2 work.

The salinity and density of the drilling fluid will also be modified as described in Section 2.4. Routine sampling of drill water for major ions, trace metals, specific conductance, HTO, ^{18}O and ^{2}H will also be undertaken to define the geochemical and isotopic profiles of drilling fluids throughout the drilling program.

3.3 Borehole Hydraulic Testing

Borehole hydraulic testing is intended to provide estimates of in-situ horizontal hydraulic conductivity.

Borehole hydraulic testing data can also be used to determine formation pressure, however results from Phase 1 analyses showed that borehole pressure history, due to drilling and other testing events preceding hydraulic testing, was sufficient to significantly affect pressure estimates. As in Phase 1, long-term formation pressure data from multilevel monitoring systems will be considered more reliable. Testing proposed for Phase 2 is based largely on the testing procedures developed for Phase 1 and described in TP-06-14 (Intera Engineering Ltd., 2007).

3.3.1 Test Equipment

All borehole testing will be conducted using a custom built straddle packer test tool. With this tool, the test-zone is isolated above and below by a 1.5 m long inflatable packer, which seals against the borehole wall. The test tool itself is connected to surface with standard 2-3/8 inch tubing. A workover rig is required to raise and lower the tool in the borehole. Additional stainless steel hydraulic lines and data communication cables connect the tool to surface hydraulics and data acquisition systems. High-precision quartz pressure transducers are mounted on the test tool and measure the pressure and temperature in the test zone, the zones above and below the test zone, and inside the tubing string. A hydraulic shut-in valve is used to connect (when open) or isolate (when closed) the test-zone to/from the inside of the tubing string. A hydraulically actuated piston is present within the test interval to generate over and under-pressure conditions for pulse tests (described below in Section 3.3.2.1).

Surface equipment consists of high-pressure hydraulic pumps for inflating packers and actuating the open/close valve and the pulse piston, nitrogen gas cylinders for maintaining constant pressures on packer inflation lines, power supplies, and a data acquisition and test control system (DAS). The DAS also provides internet connectivity to allow remote monitoring of hydraulic tests. All surface equipment is located within a temperature controlled trailer to provide environmental protection to testing equipment and test operators.

The length of test-zone used in the testing will vary. Current planning is for testing of at least one entire open borehole interval in DGR3- or DGR-4 (Salina Formation F Unit to bottom of hole) using a long (20 to 30m) straddle interval. This will provide testing results that can be compared directly to Phase 1 DGR-2 testing. Subsequently, specific intervals may be selected for more accurate characterization with a shorter (10 or 5m) test-interval. Intervals will be selected to characterize borehole sections that, based on core logging or geophysical results, may present significantly lower or higher permeabilities. Characterizing shorter sections is important as the long straddle intervals will tend to average sections of borehole that may have significant variations, and in particular will tend to minimize the impact of lower permeability intervals. Identification and quantification of the lowest permeability intervals is important for accurate prediction of geosphere performance, particularly in light of the pressurized Cambrian Formation.

3.3.2 Test Types

There are three types of hydraulic tests that can be used as part of the hydraulic testing program: slug tests, drill stem tests (DSTs), and pulse tests. For any specific test zone, the type of test planned will depend on the expected hydraulic conductivity (K) of the zone: slug tests will be performed in the zones with K ≥1 x 10^{-7} m/s; DSTs will be performed in zones with K ≥1 x 10^{-10} m/s; and pulse tests will be performed in the zones with K < 1 x 10^{-10} m/s.

Results from Phase 1 testing indicate that most tests will be pulse tests, with slug and DST tests used on a limited number of higher permeability intervals. The general testing procedure is described below:

1. The test tool is lowered until the straddle interval is at the selected location. It is important to keep an accurate tally of all tubing section and tool component lengths so that placement can be determined accurately. The tool is run-in with the shut-in valve open so that the tubing string fills with borehole fluid.

2. The packers are hydraulically inflated to approximately 13 to 14 MPa above hydrostatic pressures. Packer pressures are monitored for a short period to ensure stability.

3. The shut-in valve is closed, isolating the formation. Water within the tubing string is removed via swabbing, such that the fluid pressure at the bottom of the tubing string is several hundred kPa lower than the surrounding annulus. An equilibration period allows the test interval to reach the apparent formation pressure. Tubing string pressures are monitored for evidence of leakage past the shut-in valve. The length of the equilibration period is dependent upon the formation conductivity and the duration and extent of pre-test pressure history. Experience from DGR-1 and DGR-2 testing suggests that a one day period is sufficient for most intervals.

4. The test is performed. Procedures for different test types are described below.

5. Packers are deflated and tool positioned for next interval.

3.3.2.1 Pulse Tests

Pulse tests are expected to be the most common type of test performed. For pulse tests, a hydraulically-actuated cylinder is rapidly extended within the isolated test zone. This causes an increase in test-zone pressure. In general, the magnitude of the pulse should be approximately 300 to 750 kPa. This is sufficient to provide a high signal to noise ratio in the test response, while not sufficient to breach the packer seal, damage the equipment, or hydraulically fracture the formation.

The size of the pressure increase is dependent upon the pulse cylinder size (the volume of water displaced during actuation), the volume of the test zone, the compressibility of the test-zone fluid, the compressibility of the formation, and the compressibility or compliance of the portion of the packers and other test tool components exposed to the test-zone. Test zone volume and pulse displacement volume are generally known with fairly high precision. However, it is impossible to determine all compressibility terms with certainty. Experience in Phase 1 testing showed that for most intervals, the effective total compressibility was within a factor of two of water compressibility, indicating minimal tool compliance and formation compressibility.

