OPG's DEEP GEOLOGIC

# REPOSITORY

FOR LOW & INTERMEDIATE LEVEL WASTE

# Geoscientific Site Characterization Plan

April 2006

Prepared by:
INTERA Engineering Ltd.

INTERA 05-220-1
OPG 00216-REP-03902-00002-R00

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# DOCUMENT HISTORY

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|---|---|---|
| **Title:** | Geoscientific Site Characterization Plan | |
| **Subtitle:** | OPG's Deep Geologic Repository for Low and Intermediate Level Waste | |
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| **Prepared by:** | Kenneth Raven, Sean Sterling, John Avis, Richard Jackson, Dougal McCreath, Richard Beauheim, René Graf, Peeter Pehme, Gail Atkinson | |
| **Reviewed by:** | John Pickens, Kenneth Raven, John Avis | |
| **Approved by:** | Kenneth Raven | |

## EXECUTIVE SUMMARY

Ontario Power Generation Inc. is proposing the development a Deep Geologic Repository (DGR) for low and intermediate level radioactive waste at the Bruce Nuclear site, located near Tiverton, Ontario. The DGR will be constructed as an engineered facility comprising a series of underground emplacement rooms at a depth of about 660 m below ground surface within the Paleozoic argillaceous limestone of the Lindsay Formation.

This report describes the Geoscientific Site Characterization Plan (GSCP) recommended to acquire the necessary geoscientific information to support the development of descriptive geosphere models of the Bruce Nuclear site and the preparation of a DGR environmental assessment and site preparation/construction license application to the Canadian Nuclear Safety Commission. The GSCP described in this document addresses the site characterization data and information needs of DGR safety assessment and repository engineering functions. The important DGR geoscience data needs include: geological setting and framework, geomechanical setting and framework, hydraulic properties and state, diffusion and sorption properties, groundwater/porewater characterization and seismicity.

The GSCP provides a technical description of the selection and proposed application of preferred tools and methods for site-specific geoscientific characterization of the sedimentary bedrock formations found at the Bruce site. These tools and methods have been identified based on assessment of geoscience data needs and collection methods, review of the results of detailed geoscientific studies completed in the same bedrock formations found off the Bruce site, and recent international experience in geoscientific characterization of similar sedimentary rocks for radioactive waste disposal purposes. The GSCP also describes recommended off-site or complementary geoscientific studies considered necessary to the development of a comprehensive geosynthesis or geoscientific understanding of the Bruce site relevant to the DGR safety case.

The GSCP is a 5 year program designed for iterative development, testing and refinement of site-specific descriptive geosphere models, including geologic, hydrogeologic and geomechanical models. The GSCP is structured into three principal work components: a series of initiation activities necessary to start the site characterization work; three investigative phases; and a geosynthesis or analysis and interpretation task. The GCSP provides a detailed description of initiation requirements; Phase 1 work elements for geologic, hydrogeologic and geomechanical site characterization plans; and of geosynthesis, quality and data management plans. Phase 2 and Phase 3 GSCP activities are necessarily described in general terms and will be defined in great detail following the completion of Phase 1 work.

## CONTENTS

**Page**

## LIST OF TABLES

## LIST OF FIGURES

## LIST OF KEY ACRONYMS

AECL: Atomic Energy of Canada Ltd.
AMS: Accelerator Mass Spectrometry
ANDRA: Agence Nationale pour la Gestion des Déchets Radioactifs
BGS: Below Ground Surface
BOP: Blow-Out Prevention
CEC: Cation Exchange Capacity
CMT: Computerized Micro Tomography
CNSC: Canadian Nuclear Safety Commission
DDGS: Deep Doorstopper Gauge System
DGR: Deep Geologic Repository
DGRTP: Deep Geologic Repository Technology Program
DMS: Data Management System
DST: Drill Stem Test
EA: Environmental Assessment
EDZ: Excavation Damage Zone
EPG: Electromagnetic Pressure Gauge
FEC: Fluid Electrical Conductivity
FMI: Formation Macro Imaging
GSCP: Geoscientific Site Characterization Plan
GIS: Geographic Information System
GRG: Geoscience Review Group
GSI: Geological Strength Index
GVS: Geoscience Visualization System
ICP/MS: Inductively Coupled Plasma Mass Spectrometry
IST: In Situ Stress Measurement Tool
K: Hydraulic Conductivity
MNR: Ontario Ministry of National Resources
MOE: Ontario Ministry of the Environment
NAGRA: National Cooperative for Disposal for Radioactive Waste
NWMD: Nuclear Waste Management Division
NWRI: National Water Research Institute
OPG: Ontario Power Generation
PIP: Production-Injection Packer
PQP: Project Quality Plan
QA: Quality Assurance
RE: Repository Engineering
RMR: Rock Mass Rating
RQD: Rock Quality Designation
SA: Safety Assessment
T: Transmissivity
VSP: Vertical Seismic Profiling
XAS: X-Ray Absorption
XRD: X-Ray Diffraction
XRF: X-Ray Fluorescence

# 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 for the proposed Low and Intermediate Level Radioactive Waste Deep Geologic Repository (DGR) at the Bruce Nuclear site. Throughout the remainder of this report, the acronym “GSCP” will refer to this plan.