After the pulse has been generated, it is allowed to decay back to pre-test pressure. The time required for decay is inversely proportional to the formation conductivity. For testing in very low permeability intervals, several days of recovery may be necessary. Phase 1 pulse testing with 30m straddles in DGR-2 generally required a day or more of recovery. Proposed Phase 2 tests with short straddle intervals in very low conductivity formations, if performed, may require longer recovery times.

Additional, confirmatory, pulse withdrawal and/or injection tests may be conducted if determined necessary by the test supervisor. In general, a very short duration pulse withdrawal is performed to confirm correct deployment of the hydraulic cylinder.

3.3.2.2 Slug Tests

Slug tests are conducted by opening the shut-in valve, which exposes the test zone to the under pressured tubing string. Water will flow from the formation into the test zone and the tubing until the pressure in the tubing reaches the pre-test or apparent formation pressure. After the first slug test is complete, the shut-in valve will be closed, additional water will be removed from the tubing string, the shut-in valve will be opened, and a second test conducted. Experience from Phase 1 testing indicates that most slug tests can be performed with a single day of testing.

3.3.2.3 Drill Stem Tests

A DST is simply a slug test that is terminated prematurely (e.g., at 10 percent or less pressure recovery) by closing the shut-in valve and then monitoring the pressure recovery in the test zone. DSTs consist of two parts: a flow period and a buildup period. The flow period corresponds to the “slug test” portion and the buildup period consists of the subsequent pressure recovery monitored in the shut-in test zone. Conjunctive analysis of the flow data and buildup data allows for a better constrained estimate of hydraulic conductivity than is provided by analyzing either data set alone. A DST can take up to one to two days to complete.

3.3.2.4 Test Duration

For pulse and slug tests, uncertainty in the calculated value of hydraulic conductivity decreases the longer the test is allowed to run (i.e., as pressure recovery approaches 100 percent). Decisions to terminate tests will be based on real-time analysis of the data collected using a well-test-analysis code, such as nSIGHTS, that is capable of estimating fitting-parameter (e.g., transmissivity) uncertainty at any time during a test.

3.3.3 Phase 2 Tests Planned for Vertical Boreholes

Hydraulic testing in vertical boreholes DGR-3 and DGR-4 will be carried out in the Silurian and Ordovician rock formations. Testing will not be carried out in the overlying Devonian carbonates as that section of the hole will be cased off and not available for testing. Based on Phase 1 testing results, the bedrock formations that will be tested in DGR-3 and DGR-4 are expected to have hydraulic conductivities mostly ranging between 1 x 10^{-10} m/s to 1 x 10^{-13} m/s although higher hydraulic conductivities (up to 1 x 10^{-7} m/s) can be encountered locally in the Upper to Middle Silurian formations.

As described previously, boreholes will be initially tested using a 25m or 30m straddle. Subsequently, the tool may be reconfigured for a shorter (5 or 10m) straddle and specific intervals selected for detailed testing. Such shorter length test intervals will be selected based on several criteria:

1. Identified as massive low permeability sections from core logging; or
2. Identified fracture or high-permeability features; or
3. Intervals for which petrophysics samples have been taken to allow for more direct comparison of field and laboratory permeability measurements.

Due to scheduling issues, it is likely that DGR-3 will be selected for long-interval tests and detailed testing, if performed. Testing in DGR-4 will likely be limited to long-interval tests and additional intervals where conditions are present that are different than those encountered in DGR-3.

3.3.4 Phase 2 Tests Planned for Inclined Boreholes

Testing in boreholes DGR-5 and DGR-6 will use the same test equipment as used on DGR-3 and 4, slightly modified to address inclined borehole issues. However, it is expected that testing will be more problematic and time consuming as raising and lowering the test tool in the inclined boreholes will be more difficult than in the vertical DGR-3 and DGR-4 boreholes. The test tool and tubing must be protected to prevent chafing of components against the bottom side of the borehole.

Hydraulic testing in inclined boreholes DGR-5 and DGR-6 will be focused on characterizing any vertical or sub-vertical features encountered in drilling. Specific straddle intervals and target depths will be determined after drilling is complete.

If no specific targets are identified, testing will be confined to the Ordovician shales (Queenston, Georgian Bay, Blue Mountain Formations and Collingwood Member) and limestones (Cobourg, Sherman Fall, Kirkfield, Coboconk and Gull River Formations) using short straddle intervals to provide further confirmation of results for horizons previously selected for detailed testing in DGR-3 and DGR-4.

3.4 Groundwater Geochemistry

The chemical composition, including selected stable isotopes, of groundwater in the shallow, intermediate and deep systems will be determined and used to estimate the groundwater origin and examine how groundwater chemistry has evolved. Specific ions and isotopes that do not undergo geochemical reactions, e.g., chloride and bromide, may also be used to trace groundwater flow. By combining geologic and hydrogeologic data with groundwater tracers and estimates of groundwater age, the primary processes controlling solute transport may be determined (e.g. Gimmi et al., 2007; Bigler et al. 2005; Patriarche et al. 2004a,b; Rübel et al. 2002). These results will be incorporated into the descriptive hydrogeologic site model and the groundwater compositions can be incorporated in the hydrogeologic modeling and in Safety Assessment simulations. The application of this approach in Phases 1 and 2 and the supporting laboratory activities are described in Section 3.6.

3.4.1 Groundwater Compositions

Opportunistic groundwater samples and associated groundwater gas samples were collected from the shallow groundwater flow system from the Amherstburg (1 interval), Bois Blanc (2 intervals) and Bass Island (1 interval) formations in DGR-1, following protocols described in TP-06-11 (Intera Engineering Ltd., 2007).