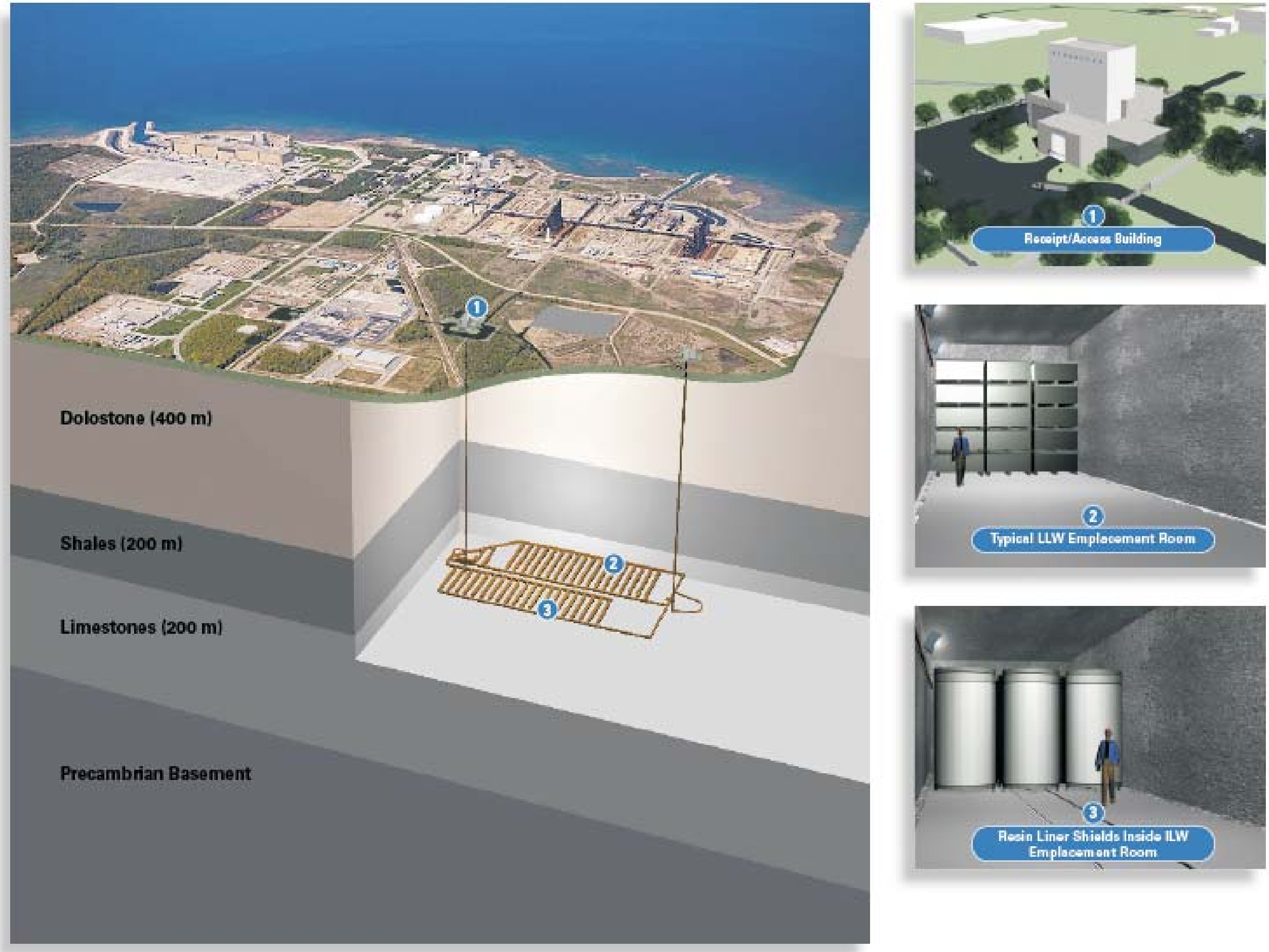
The report describes the geoscientific site characterization activities recommended to acquire the necessary geoscientific information to support the preparation of a DGR Environmental Assessment and Site Preparation/Construction License application. As such the GSCP fully addresses data and information needs of DGR Safety Assessment and Repository Engineering functions.

The DGR is proposed to be constructed at a depth of about 660 m below ground surface within the argillaceous limestone of the Lindsay Formation. Figure 1.1 shows an artist’s rendering of the DGR concept, including the principal surface buildings, access and ventilation shafts, and the underground emplacement rooms for low and intermediate level radioactive waste. 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 Nuclear site. Figure 1.2 illustrates the currently proposed conceptual layout of the DGR underground facilities. 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.

This report has been prepared based on presentations and recent discussions and follow-up review comments from the DGR Site Characterization Plan Workshop held October 17/18, 2005 at OPG University Avenue offices, Toronto, Ontario. This 2-day Workshop was convened to solicit discussion and develop consensus on the scope and content of a site-specific GSCP. The Workshop was attended by senior INTERA Geoscience Task Leaders, OPG and OPG’s Geoscience Review Group (GRG). The Geoscience Review Group (see Section 1.5) provides OPG with independent oversight and peer review of the GSCP based on international experience in similar work programs.

This report provides the technical description of the GSCP. It includes a description of both the selection and proposed application of preferred tools and methods for the site-specific geoscientific characterization of the DGR site. The information gathered through such site-specific investigations will serve as the basis for development of a Descriptive Geosphere Model of the Bruce Nuclear site that supports Repository Engineering and Safety Assessment functions. The report also describes activities associated with off-site or complementary geoscientific studies related to the development of a Geosynthesis for the proposed project. The purpose of the Geosynthesis is to provide an integrated geoscientific understanding of the past, present and future evolution of the Bruce Nuclear site relevant to the DGR Safety Case.

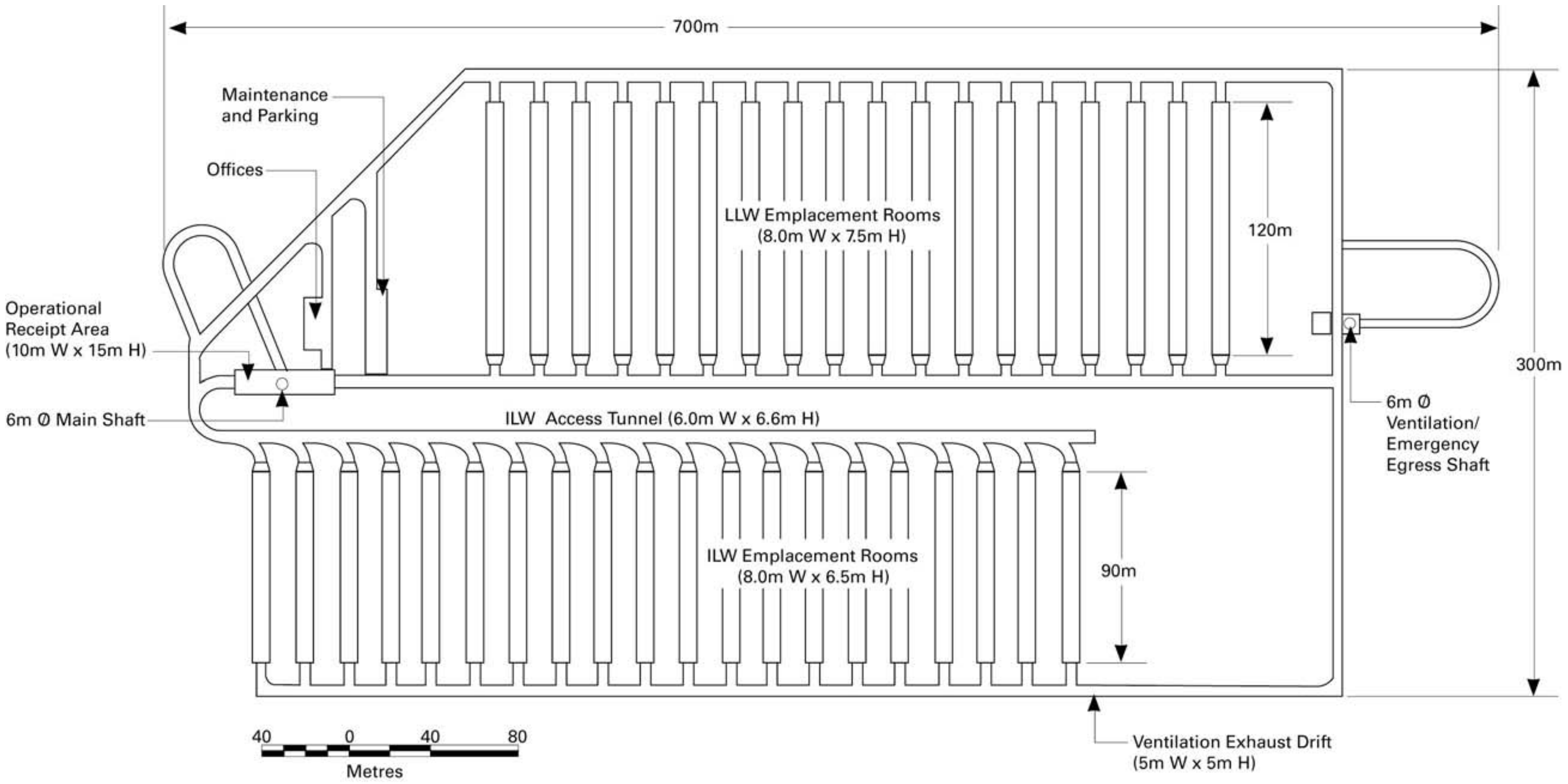
The GSCP presented here is a summary of the methods and scope recommended by INTERA Geoscience Task Leaders, and reflects discussions with OPG and GRG and incorporates GRG (2005a, 2005b, 2006) recommendations. We have taken the various contributions and reformatted them to provide a uniform presentation.