In order to further characterize the chemical compositions of these shallow groundwaters during Phase 2 investigations, groundwater samples will be collected from Westbay packer systems in the US-series boreholes (US-3, US-7 and US-8) from selected measurement ports according to the protocols described in TP-07-09 (Intera Engineering Ltd., 2007). Together with the opportunistic groundwater samples collected during the drilling of DGR-1, these samples will be used to characterize groundwater chemistry within the shallow groundwater flow system (Amherstburg, Bois Blanc and Bass Island formations).

During Phase 1 drilling, it was not possible to collect opportunistic groundwater samples below the Bass Island formation through the Silurian formations to the top of the Ordovician Queenston Formation at the bottom of DGR-1. In Phase 2, targeted groundwater sampling will be conducted during the drilling of DGR-3 and DGR-4 for zones within the Silurian A2 Evaporite Unit and within the Guelph Formation. Sections within these two formations were identified as potential aquifers with hydraulic conductivities in the range of 10^{-7} to 10^{-8} m/s based on the results of straddle packer testing in DGR-1. If groundwater flow is sufficient, samples from these intervals will provide additional samples to determine the chemical composition of groundwaters within the intermediate flow system. In order to retrieve groundwater samples from these target zones with minimum contamination by drill fluid, an estimated 2 to 3 days of monitoring and/or purging of the packer-isolated test intervals will be required.

During drilling of DGR-2, there were no opportunities to sample groundwater above the Cambrian Formation. This is consistent with in-situ hydraulic conductivity measurements made over this sequence, which were all less than 6×10^{-11} m/s. Opportunistic samples were obtained from the flowing Cambrian Formation at a depth of 844 m. Gas sampling of the Cambrian groundwater for measurements of CO_2, CH_4, He and isotopic composition ($\delta^{13}C$) was also conducted on the basis that the groundwater effervesced, but do not provide quantitative measurements of gas concentrations. In Phase 2, additional opportunistic groundwater samples will be collected from the Cambrian during the drilling of DGR-3 and DGR-4.

3.4.2 Groundwater Analytical Program

The Phase 2 analytical program for groundwaters (Analytical Groups A, B, C, and E), which includes opportunistic, targeted and Westbay samples, and associated gas samples (Analytical Group D; opportunistic and targeted samples) is described below:

<u>[Group A] Master Variables & Major Ions:</u> (pH, Eh, electrical conductivity, temperature) and major ions (Ca, Na, Mg, K, Sr, SO_4, HCO_3, Si, F, I, HS, Cl, dissolved organic and inorganic carbon, which may be partly anionic). These analytes will provide a charge-balanced analysis that can be used for geochemical modeling (see Section 3.6). pH and Eh (Pt electrode

potential vs. the H_2 electrode) will be measured in the field, where sample volumes allow, otherwise all groups of analytes will be measured in the receiving laboratories.

[Group B] Trace Elements and Environmental Isotopes*:* (Cs, Rb, Ba, Gd, Ra, Cr, Al, Fe, Mn, Co, Ni, Cu, Zn, U, Th, As, Se, I, B and Br) and environmental isotopes ($\delta^{18}O$, $\delta^{2}H$, $\delta^{34}S$, $\delta^{3}H$, $^{87/86}Sr$ and $\delta^{13}C$). Specific analytes (e.g. Fe, As) provide information on the redox state of the groundwaters while others provide information on their origin (e.g. stable water isotopes, ratios of Cl to Br).

[Group C] Radioisotopes: ^{14}C in the shallow bedrock groundwater samples are useful for residence time estimation and even their absence can be useful in establishing minimum residence times (Gimmi and Waber, 2004).

[Group D] Gases*:* (Rn, Ar, Ne, N_2 and CH_4): Measurements of radon are needed to quantify the exposure risk to personnel during construction and operation of the DGR; the noble gases (including total He (^4He), Ar, and Ne) may provide information on the temperature of infiltration during groundwater recharge; the presence of methane is suggestive of anoxic groundwater.

[Group E] Drill Water Tracers: Fluorescein (field tested) and tritium (lab-tested). The Phase 2 groundwater analytical program is similar to the Phase 1 program except environmental isotopes $\delta^{13}C$ and $\delta^{34}S$ have been added to Group B and $\delta^{37}Cl$, $\delta^{11}B$ and $\delta^{7}Li$ were excluded.

The analytical program recommended for groundwaters in Phase 2 of the GSCP is summarized in Table 3.1. This program includes groundwater sampling to be completed between May 2008 and October 2009.

Table 3.1 Summary of Phase 2 Groundwater Characterization Program

Analytes	***Targeted Formation***	***Estimated Number of Tests***
Master Variables & Major Ions [Group A]	US-Series Wells	40 - Westbay Samples
	Silurian Formations	6 - Targeted Samples
	Cambrian Formation	2 - Opportunistic Samples
Trace Elements and Environmental Isotopes [Group B]	US-Series Wells	40 - Westbay Samples
	Silurian Formations	6 - Targeted Samples
	Cambrian Formation	2 - Opportunistic Samples
Radioisotopes [Group C]	US-series Wells	8 - ^{14}C,
	Silurian Formations	3 - ^{14}C (Targeted Samples)
Gases [Group D]	Silurian Formations	6 - Targeted Samples
	Cambrian Formation	2 - Opportunistic Samples
Drill Water Tracers [Group E]	All Formations	100 - Westbay, Opportunistic & Targeted Samples

3.5 Physical and Transport Properties of the Intact Rock Matrix

Determination of physical and mass transport properties of the Ordovician shales and limestone formations at the laboratory-scale for Phase 2 are discussed in the following sections. Details on Phase 1 core sample depths and how the samples were distributed for testing is given in Appendices A and B of TP-06-10 (Intera Engineering Ltd., 2007).

3.5.1 Diffusion Properties

In Phase 1, the diffusive properties of the Ordovician formations including the upper barrier shales (Queenston, Georgian Bay and Blue Mountain Formations), the Cobourg Formation and lower barrier rocks (Sherman Fall, Kirkfield, Coboconk, Gull River and Shadow Lake Formations) were examined using both X-ray radiography and through-diffusion methods (TP-06-12; Intera Engineering Ltd., 2007). Iodide and tritium (HTO) were used as diffusion tracers in Phase 1.

Prior to the start of Phase 1 investigations, the X-ray radiography method was tested on archived core samples of the Queenston shale from Niagara region and Cobourg Formation limestone from the Darlington area, as well as on relatively fresh samples of the Cobourg Formation limestone drilled in Bowmanville, Ontario. The measured diffusion coefficients determined by the X-ray radiography method compared well with those from standard through-diffusion experiments.

During Phase 1, the X-ray radiography technique was successfully applied to the Ordovician shales. However, due in part to the lower porosities of the limestones from DGR-2, it was not possible to use this method to obtain diffusion coefficients for the majority of limestone samples examined from DGR-2. However, several measurements for the Ordovician limestones were obtained using the through-diffusion method.

In Phase 2, the through-diffusion technique will be used exclusively to examine the diffusive properties of the Ordovician limestones (Cobourg Formation and lower barrier rocks). A preliminary examination of both the anisotropy and heterogeneity in the diffusive properties within the Cobourg Formation will be conducted using this technique. The X-ray radiography technique will be used for the upper barrier shales, with three through-diffusion tests conducted for comparison and confirmation of the properties determined using X-ray radiography.

The laboratory diffusion testing program is summarized in Table 3.2. A total of 46 diffusion tests will be completed in the Phase 2 GSCP. The exact distribution of tests and number of tests undertaken for vertical and horizontal properties may change from that listed in Table 3.2.

Table 3.2 Summary of Phase 2 Laboratory Diffusion Testing Program for Vertical Boreholes

Method	***Analytes***	***Parameters / Information***	***Formation & Total Estimated Number of Tests***
Through-diffusion (Parallel & perpendicular to core axis)	HTO and I	D_e, α [see Note Below for Explanation of Parameters]	6 - Ordovician Shales (Queenston, Georgian Bay and Blue Mountain Formations)
	HTO and I	D_e, α (Anisotropy & Heterogeneity of Formational Properties)	16 – Cobourg Formation
	HTO and I	D_e, α (Anisotropy & Heterogeneity of Formational Properties)	8 - Sherman Fall, Kirkfield, Coboconk, Gull River and Shadow Lake Formations
X-ray radiography (Parallel & perpendicular to core axis)	I	D_e (Anisotropy of Formational Properties)	16 - Ordovician Shales (Queenston, Georgian Bay and Blue Mountain Formations)
Note: D_e = effective diffusion coefficient; α = rock capacity factor (i.e., the diffusion accessible porosity for a non-sorbing solute)			

3.5.2 Petrophysical Properties

Petrophysical testing proposed for Phase 2 will include characterization of the physical properties of solid cores from the Ordovician shales and limestones, using the following tests, all which will completed on each core:

- Mercury injection porosimetry;
- Porosity and fluid saturations; and
- Brine and gas pulse permeability.

Mercury injection tests were used to determine threshold capillary pressures and pore-throat sizes distributions in core samples from the Ordovician shales and limestones and one sample of the Cambrian sandstone during Phase 1 site characterization activities. Mercury injection tests and other petrophysical tests are important in determining two-phase flow parameters used in gas transport modelling (TP-08-19, Intera Engineering Ltd, 2008). A total of 17 mercury injection tests were conducted during Phase 1 investigations. In Phase 2, 11 tests are planned for the Ordovician shales and limestones in each vertical borehole. The purpose of these tests is to confirm consistency with respect to the formation properties measured in DGR-2.

Effective and total porosities were measured on 22 core samples using the Boyle's Law method. The effective porosities were measured on preserved core samples without any pre-treatments; measurements of total porosity were made on core samples which had been subjected to fluid extraction using the Soxlet procedure, followed by drying as described in TP-07-03 (Intera Engineering Ltd., 2007). Fluid saturations (e.g., oil, gas and brine contents) of pore space were measured with the Soxlet and drying procedures. These same porosity and fluid saturation tests will be completed on 11 core samples from each of borehole DGR-3 and DGR-4.

Additional measurements of physical properties including porosities calculated from the water content and bulk and grain densities, and water contents measured during vacuum distillation were generated during the course of other geochemical determinations (e.g. of diffusion coefficients, pore water compositions). The results from Phase 1 and 2 for each of these methods will be evaluated and compared in the Descriptive Geosphere Site Model Report.

Permeability estimates for gas and brine in the host and barrier formations are required to model pressure build-up and dissipation rates for gases from within the DGR, and to assess potential for host rock fracturing. Twenty gas pulse pressure decay measurements of vertical permeability and eight of horizontal permeability at confining stress were conducted during Phase 1 on core samples from the Ordovician shales and limestones, and from the Cambrian Formation sandstone from DGR-2. In Phase 2, vertical and horizontal brine permeability and vertical gas permeability will be measured on “as received” cores and vertical gas permeability will be measured on cleaned core with fluids removed. A total of 11 sets of pulse permeability tests at confining stress are planned for the Ordovician formations in each vertical borehole drilled during Phase 2.