Artist's Rendering of a DGR at the Bruce Nuclear Facility
Geoscientific Site Characterization Plan for Bruce DGR

Figure 1.1
05-220-1

April 2006
ADG F1-1 DRRpanel1a2.cdr



Conceptual Layout of DGR Underground Facilities
Geoscientific Site Characterization Plan for Bruce DGR

Figure 1.2
05-220-1

April 2006
ADG F1-2 Conceptual layout.cdr

## 1.2 REPORT ORGANIZATION

This document consists of the following sections:

| | |
|---|---|
| Section 1: | Introduction – the remaining parts of Section 1 describe organization of this report, GSCP objectives and scope, the GRG, technical workshops and the strategy for development of the GSCP. |
| Section 2: | Geoscience Data Needs and Collection Methods – a summary of the approach followed in identifying and rationalizing data needs and in screening and selecting methods to collect geoscience data. |
| Section 3: | Geoscientific Site Characterization Plan – a description of the work phases, overall project schedule, work element organization and reports hierarchy. |
| Section 4: | Geologic Characterization Plan – a description of the objectives, major work elements and implementation issues for the geological characterization component of the GSCP. |
| Section 5: | Hydrogeologic Characterization Plan – a description of the objectives, major work elements and implementation issues for the hydrogeological characterization component of the GSCP. |
| Section 6: | Geomechanics Characterization Plan – a description of the objectives, major work elements and implementation issues for the geomechanical characterization component of the GSCP. |
| Section 7: | Geosynthesis – a description of the objectives, major work elements and implementation issues for the geosynthesis component of the GSCP. |
| Section 8: | Project Schedule – a summary of the sequencing and timing of major work elements during Phase 1 of the GSCP. |
| Section 9: | Quality Plan – the GSCP Project Quality Plan (PQP) is described at an overview level. The PQP goals, sources, and basic elements are described. |
| Section 10: | Data Management – identifies data management requirements and describes possible software solutions. |
| Section 11: | Requirements for GSCP Initiation – summarizes those activities or tasks that need to be completed prior to Phase 1 investigations to implement the GSCP. |
| Section 12: | References. |
| Appendix A: | Geoscience Data Collection Methods – provides a tabular listing of all data collection methods considered in the development of the GSCP, their advantages and disadvantages and relative costs. |

## 1.3 GSCP OBJECTIVES

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

The current conceptual geosphere model of the site describes a sequence of layered sedimentary rocks, overlying the Precambrian basement, located at a depth of ~850 m. Figure 1.3 shows a schematic representation of the assumed bedrock stratigraphy based on outcrop nomenclature and DGR depth location at the Bruce Nuclear site. 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 limestone at a depth of 660 m, about 50 m below the assumed shale/limestone contact. It is also assumed that groundwater in the deeper units (i.e., from 425 to 850 m depth) is ancient and highly saline. The assumed low permeability of the rock indicates a stagnant flow system where transport of contaminants will be dominated by diffusion. All of these assumptions are based on data acquired at locations elsewhere in Ontario, some of which are several hundred kilometres removed. Currently, there are no site-specific data below a depth of about 100 m at the Bruce Nuclear site.

The primary focus of the GSCP is on subsurface characterization. Furthermore, this subsurface characterization is to be completed through surface-based investigations only and therefore the GSCP does not include underground based investigation. The GSCP is intended to provide the site-specific data necessary to validate (or invalidate) the assumptions of Section 2.1, and to support a CNSC license application for site preparation/construction. The geosphere data, and particularly the data describing the Ordovician intervals, are vital to development of the overall DGR safety case, which relies heavily on the concept of long-term geologic isolation.

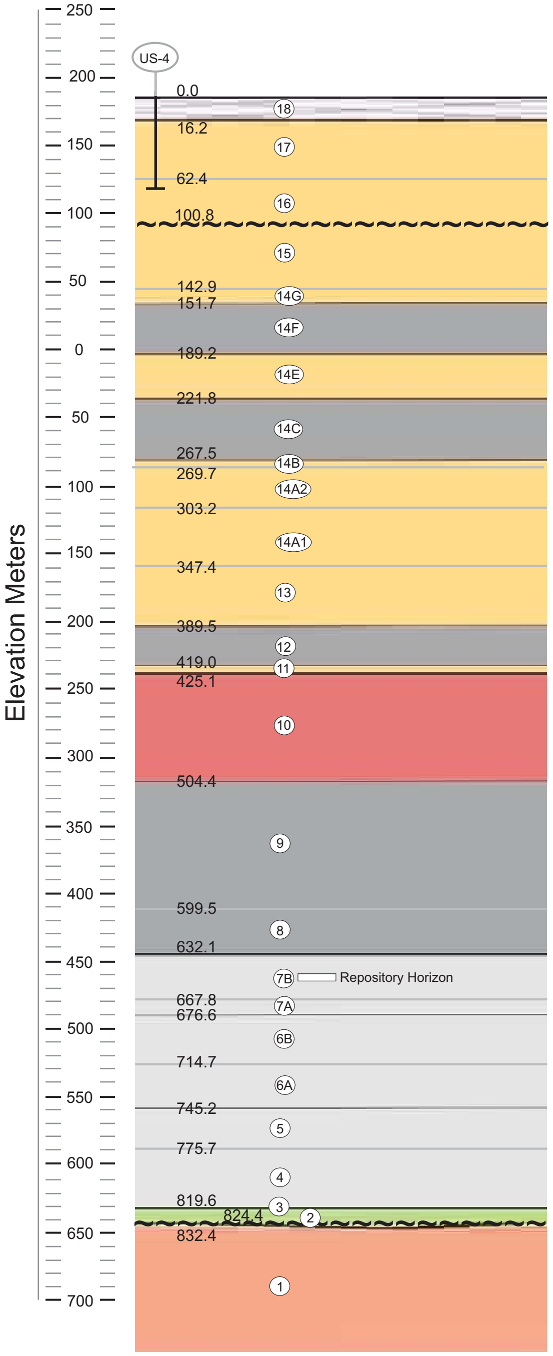
The elements of the GSCP described within this report are considered consistent with the Canadian Nuclear Safety Commission (CNSC) Wastes and Geosciences Division discussion paper entitled “Siting and Site Characterization for Long-Term Radioactive Waste Containment Facilities – Version 1.1, May 2005”. The GSCP does, however, only describe those activities required for subsurface characterization with the intent that this work would be integrated with surface based information during preparation of the DGR Environmental Assessment and Site Preparation/Construction License application.

## 1.5 THE GEOSCIENCE REVIEW GROUP

Independent oversight and peer review of the GSCP through its various stages of development is provided by OPG’s Geoscience Review Group (GRG). The GRG is comprised of internationally renowned scientists and engineers who, among other roles, ensure that information and lessons learned in similar international DGR work programs are reflected in the GSCP.

The GRG is comprised of the following members, who provide expertise in the following areas:

- Dr. Derek Martin, University of Alberta - Rock Engineering and Geomechanics
- Dr. F. Joe Pearson, Consultant - Groundwater Geochemistry
- Dr. Andreas Gautschi, Swiss National Cooperative for Disposal for Radioactive Waste (NAGRA) - Geosynthesis and Geoscience Overview



## STRATIGRAPHIC LEGEND

PLEISTOCENE
18 SURFICIAL DEPOSITS

MIDDLE DEVONIAN
17 AMHERSTBURG FORMATION - LIMESTONE AND DOLOSTONE

LOWER DEVONIAN
16 BOIS BLANC FORMATION - CHERTY DOLOSTONE
~~~~~~ SILURIAN / DEVONIAN DISCONTINUITY

UPPER SILURIAN
15 BASS ISLAND FORMATION - DOLOSTONE
14 SALINA FORMATION
14G G MEMBER - DOLOSTONE AND SHALE
14F F MEMBER - DOLOMITIC SHALE AND SHALE
14E F MEMBER - DOLOSTONE
14D D MEMBER - SALT (ABSENT IN SITE AREA)
14C C MEMBER - DOLOMITIC SHALE AND SHALE
14B B MEMBER - DOLOSTONE AND ANHYDRITE (2m)
14A2 A2 MEMBER - DOLOSTONE, SHALY DOLOSTONE
14A1 A1 MEMBER - DOLOMITIC SHALE AND SHALE

MIDDLE SILURIAN
13 GUELPH, LOCKPORT AND REYNALES FORMATIONS - DOLOSTONE

LOWER SILURIAN
12 CABOT HEAD FORMATION - GREY SHALE
11 MANITOULIN FORMATION - ARGILLACEOUS DOLOSTONE

UPPER ORDOVICIAN
10 QUEENSTON FORMATION - RED SHALE AND SILTSTONE
9 GEORGIAN BAY FORMATION - GREY SHALE AND SILTSTONE
8 COLLINGWOOD FORMATION - GREY SHALE

MIDDLE ORDOVICIAN
7 LINDSAY FORMATION
7B UPPER MEMBER - LIMESTONE AND ARGILLACEOUS LIMESTONE
7A SHERMAN FALLS MEMBER - LIMESTONE
6 VERULAM FORMATION
6B UPPER MEMBER SHALY LIMESTONE
6A LOWER MEMBER ARGILLACEOUS LIMESTONE
5 BOBCAYGEON FORMATION - SHALY LIMESTONE TO CRYSTALLINE LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LIKE FORMATION - SILTSTONE, SANDSTONE

CAMBRIAN
2 CAMBRIAN SANDSTONE
~~~~~~ CAMBRIAN / PRECAMBRIAN UNCOMFORMITY

PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS

NOTE:
1. STRATIGRAPHIC SEQUENCE WAS DEVELOPED FROM A COMPOSITE OF THE SHALLOW BOREHOLE US-4 ONSITE AND THE DEEPER OFFSITE GAS EXPLORATION WELL TEXACO #6 IN BRUCE TWP LOT E CONCESSION IV BASED UPON A MATCH POINT AT THE AMHERSTBURG / BOIS BLANC CONTACT

Assumed Bedrock Stratigraphy and DGR Depth Location at Bruce Site
Geoscientific Site Characterization Plan for Bruce DGR

| | |
|---|---|
| Figure 1.3<br>05-220-1 | April 2006<br>ADG F1-3 Bedrock Stratigraphy.cdr |

The GRG has produced three peer review reports (GRG, 2005a; 2005b; 2006) on the GSCP. This GSCP report incorporates the GRG review comments.

## 1.6 TECHNICAL WORKSHOPS

The GSCP described in this report has evolved based on presentation and discussion amongst geoscience experts at two technical workshops convened as part of the GSCP development project. These technical workshops were attended by OPG, INTERA Geoscience Task Leaders and members of the Geoscience Review Group, as well as selected invited participants to address important geoscience issues.

A 2-day technical workshop on geoscience data needs and collection methods screening was held August 16 and 17, 2005 at the Bruce Nuclear site. This workshop was held to solicit discussion and to develop consensus on geoscience data needs and preferred methods of obtaining such data as part of the GSCP. The results of this workshop are summarized by INTERA (2005) and GRG (2005b).

A second 2-day technical workshop was held on October 17 and 18, 2005 in Toronto. This workshop was convened to present, discuss and seek consensus on the content, scope, methods and schedule for the DGR site characterization plan. GRG Report 2 (GRG, 2005a) was prepared following this second workshop.

GRG Report 3 (GRG, 2006) was prepared following release of a final draft version of this GSCP report in December 2005.

## 1.7 GSCP STRATEGY

The strategy for development of the GSCP is founded on the following key elements:

- A 5-year three phase site characterization program designed for iterative development, testing and refinement of a site-specific Descriptive Geosphere Model(s). This approach allows for adaptive management of the GSCP to respond to acquired geoscientific knowledge and emerging information requirements for DGR Safety Case development.
- An assessment of internationally accepted site-specific geoscience attributes relevant to understanding technical site acceptability.
- Peer review of the GSCP by OPG stakeholders, regulatory agencies and the independent Geoscience Review Group.
- Integration of the GSCP with on-going regional geologic and hydrogeologic studies in southwestern Ontario relevant to assessing concepts of long-term DGR safety.
- Use of scientific visualization techniques to improve transparency and traceability of multi-disciplinary data interpretation and, hence, the ability to communicate GSCP results to stakeholder audiences.
- Initiation of complementary geoscience analogue studies to assist with the explanation of geoscience phenomena and confidence related to the understanding of long-term DGR safety.
- Direct inclusion of international geoscience site characterisation experience in investigating deep sedimentary formations for long-term radioactive waste management purposes.

- Participation in various international forums focused on development of geoscience approaches and methods for demonstrating safety of geological disposal in sedimentary formations.
- Performance of GSCP activities under an appropriate Project Quality Plan.
- Selection and scheduling of GSCP activities to specifically minimize GSCP and DGR project risk and cost.

## 1.8 ACKNOWLEDGMENTS

This document, while authored by INTERA Engineering Ltd. and remaining the responsibility of INTERA, is based on major geoscience contributions provided by members of the INTERA GSCP Project Team. The contributions of the following individuals are acknowledged in the preparation of this report.