3.6 Pore Fluid Geochemistry

Water is predominantly contained within the pore spaces of the rock matrix in unfractured, low permeability sedimentary formations. Information on the major ion compositions of these waters, estimates of the pH and redox conditions and of the partial pressure of CO_2 are required by Safety Assessment predictions of the geochemical conditions within a DGR, and to assess the performance of engineered barriers (e.g. shaft seals). The approach used in both Phases 1 and 2 of the DGR Project is to examine pore water compositions across the Upper and Middle Ordovician formations. Part of this work will focus on delineating the distribution of natural tracers including Cl, Br and I as well as isotopes ($\delta^{18}O$ and $\delta^{2}H$) and noble gases in pore waters, which may be combined with geologic and hydrogeologic data to asses the primary transport process, advection and dispersion or diffusion, affecting solute transport at the site

Prior to and during the course of Phase 1 investigations, extraction methods for pore waters previously applied in international site characterization activities underwent development and adaptation for application to shales and limestones containing highly saline pore waters. The status of methods developed and applied during Phase 1 site characterization activities for characterizing the chemical and isotopic ($\delta^{18}O$, $\delta^{2}H$) compositions of pore water are described in the following subsections.

3.6.1 Chemical Composition

Two main approaches will be used to characterize the chemical composition of pore water within the Ordovician shale and limestone sequences in Phase 2: 1) crush and leach with cation exchange capacity testing, mineralogic characterization and reconstructive geochemical modeling and 2) crush and leach with mineralogic characterization and vacuum distillation.

The primary approach used to characterize the chemical composition of pore waters involves the measurement of major ions by crushing the core samples and leaching the pore water from the rock matrix at various water rock ratios and the determination of cation ion exchange capacities. In Phase 1 investigations, routine methods for aqueous leaching were found to be applicable to the Ordovician shales and argillaceous limestones, although chemical analysis of leachates was found to be more involved as a result of their high salinities. Several aqueous extractions were conducted under oxygen-free conditions to reduce artifacts in measured aqueous sulphate concentrations due to oxidation of sulphide-bearing minerals (e.g. pyrite) in the Ordovician formations. It was determined that although the Ni consumption method can be used as a proxy for cation exchange capacity (CEC), in-situ sorbed cation populations cannot be quantified using this method, because their concentrations are too low relative to cation concentrations in the pore water.

The mineralogical tests include the preparation and examination of thin sections, quantitative XRD analyses, and the determination of organic and inorganic carbon and sulphur. These sources of information are then combined, and reconstructive geochemical modeling applied to evaluate and further constrain estimates of the pore water composition. No modifications to the methodology used to determine bulk mineralogy in Phase 1 were required; however, a pre-treatment process was developed, tested and incorporated into the clay mineral methodology for application to core samples containing a high content of organic matter. Routine methods for surface area determinations (BET) were also found to be applicable. X-ray diffraction analyses (XRD) and Scanning Electron Microcopy (SEM) were used to identify any potential salts, including halite, gypsum/anhydrite, and epsomite in the core. In Phase 2, other soluble salts (e.g. celestite, $SrSO_4$) will also be examined, based on the results from geochemical modeling of pore waters conducted during Phase 1. Confirmation of the presence of solid salts in the core matrix in mineralogical studies provides further constraints on the chemical compositions of the pore waters.

Crush and leach with mineralogical characterization and vacuum distillation is similar to the crush and leach with CEC testing and mineralogical characterization with the difference that the mass of dissolved species in the aqueous extract is normalized to the water loss mass (porosity) determined from vacuum distillation. These aqueous extractions would also be performed under anoxic conditions to mitigate artifacts created by oxidation of pyrite and other sensitive minerals present in the core.

An additional technique for the extraction of pore waters known as the forced advective displacement method was also tested during Phase 1. Scoping tests of this method were conducted on one core sample from the Ordovician shales and one from the Cobourg Formation. In preliminary testing of argillaceous limestone (Cobourg Formation, Bowmanville, Ontario), a sufficient volume of pore water was extracted for analysis of pore water chemical composition. The forced advective method is the only method applied in Phase 1 investigations with the potential to directly provide pore waters for both chemical and isotopic analysis.

Therefore, this method will be applied to an additional sample of Ordovician shale and of the Cobourg Formation during Phase 2.

3.6.2 Stable Isotopic Composition

Characterization of the stable isotopic compositions of pore waters within the Ordovician shales and limestones was attempted using both the vacuum distillation and diffusive equilibration methods during Phase 1. Although adaptation of the diffusive equilibration method to measure $\delta^{18}O$ and $\delta^{2}H$ in saline porewaters in the Ordovician shales and limestones advanced during Phase 1, the analytical uncertainties for both $\delta^{18}O$ and $\delta^{2}H$ are currently considered unacceptable in terms of providing meaningful values for interpretation of pore water isotopic compositions. Therefore, only vacuum distillation will be used to obtain samples for stable isotopes in Phase 2.

Vacuum distillation at temperatures of 150 and 200 °C were applied to extract pore waters for analysis of stable water isotopes ($\delta^{18}O$ and $\delta^{2}H$), $\delta^{13}C$ in extracted carbon dioxide and methane ($\delta^{13}C$, $\delta^{2}H$) from cores taken in the Ordovician shales and limestones and in the Cambrian Formation sandstones. Measurements made at these two temperatures are reported to show good reproducibility, although specific experiments are required during the course of Phase 2 to verify that the water extracted using this technique represents free porewater, and does not include bound water from salt minerals such as gypsum ($CaSO_4 \cdot 2H_2O$) or clay minerals, which may released at lower temperatures. Step-wise thermogravimetric analyses have been recommended by the Geoscience Review Group as a possible method to constrain the temperatures at which different waters are released during vacuum distillation.