- Kenneth Raven - Project Manager and Task Leader Geology & Geophysics, INTERA Engineering Ltd.
- John Avis - Task Leader, Quality Plan/Data Management & Modeling/Data Visualization INTERA Engineering Ltd.
- Sean Sterling – Task Leader, Borehole Drilling, Sealing & Monitoring Systems, INTERA Engineering Ltd.
- Richard Beauheim – Task Leader, Borehole Hydraulic Testing, Sandia National Laboratories.
- Dr. Richard Jackson – Task Leader, Geochemistry and Laboratory Testing, INTERA Inc.
- Dr. Dougal McCreath – Task Leader, Geomechanics, Laurentian University.
- Dr. John Pickens – GSCP Review and Integration, INTERA Inc.
- Bill Millican - Quality Assurance, INTERA Inc.
- Nicola Calder – Data Model Development & Numerical Modeling, INTERA Engineering Ltd.
- David Forsyth – 2-D Seismic Surveys, Geological Survey of Canada
- René Graf – 3-D Seismic Surveys, Proseis AG.
- Peeter Pehme – Borehole Geophysics, University of Waterloo.
- Randy Roberts – Borehole Hydraulic Testing, Sandia National Laboratories.
- Dr. Gail Atkinson – Seismicity, Carleton University.
- Dr. Ian Clark, Isotope Geochemistry, University of Ottawa
- Dr. Tom Kotzer, Radiochemistry and Sorption, University of Saskatchewan
- Dr. Luc Van Loon, Diffusion Testing, Paul Scherrer Institute
- Dr. Mark Cave, Porewater Extraction, British Geological Survey

## 2. GEOSCIENCE DATA NEEDS AND COLLECTION METHODS

Geoscience data needs and collection methods are discussed in detail in an earlier report (INTERA, 2005). This section provides a short summary of the rationale and approach followed in identifying geoscience data needs and in screening and selecting preferred methods for collecting the required geoscientific information.

### 2.1 FAVOURABLE SITE CHARACTERISTICS AND FEATURES

The DGR concept for the Bruce Nuclear site is largely based on an existing descriptive geosphere site model in which the geoscientific conditions and features are judged favourable for the long-term isolation and containment of low and intermediate level radioactive waste. It is helpful and appropriate to list these assumed site characteristics and features as they provide a reasoned basis to justify GSCP data requirements.

The assumed favourable geoscience characteristics and features for the Bruce Nuclear site relevant to demonstrating repository safety are as follows.

- The deep 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.
- Active faulting and seismicity at and near the site are 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 deep shale and argillaceous limestones are thick and of very low permeability, providing a very tight 200 m thick bedrock horizon for the waste management facility, and an additional very tight 200 m thick barrier to upward migration from the facility.
- Mass transport in the deep shales and limestones is diffusion dominated. The deep groundwater system in the shales and limestones is saline (about 100-200 g/L), stagnant, stable and ancient, not showing evidence of either glacial perturbations or cross formational flow or mixing.
- The shallow water supply aquifer in the upper carbonate bedrock is hydrogeologically isolated and protected from the stagnant deep saline groundwater system.

The GSCP considers these assumed site characteristics and features, because they are judged fundamental to demonstrating the long-term performance and safety of the DGR. In addition, data needs have been included to allow assessment of DGR construction and operational feasibility and impacts.

### 2.2 IDENTIFICATION OF GEOSCIENCE DATA NEEDS

Geoscience data needs for the GSCP are summarized in Table 2.1. Table 2.1 is a master table of geoscience data needs for the GSCP identified from individual INTERA Task Leader and Project reviews completed as part of this project. Table 2.1 includes all geoscience data needs from Phase 1, 2 and 3 investigations.

Table 2.1 presents data needs organized by the following geoscience disciplines.

1. Geological Setting and Framework
2. Geomechanical Setting and Rock Properties
3. Hydraulic Properties and State
4. Diffusion and Sorption Properties
5. Groundwater/Porewater Characterization
6. Seismicity

Data needs are identified for each geoscience discipline listed above. A rationale or justification is also provided in Table 2.1 for each identified data need that explains why the data are needed and how they contribute to the site-specific descriptive geosphere models and the Safety Case for the proposed DGR.

In this GSCP, we follow the practice used by NAGRA (Gimmi and Waber, 2004) of defining ‘groundwater’ as free-flowing or free-phase water, whereas low-permeability rocks yield ‘porewater’ upon extraction.

**Table 2.1: Master Table of Geoscience Data Needs**

| Geoscience Discipline | Data Need | Rationale for Inclusion |
|---|---|---|
| **1. Geological Setting and Framework** | **1.1 Existing Geological Information**<br>- local and regional information on overburden and lithology and structure of bedrock units from ground surface to Precambrian.<br>- establish basin history, tectonics, sediment source, dissolution events, and thermochronology from time of sedimentation.<br>-establish geologic history over time frames of several million years<br>- establish petroleum geology resources | Provides regional geological framework for design of site characterization plan, for design of baseline monitoring program to define background conditions, understanding of geologic homogeneity of deep Ordovician bedrock units, and understanding of long-term geologic stability of site. Provides assessment of resource potential and therefore likelihood of human intrusion scenario. |
| | **1.2 Existing Geophysical Information**<br>- regional aeromagnetics and gravity surveys, existing 2-D and 3-D seismic surveys completed for oil and gas exploration investigations. | Provides regional geological structural framework to GSCP. Seismic surveys may assist in evaluation of merit of completing these surveys at the Bruce Nuclear site. |
| | **1.3 Stratigraphic Sequence**<br>- overburden and bedrock units from ground surface to Precambrian. | Provides geometric framework for 3-D geosystems model of DGR, an integral part of facility performance assessment, design and safety case. |
| | **1.4 Formation Thicknesses and Attitudes**<br>- elevations of top and bottom of each unit/formation. | Provides geometric framework for 3-D geosystems model of DGR, an integral part of facility performance assessment and safety case. Uniformity of formation thickness and attitude can also support the safety case via predictable geology. |

**Table 2.1: Master Table of Geoscience Data Needs**

| **Geoscience Discipline** | **Data Need** | **Rationale for Inclusion** |
|---|---|---|
| **1. Geological Setting and Framework (cont'd)** | **1.5 Structural Framework**<br>- major (faults/fracture zones) and minor (joints, fractures) within 1 km of DGR in all bedrock units, particularly within Ordovician shales and limestones. | Important for assessing potential for advective transport from DGR, and for assessing likelihood of earthquake-induced fracturing of host rocks for the DGR. |
| | **1.6 Bedrock Petrography and Mineralogy**<br>- petrographic, mineralogic and elemental composition (U, Th, K, Ra Rb) of all bedrock units, including geochemistry of pore and fracture surfaces.<br>- identification of thermal diagenetic changes in mineralogy and secondary mineral precipitation changes to rock porosity. | Provides identification of bedrock units, allows unit interpolation between holes. Necessary for reliable characterization of pore fluid chemistry, radionuclide sorption and retardation, isotope in-growth calculations (i.e., $^{129}$I and $^{36}$Cl), and estimation of natural background radioactivity (Ra, Rb). |
| **2. Geomechanical Setting and Rock Properties** | **2.1 Existing Geomechanical Information**<br>- compilation and evaluation of geomechanics data (stresses, rock material properties and rock mass properties) from other excavations in these bedrock units. | Important for providing context to the required geomechanics testing, and indication of range of likely parameter variability and spatial variability within similar formations tested elsewhere. |
| | **2.2 In Situ Stress Regime**<br>- 3-D stress tensors for Ordovician shales and limestones and overlying shales. | Required for design of DGR openings (layout, dimensions, support) and for design of access and ventilation shafts. |
| | **2.3 Rock Material Properties**<br>- suite of laboratory geomechanical tests of rock core of Ordovician shales and limestones and overlying shales including: standard index tests, strength & deformation parameters, anisotropy characteristics, creep parameters, swelling/squeezing parameters and thermal properties. | Required for use throughout DGR design, construction and monitoring phases to evaluate responses of rock materials to changes in stress, geochemical regime, moisture content and temperature. |
| | **2.4 Rock Mass Properties**<br>- geomechanical properties of overall rock mass including discontinuities and variably spaced shale partings. Focus on rock mass classification systems (Q, RMR, GSI) and geomechanical properties of discontinuities in host rock horizon, but data needed for all bedrock units that will be excavated. | Required for engineering analyses, environmental impact assessment (waste rock disposal/reuse), and design of the DGR facility including DGR rooms and shafts. |
| **3. Hydraulic Properties and State** | **3.1 Existing Hydrogeological Information**<br>- hydrogeological properties of overburden and bedrock units from investigations undertaken at Bruce Nuclear site and elsewhere in Ontario. | Provides hydrogeological basis for assumed favourable geoscientific features and characteristics of site. Provides indication of likely range of hydrogeological properties for deep bedrock units. Assists in design of |

**Table 2.1: Master Table of Geoscience Data Needs**

| **Geoscience Discipline** | **Data Need** | **Rationale for Inclusion** |
|---|---|---|
| **3 Hydraulic Properties and State (cont'd)** | | proposed testing & sampling programs. |
| | **3.2 Rock Mass Hydraulic Properties**<br>- spatial distribution and anisotropy of bulk rock mass permeabilities/storativities for all bedrock formations hosting and overlying /underlying DGR. For Ordovician shales and limestones the hydraulic properties of joints and shale partings or interbeds need to be quantified. | Needed to quantify relative importance of advective versus diffusive transport properties, advective groundwater fluxes into/out of DGR, to estimate time to re-saturate DGR, and to model groundwater flow and radionuclide transport as part of DGR performance assessment and Safety Assessment. |
| | **3.3 Hydraulic Heads**<br>- transient and steady-state hydraulic heads within all bedrock formations. | Needed to define hydraulic gradient fields within and between bedrock formations, and to model groundwater flow in performance assessment. Anomalous heads can also support safety case. Transient head response both following casing installation and following shaft and DGR excavation can also be used to estimate bulk rock permeability and storage properties. |
| | **3.4 Total and Effective Rock Matrix Porosities**<br>- intact rock total and transport porosity and porosity geometry for Ordovician and Silurian bedrock formations. | Required for calculation of advective velocities from estimated Darcy fluxes, and to interpret pore matrix fluid chemistries derived from rock core. Larger interconnected matrix porosities in fractured rock units can contribute to the safety case through enhance dispersion and retardation by matrix diffusion. |
| | **3.5 Fracture/Fault Hydraulic Properties**<br>- Transmissivity (T), storativity (S) and equivalent fracture aperture (2b) for important structural discontinuities (faults, fracture zones) proximate to the DGR. | Necessary to calculate advective groundwater and radionuclide migration rates within fracture pathways, if present. |
| | **3.6 Gas–Brine Flow Properties**<br>- gas entry pressure (pressure at which gas can begin to displace brine from rock pores) and gas-brine relative permeability testing to assess gas migration into excavation damage zones and away from DGR. | Needed to model pressure buildup and dissipation rates for gases generated by corrosion and other processes in the DGR and to assess potential for host rock fracturing. Gas pressure buildup affects fluid flow to/from the DGR, as well as the mechanical response (closure) of the rock. |

**Table 2.1: Master Table of Geoscience Data Needs**

| **Geoscience Discipline** | **Data Need** | **Rationale for Inclusion** |
|---|---|---|
| **3 Hydraulic Properties and State (cont'd)** | **3.7 Groundwater Densities**<br>- unit weight of groundwater due to dissolved gas and total dissolved solids, temperature, pressure and g within each bedrock formation. | Required to accurately assess effects of density on groundwater flow in numeric simulations of variable density groundwater flow. Can also contribute to safety case through demonstration of stagnant deep flow systems. |
| **4. Diffusion and Sorption Properties** | **4.1 Effective Diffusion Coefficients**<br>- $D_e$ values for radionuclides of interest to Safety Assessment (e.g., $^{3}$H, $^{129}$I, $^{36}$Cl, $^{99}$Tc, $^{90}$Sr) in low permeability Ordovician shales and limestones in both vertical and horizontal directions.<br>- Large scale $D_e$ values may also be estimated from inverse modeling of formation specific isotope concentration profiles. | Required as the current conceptual model assumes that migration within the Ordovician sediments is diffusion dominated. |
| | **4.2 Effective Diffusion Porosities**<br>- estimated at the same time as $D_e$ values for radionuclides of interest in low- permeability Ordovician shales and limestones | Required for assessment of diffusive migration in host rocks and surrounding low-permeability formations. This porosity estimate will provide a first approximation of the 'geochemical porosity' for geochemical modeling of the pore-water chemistry. |
| | **4.3 Sorption Parameters**<br>- retardation factors, adsorption isotherms and Kd for Sr and other weakly and strongly sorbed elements, in the Ordovician shales and limestones (NB., to be done in Phases 2 & 3) | Retardation due to sorption will provide additional retention in the low permeability rocks immediately surrounding the DGR. |
| **5. Groundwater /Porewater Characterization** | **5.1 Existing Hydrogeochemical Information**<br>- hydrogeochemical properties of overburden and bedrock units from investigations undertaken at Bruce Nuclear site and elsewhere in Ontario. | Provides indication of likely range of hydrogeochemical properties for deep bedrock units. Provides baseline water quality information for local shallow bedrock water supply aquifer. Assists in design of proposed testing and sampling programs. Provides indication of the properties of waste rock and of pumped out water/brines for use in Environmental Assessment (EA) |
| | **5.2 Major Ion & Trace Element Chemistry**<br>- definition of the major ion and trace metal composition of porewater and groundwater within all bedrock and overburden units.<br>- baseline groundwater quality within the shallow bedrock aquifer on-site that serves as a local off-site water supply. | Characterization of the major ion and trace element chemistry in shallow, intermediate and deep bedrock units can provide evidence of lack of cross formational flow and response to other flow perturbations within the deep Ordovician shale and limestone formations. Necessary for the geochemical reconstruction of the |