3.6.3 Pore Water Gases

Information on gases such as carbon dioxide (CO_2) and methane (CH_4) within the rock matrix pores provides additional constraints on pore water composition and pore water chemistry. During Phase 1, pore water concentrations of carbon dioxide (CO_2) and methane (CH_4) were determined based on their release during vacuum distillation (see above). The $\delta^{13}C$ of carbon dioxide, methane and $\delta^{2}H$ of methane were also measured.

During Phase 1, concentrations and isotopic compositions of noble gases in the rock matrix ($^{3}He/^{4}He$ ratios, ^{4}He and Ne concentrations) were analyzed from micro-cores degassed into sealed, pre-evacuated copper tubes according to protocols described in TP-07-02 (Intera Engineering Ltd, 2007). The gases released into the copper tubes were then trapped, separated and analyzed by mass spectrometry. During Phase 2, modifications will be made to the sampling protocol to improve sample recovery by sealing core samples into containers immediately after the core is retrieved.

The pore water characterization program planned for the vertical boreholes during Phase 2 is summarized in Table 3.3. “Aqueous extraction” in Table 3.3 refers to the combined information from aqueous extraction and cation exchange, mineralogical and pore space analyses and reconstructive modeling. For details on the depths from which cores were collected during Phase 1 and their distribution for testing is given in Appendices A and B of TP-06-10 (Intera

Engineering Ltd, 2007). In Phase 2, this plan will be updated to include sample distribution for core from both DGR-3 and DGR-4.

Table 3.3 Summary of Phase 2 Porewater Characterization Program for Vertical Boreholes

Methods	***Analytes***	***Targeted Formation***	***Total Estimated Number of Tests***
Aqueous Extraction	Master Variables & Major Ions [Group A]	Upper Barrier Shales (Queenston, Georgian Bay and Blue Mountain Formations)	11
		Cobourg Formation	10
		Underlying Barrier rocks (Sherman Fall, Kirkfield, Coboconk, Gull River and Shadow Lake Formations)	7
Crush and Leach and Vacuum Distillation	Master Variables & Major Ions [Group A] Environmental Isotopes [Group B]	Upper Barrier Shales (Queenston, Georgian Bay and Blue Mountain Formations)	13
		Cobourg Formation	13
		Underlying Barrier Rocks (Sherman Fall, Kirkfield, Coboconk, Gull River and Shadow Lake Formations)	9
Core Out-Gassing	Gases [Group D – Noble gases He and Ne only]	Upper Barrier Shales (Queenston, Georgian Bay and Blue Mountain Formations)	10
		Cobourg Formation	10
	Underlying Barrier rocks (Sherman Fall, Kirkfield, Coboconk, Gull River and Shadow Lake)	Underlying Barrier Rocks (Sherman Fall, Kirkfield, Coboconk, Gull River and Shadow Lake Formations)	10

3.7 Characterization of Organic Matter

In Phase 1, total organic carbon (TOC) was determined for core samples. In Phase 2, testing is expanded to include characterization of organic matter including kerogen type and thermal maturity within the Ordovician shale and limestone formations. The rock evaluation pyrolysis method will be applied, which involves controlled heating in an inert (helium) atmosphere to quantitatively determine the free hydrocarbons contained in the sample, and the hydrogen- and oxygen-containing compounds that are volatilized during the cracking of kerogen. TOC, volume percent organic matter and clay mineralogy by XRD will also be characterized as part of organic shale analyses.

In Phase 2, ten samples of organic rich shales and other Ordovician shale formations in each vertical borehole (DGR-3 and DGR-4) will be subject to rock evaluation pyrolysis testing and organic shale analyses.

3.8 Formation Pressures and Hydraulic Heads

Following the completion of borehole hydraulic testing, boreholes DGR-3 and DGR-4 will be completed with MP55 multilevel groundwater monitoring casings manufactured by Westbay Instruments Inc. Similar casing completions were installed in DGR-1 and DGR-2 in the Phase 1 GSCP.

The proposed casing installation in DGR-3 and DGR-4 will be a mix of PVC and stainless steel components in order to overcome the very high differential head conditions observed within boreholes DGR-1 and DGR-2 due to Cambrian Formation overpressure, gas related overpressures within the Salina Formation A0 Unit and the Georgian Bay Formation, and under-pressures within the Blue Mountain and Georgian Bay Formations. Approximately 25 to 40 packer-isolated monitoring intervals will be created within each of boreholes DGR-3 and DGR-4.

Quarterly monitoring of formation pressures will be conducted in deep boreholes DGR-1, DGR-2 DGR-3 and DGR-4, as well as shallow boreholes US-3, US-7 and US-8.

Formation pressures and updated fluid density profiles generated from groundwater and porewater characterization programs will be used to calculate freshwater, density neutral and environmental heads.

3.9 Refinement of the Descriptive Hydrogeologic Site Model

The descriptive hydrogeologic model of the DGR site developed during Phase 1 will be updated during Phase 2. This will involve refinement of the borehole hydraulic testing results and formation pressures and heads for the Silurian and Ordovician formations at the Bruce DGR site and the groundwater and porewater chemistry, environmental isotope chemistry and gas contents, diffusive properties and petrophysical properties including porosity and brine and gas permeability for the Ordovician shale and limestone formations that will host, overlie and underlie the proposed DGR. These new hydrogeological data will be incorporated with the existing Phase 1 data and the current descriptive geologic site model to develop an updated and refined descriptive hydrogeologic model of the DGR site.

4 GEOMECHANICS CHARACTERIZATION PLAN

4.1 Objectives and Scope

The Phase 2 geomechanical characterization activities presented here are developed to expand and refine the Phase 1 geomechanical site characterization work undertaken in 2006 and 2007. These new data will be used to refine the descriptive geomechanical site model, which will be used to improve the descriptive geosphere site model of the Bruce site and surrounding area.