**Table 2.1: Master Table of Geoscience Data Needs**

| Geoscience Discipline | Data Need | Rationale for Inclusion |
|---|---|---|
| **5. Groundwater Porewater Characterization (cont'd)** | - natural stable iodine concentration in shallow bedrock aquifer to define maximum possible dose from $^{129}I$.<br>- definition of quality of water to be pumped from the DGR<br>- master variables, pH and Eh, to allow charge balance calculations and geochemical modeling of the pore-water and groundwater chemistry<br>- cation exchange capacity (CEC) and exchangeable cations for Ordovician shales and limestones<br>- trace elements, e.g., Fe, Mn, U and As in porewaters and groundwaters | pore-water chemistry of the Ordovician rocks, for use in EA (quality of water pumped from DGR), and for use in Safety Assessment (maximum possible dose from $^{129}I$).<br>CEC and the exchangeable cations will be measured to interpret porewater chemical evolution through geochemical modeling |
| | **5.3 Isotope Chemistry**<br>- data on $^{18}O$, $^{2}H$, $^{3}H$, and $^{87}Sr$ and to lesser degree on $^{36}Cl$, $^{14}C$ and $^{129}I$ in matrix porewaters and groundwaters<br>- if fractures and fracture-filling minerals are detected in the Ordovician rocks during Phase 1, then additional solid samples will be tested for other isotopes, e.g., $^{13}C$, $^{18}O$ and $^{87}Sr/^{86}Sr$. during Phases 2 and 3 | Required to provide information to demonstrate absence of modern recharge water and late Quaternary glacial water intrusion to deep shale and limestone formations surrounding DGR. Also this data may – under certain conditions – support residence times of >1,000,000 years through the acquisition of complementary information on minimum residence times. |
| | **5.4 Dissolved Gases**<br>- data on He, Ar, Ne and $N_2$ dissolved gas contents and isotopes of porewaters and groundwaters in bedrock units. See Redox States below. | Necessary to confirm diffusion-dominated mass transport profiles, and to estimate water residence times and ages through He, Ar, $N_2$, and $^{3}He/^{4}He$, $^{40}Ar/^{36}Ar$ and Ne isotope ratios. |
| | **5.5 Redox States**<br>- estimation of approximate redox potential of porewaters and groundwaters by measurement of Eh (i.e., measured Pt electrode potential), ); gases such as $CH_4$ and $H_2S$; redox-sensitive trace elements such as Fe, Mn, As, U; and geochemical modeling involving redox pairs such as sulphate-sulphide and bicarbonate-methane | Important for identification of redox state of principal radionuclides for use in geochemical modeling to reconstruct pore-water chemistry and to predict future redox conditions and radionuclide speciation. |
| | **5.6 Water Physical Properties**<br>- viscosity and temperature of pore waters and groundwaters. | Necessary as rates of diffusion and advection are a function of density, viscosity and temperature. |
| **6. Seismicity** | **6.1 Map Significant Local Faults**<br>- identification and mapping of all significant faults and fracture zones within 1 km of the DGR. | Required for assessment of potential for seismic-induced rupturing of DGR along or as splays of pre-existing structural discontinuities and/or the presence of potential pathways or boundary conditions for numerical flow system simulation. |

**Table 2.1: Master Table of Geoscience Data Needs**

| Geoscience Discipline | Data Need | Rationale for Inclusion |
|---|---|---|
| **6. Seismicity (cont'd)** | **6.2 Local Seismographic Monitoring**<br>- seismicity data from 3 additional seismograph stations for 5 years and for and additional 5 years to confirm results. | Improved local seismographic monitoring (within 50 km of the Bruce site) will improve the correlation of microseismicity with specific local and regional structural features, and secondarily improve estimates of earthquake focal depths, and improve estimates of local seismicity. |

## 2.3 ASSESSMENT OF DATA COLLECTION METHODS

Alternate data collection methods (see Appendix A) were evaluated for inclusion in the GSCP based on application of screening criteria. The following screening criteria were used for determining preferred site characterization methods for use in the GSCP.

- **Practicality:** the method must have a high probability of success in acquiring the required data with available technology and within the time available for site characterization work.
- **Demonstrated Effectiveness:** the method must have been used successfully in geologic settings and conditions similar to those anticipated at the Bruce Nuclear site.
- **Accuracy:** the method must be able to collect the data with an accuracy that is sufficient for the intended data use.
- **Compatibility:** the method should be compatible with and not limit other data collection methods, if the method potentially serves several data collection needs (i.e., borehole drilling and monitoring systems).
- **Quality Assurance:** the method should have a high degree of quality assurance (i.e., measurement precision, repeatability, opportunities for equipment calibration, well documented procedures, data control/management etc).
- **Cost-effective:** the method should be cost-effective relative to other data collection methods considering all of the above attributes.

## 2.4 RECOMMENDED DATA COLLECTION METHODS

Table 2.2 summarizes the data collection methods recommended to meet the data needs identified in Table 2.1. The listing of all data collection methods considered in selecting INTERA recommended data collection methods are given in Appendix A. Additional information from OPG's deep geologic repository technology program (DGRTP, see Section 3.2) may be incorporated into the recommended data collection methods for the GSCP defined in this report.

Data collection tables of Appendix A and Table 2.2 list data collection methods for each geoscience data need. These data collection method tables are number keyed to the data need listed in Table 2.1. For example, data collection methods for data needs 2.2 – In Situ Stress Regime and 3.3 - Hydraulic Heads listed in Table 2.1, are listed as entries 2.2 and 3.3 in Table 2.2 and in Appendix A as Tables A.2.2 and A.3.3.

**Table 2.2: Geoscience Data Needs and Recommended Data Collection Methods**

| Geoscience Discipline | Data Need | Recommended Data Collection Methods |
|---|---|---|
| **1. Geological Setting and Framework** | **1.1 Existing Geological Information** | All methods listed in Table A.1.1. Much of the available geologic data has already been compiled by Golder (2003) and by Mazurek (2004). Special additional attention to role of dolomitized fault zones in Trenton Black River Group and potential presence salt horizons in Salina Formation is required. |
| | **1.2 Existing Geophysical Information** | All methods listed in Table A.1.2, except existing seismic reflection data which is judged to be too distant and not cost-effective for use in the GSCP. |
| | **1.3 Stratigraphic Sequence** | All methods listed in Table A.1.3 and A.1.4. Seismic reflection surveys are judged to be particularly useful in this regard, if found technically and logistically feasible for the Bruce Nuclear Site. |
| | **1.4 Formation Thicknesses and Attitudes** | All methods listed in Table A.1.3 and A.1.4. Seismic reflection surveys are judged to be particularly useful in this regard, if found technically and logistically feasible for the Bruce Nuclear Site. |
| | **1.5 Structural Framework** | All methods listed in Table A.1.5. Seismic reflection surveys are judged to be particularly useful in this regard, if found technically and logistically feasible for the Bruce Nuclear Site.. |
| | **1.6 Bedrock Petrography and Mineralogy**. | All methods listed in Table A.1.6. |
| **2. Geomechanical Setting and Rock Properties** | **2.1 Existing Geomechanical Information** | All methods listed in Table A.2.1. Focus to Queenston and Georgian Bay shales and Lindsay limestone. |
| | **2.2 In Situ Stress Regime** | All methods listed in Table A.2.2 are potentially useful depending on rock quality encountered. Hydro-fracturing of intact sections of Queenston and Georgian Bay shales and Lindsay limestone recommended for Phase 1. Selected overcoring methods (Deep Doorstopper) recommended for Phase 1. Priority rock unit is Lindsay limestone. Explore possibility of the use of lab core testing as supplementary method to determine in-situ stress values and orientations. |
| | **2.3 Rock Material Properties** | All methods listed in Table A.2.3. Priority is Lindsay limestone followed by overlying shales of the Queenston and Georgian Bay Formations |
| | **2.4 Rock Mass Properties** | All methods listed in Table A.2.4. Priority is Lindsay limestone followed by overlying shales of the Queenston and Georgian Bay Formations. |