The following sections present descriptions of major work elements to be addressed in the Phase 2 investigation program. Like the Phase 1 investigation, it is comprised of field and laboratory testing. The seven major geomechanics work elements are listed below:

- Seismic Monitoring and Hazard Assessment
- Geomechanical Core Logging, Core Preservation and Field Index Testing
- Borehole Geophysical Logging
- In-situ Stress Estimation
- Laboratory Geomechanical Testing
- Rock Mass Property Characterization
- Refinement of Descriptive Geomechanical Site Model

4.2 Seismic Monitoring and Hazard Assessment

During the Phase 1 work, a local seismograph network was installed by Polaris (University of Western Ontario) within a 50 km radius around the proposed DGR site to monitor micro local and regional seismic events. The network consists of a previously existing surface seismological station (BRCO) and three new borehole stations with seismograph units installed between 25 to 40 mBGS.

Monitoring microseismic events will improve our understanding of occurrence of earthquakes and the data may be used to delineate structural features in the area that may be associated with low level seismicity. The seismicity data collected by these stations are transmitted instantaneously via satellite-telemetry to the central hubs at the Geological Survey of Canada (GSC) in Ottawa and the University of Western Ontario in London. Polaris currently undertakes the maintenance of the three borehole seismograph stations. Earthquake data are analyzed and cataloged by the Geological Survey of Canada using data acquired from the new borehole seismograph stations with others stations in the region

A preliminary seismic hazard assessment has already been carried out as part of the Phase 1 geosynthesis program. This seismic hazard assessment was based on available earthquake data to address the occurrence of a low probability moderate to large magnitude event happening near the Bruce site. The seismic hazard assessment will be updated in Phase 2 with the data collected from the Bruce seismic network and from the proposed site characterization activities prior to the submission of the DGR Environmental Assessment and the license application for repository construction in 2011.

4.3 Geomechanical Core Logging, Core Preservation and Field Index Testing

Core logging and core preservation will be continued in a manner consistent with that followed in Phase 1. Core logging will provide detailed descriptions of the rock lithology and stratigraphy, degree of weathering, Rock Quality Designation (RQD) and characteristics of fractures and other structural features.

During the Phase 2 investigation, P- and S-wave velocity measurement and limited point load testing will be undertaken on fresh core. The test results will provide a qualitative measure of the strength and anisotropy of the rock throughout the sedimentary sequence. Limited point load testing will be performed both diametrally and axially. Additionally, the shale content of the test samples shall be estimated based on visual inspection. Although this procedure is subjective, it provides a qualitative measure of variability in both geological composition and compressive strength of the rocks.

In the Phase 2 work, slake durability testing, will be conducted to confirm that there is no significant slaking behavior in the target horizon, and to assess if there is any significant slaking behavior of the materials surrounding the proposed shaft seals. Testing will be performed on the Ordovician shales above the Cobourg Formation, in the Cobourg Formation limestone itself (target horizon), and at the shale horizons of proposed shaft seals in the overlying Silurian rocks. It is anticipated that approximately 20 tests in total (10 per vertical hole) will be adequate to detect any variation in slaking behavior compared to the DGR 1 and DGR-2 results,

4.4 Borehole Geophysical Logging

The borehole geophysical logs required for geomechanical characterization of the DGR site are described in Section 2.7. Borehole geophysical logging for geomechanical characterization purposes will be undertaken in Phase 2 boreholes DGR-3 and DGR-4.

4.5 In-situ Stress Estimation

Currently, there is a lack of site specific information on in-situ stresses, and the in-situ stress data that have been assumed for design purposes are based on far field measurements within the Michigan and Appalachian Basins (Lam et al, 2007). One of the primary objectives of the Phase 2 program is to delineate the stress regime at the Bruce site. Unfortunately, the available methods for accurate measurement of in-situ stresses in deep boreholes such as those at the DGR site have severe limitations and uncertainties associated with them (Martin et al, 2001).

Bounding estimates of in-situ stresses may be obtained from the observations of borehole breakouts and spalling at the Bruce site. These estimates may be used as preliminary data to examine the stress regime at the site. Because the boreholes are themselves small-scale excavations, the response of the borehole walls provides direct information on the relationship between the in-situ (and induced) stresses at the site and the laboratory estimates of the strength of the rock materials in the various geological horizons. Valley and Evan (2007) give examples of such an approach, based on evaluation of data from down-hole geophysical logging, core logging, and laboratory testing. This approach was applied in Phase 1 and may be applied to the Phase 2 exploratory data.

4.6 Laboratory Geomechanical Testing

Phase 2 laboratory geomechanical testing will be an extension of the Phase 1 testing program and provide a more comprehensive suite of data concerning the geomechanical properties of the rock material. Complete standard descriptions and petrographic/mineralogical analyses for rock materials will be carried out on corresponding samples in the Phase 2 investigation using the data collection techniques described in Sections 2.6 and 2.8.

The proposed schedule of all laboratory geomechanical testing is summarized below in Table 4.1.

Table 4.1 Summary of Phase 2 Laboratory Geomechanical Testing Program

Method	***Targeted Formation***	***Number of Tests***			
		DGR-3	***DGR-4***	***DGR-5***	***DGR-6***
Uniaxial Compression Test (with AEM)	Cobourg/Sherman Fall Formation	12	12	4	4
	Upper Ordovician Formations	10	10	4	4
	Devonian and Silurian Formations	5	5		
Cross-anisotropic Test	Cobourg/Sherman Fall Formation	2	2		
	Upper Ordovician Formations	2	2		
Brazilian Splitting Tension Tests	Cobourg/Sherman Fall Formation	4	4		
	Upper Ordovician Formations	9	9		
Triaxial Test	Cobourg/Sherman Fall Formation	6	6		
	Upper Ordovician Formations	3	3		
Long-term Strength Degradation/Creep Test	Cobourg/Sherman Fall Formation	3	3		
	Upper Ordovician, Devonian and Silurian Formations	3	3		
Free Swell Tests	Upper Ordovician Formations	3	3		
	Devonian and Silurian Formations	4	4		
Direct Shear Tests	Cobourg/Sherman Fall Formation	8	8		
	Upper Ordovician Formations	4	4		
Cherchar Abrasivity Index Test	Cobourg/Sherman Fall Formation	10	10		

4.6.1 Strength and Deformation Parameters

Uniaxial compressive testing of selected core samples from the host and cap rock units will be performed to fill in the existing data gaps and to detect any spatial variation in strength across the site, i.e., between Phase 1 and 2 boreholes. Emphasis will be put on determining the long-term strength degradation properties of the host rocks, and determining of the triaxial (Hoek-Brown) strength parameters of the host rock. Uniaxial compressive tests will also be conducted on samples retrieved from the formations that are planned for the installation of the shaft seals according to the DGR Conceptual Design (Hatch Ltd, 2008).

Special uniaxial compression tests for cross-anisotropic deformation parameters will be performed to obtain the strength and deformation modulus of rock in the vertical, horizontal and possibly inclined directions. In the Phase 2 investigation these tests will be limited to samples from the Queenston, Georgian Bay, Cobourg and Sherman Fall Formations. Uniaxial compressive tests on samples at the corresponding depths obtained from the two inclined boreholes (DGR-5 and DGR-6) will be carried out to verify the results of the cross-anisotropic testing.

Triaxial compression tests will be conducted on the host and cap rocks under various confining pressures to evaluate appropriate strength envelopes for design purposes. The actual number of tests required will depend on the consistency of the results that are obtained from different samples under various confining stresses. Brazilian (split) tensile testing will be performed on the host and cap rocks to evaluate tensile strength. Provision will be made for direct tension testing on selected samples containing weak bedding partings.

Direct shear testing will be conducted on selected samples to determine the shear strength and stiffness of bedding planes of host and cap rocks. The shear surface will be profiled before and after the shear test to facilitate the determination of the base friction angle.

Time dependent strain or long-term strength degradation/creep tests under staged low constant loading will be performed on Cobourg Formation samples from DGR-3 and DGR-4 for the determination of the stress level below which no long-term strength degradation would take place. Additional creep tests will also be conducted on cores obtained from the Upper Ordovician, Silurian and Devonian Formations at selected shat seal locations.

4.6.2 Swelling/Squeezing Parameters

The swelling/squeezing aspect of the cap and host rocks was investigated in Phase 1 and showed the Cobourg and Sherman Fall limestones do not exhibit any swelling in brine. The swelling potential observed in the three shale formations, the Queenston, Georgian Bay and Blue Mountain, under a fresh water environment are noticeably lower than the measurement in the same formations at other locations in Ontario. A limited number of free swell tests (7 per vertical borehole) in fresh water will be conducted on samples from the vertical boreholes, DGR-3 and DGR-4 to confirm that swelling behavior of the rock is consistent across the site. Tests will also be done on samples from the shale formations in the overlying Silurian rock sequence, including the Salina F Unit, Salina C Unit and Cabot Head Formation shales.

4.6.3 Abrasivity Tests

As a part of the Phase 1 work, ten Cherchar Abrasivity Index (CAI) tests were conducted on samples from the Cobourg and Sherman Fall formations to evaluate the cutter-wear of a road header and other excavators and the cutability of the host rock (TR-07-04, Intera Engineering Ltd, 2007). Twenty additional tests in the limestone will be performed on samples from DGR-3 and DGR-4 in Phase 2 work.

4.7 <u>Rock Mass Property Characterization</u>

Rock mass properties were evaluated in Phase 1 and will be continued in Phase 2. The results from Phase 1 will produce a description of the discontinuities associated with the rock units.

The data from Phase 2 will increase the confidence in the geomechanical property estimation for the overall rock mass at each geological horizon important for repository design. In particular, the two inclined boreholes (DGR-5 & DGR-6) will provide critical information on the occurrence, spacing and nature of any vertical jointing at the site.

The following activities are proposed in Phase 2 to evaluate and refine estimates of the DGR rock mass properties:

- Compile and evaluate all available information on rock mass properties derived from precedent excavations in the same geological formations.
- Provide an extensive description of the actual stratigraphy and lithology of the site based on the geological information obtained from the Phase 2 drilling and testing.
- Develop a thorough site description of the discontinuities associated with each geologic unit, based on core logging and downhole geophysical logging data. This will include analysis of discontinuity occurrence and engineering characteristics. This information together with the rock mass properties are essential for rock mass classification systems and empirical correlations to be used in repository design.

4.8 Refinement of Descriptive Geomechanical Site Model

The descriptive geomechanical model of the DGR site developed during Phase 1 will be updated during Phase 2. This will involve incorporation of the new field and laboratory geomechanical data collected in Phase 2 with the current descriptive geologic site model to develop an updated descriptive geomechanical model of the DGR site. The new geomechanical data will include new data on intact rock strength, swelling, slaking and abrasivity behaviour, discontinuity occurrence and characteristics, and rock mass property characterization. These data will be collected from both the Ordovician shale and limestone formations and the overlying Silurian and to a lesser extent the Devonian rock formations.

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