**Table 2.2: Geoscience Data Needs and Recommended Data Collection Methods**

| Geoscience Discipline | Data Need | Recommended Data Collection Methods |
|---|---|---|
| **3. Hydraulic Properties and State** | **3.1 Existing Hydrogeological Information** | All methods listed in Table A.3.1. Re-establish shallow bedrock wells US-1, -5, -6 and -7 at Bruce site. |
| | **3.2 Rock Mass Hydraulic Conductivities** | All methods listed in Table A.3.2 are potentially applicable depending on range of formation permeability (k) and data need. Priority is to testing Lindsay limestone and overlying shales of the Queenston and Georgian Bay Formations, followed by shallower advection-dominated bedrock units. Open-hole straddle packer pulse testing followed by pulse testing of Westbay completions are recommended for low k units. Laboratory testing of intact cores will be required to reliably define lower limit of k for tight rocks. |
| | **3.3 Hydraulic Heads** | All methods listed in Table A.3.3 are potentially applicable. Monitoring in Westbay multi-level casings are recommended. In Phase 2 or 3, consideration should be given to permanent installation of one wireless EPG sensor to provide further confirmation of Westbay pressure head measurements. |
| | **3.4 Total and Effective Rock Matrix Porosities** | All methods listed in Table A.3.4. |
| | **3.5 Fracture/Fault Hydraulic Properties** | All methods listed in Table A.3.5 are potentially applicable. Proposed real time analysis of hydraulic well bore tests will allow for adaptive selection of the most appropriate test method. |
| | **3.6 Gas–Brine Flow Properties**<br>. | All methods listed in Table A.3.6. Borehole gas-entry tests proposed for Phase 2, should be supplemented with underground laboratory experiments and lab testing of core in Phase 1. |
| | **3.7 Groundwater Densities** | All methods listed in Table A.3.3 |
| **4. Diffusion and Sorption Properties** | **4.1 Effective Diffusion Coefficients** | All methods listed in Table A.4.1.and A.4.2 are potentially applicable for measurement of diffusion coefficients. Focus should be to “through-diffusion” tests for $^3$H (HTO), and other conservative tracers (halides, dyes) in Phase 1. In-situ diffusion tests should only be contemplated from underground openings. |
| | **4.2 Effective Diffusion Porosities** | Most reliably measured with “through diffusion tests”. |
| | **4.3 Sorption Parameters** | All methods listed in Table A.4.3. Batch Kd tests are preferred for strongly sorbed elements as well as most of the elements possibly contributing to dose estimates. Retardation factors and Kds can also be directly interpreted from “in-diffusion” tests. |

**Table 2.2: Geoscience Data Needs and Recommended Data Collection Methods**

| Geoscience Discipline | Data Need | Recommended Data Collection Methods |
|---|---|---|
| **5. Groundwater /Porewater Characterization** | **5.1 Existing Hydrogeochemical Information** | All methods listed in Table A.5.1. Re-establish shallow bedrock wells US-1, -5, -6 and -7 at Bruce site. |
| | **5.2 Major Ion and Trace Element Chemistry** | All methods in Tables A.5.2 and A.5.3 are potentially applicable. Collection of opportunistic groundwater samples during drilling is likely to provide representative samples for the Silurian and Devonian bedrock. However, pore-fluid extraction by high-pressure fluid displacement, and by crush and leach appear most promising for shales and argillaceous limestones. These and other methods will need to be tested on core samples collected from other investigations, prior to drilling the first borehole in Phase 1. |
| | **5.3 Isotope Chemistry** | All methods in Tables A.5.2 and A.5.3 are potentially applicable. However, diffusive exchange is very promising for $^{18}O$ and $^{2}H$, with other methods applicable for major ion chemistry being suitable for other isotopes: $^{3}H$, $^{36}Cl$ and $^{129}I$. |
| | **5.4 Dissolved Gases** | All methods in Table A.5.4 are potentially applicable. Extraction of noble gases (He, Ne, Ar ) by vacuum-assisted sequential heating of core appears most promising. |
| | **5.5 Redox States** | All method listed in Table A.5.5. |
| | **5.6 Water Physical Properties** | All methods listed in Table A.5.6. |
| **6. Seismicity** | **6.1 Map Significant Local Faults** | All methods listed in Table A.6.1 |
| | **6.2 Local Seismographic Monitoring** | All methods listed in Table A.6.2. |

The tables of Appendix A provide a description of methods and qualitative costs (low, moderate, expensive) for collecting data to meet identified geoscience data needs. In situations where alternate methods of collecting data (i.e., in-situ stress measurement, borehole hydraulic testing, porewater extraction) have been identified as useful, a short listing of advantages and disadvantages of the different methods are provided. The Appendix A data collection tables do not describe the recommended quantities or distribution of these tests. This information is provided in summary tables in Sections 4, 5 and 6 of this report.

# 3. GEOSCIENTIFIC SITE CHARACTERIZATION PLAN

## 3.1 MANAGEMENT STRUCTURE FOR GSCP INITIATION

The management structure for the GSCP project will be dependent upon project implementation decisions still in progress at OPG.

## 3.2 OPG'S DGRTP

OPG's Deep Geologic Disposal Technology Program (DGRTP), which has been in place since 1996, coordinates geoscience research studies that advance Canadian expertise and methodologies for the characterization and simulation of the Canadian Shield environs relevant to Safety Assessment of a DGR for used nuclear fuel (Jensen et al., 2005). Many of the DGRTP geoscience work program activities conducted in support of used nuclear fuel waste management in the Shield have relevance to the GSCP project.

For example, DGRTP studies on long-term climate change, permafrost analogues, thermodynamic modeling of glacial recharge, hydraulic test analyses, porosity characterization, diffusion testing, geosynthesis and scientific data visualization and regional groundwater flow modeling may contribute to the GSCP, directly in terms of field and/or laboratory testing methods, or indirectly as parallel supporting geosynthesis and natural analogue studies.

The exact nature and extent by which DGRTP studies will contribute to the GSCP has not been determined at this time.

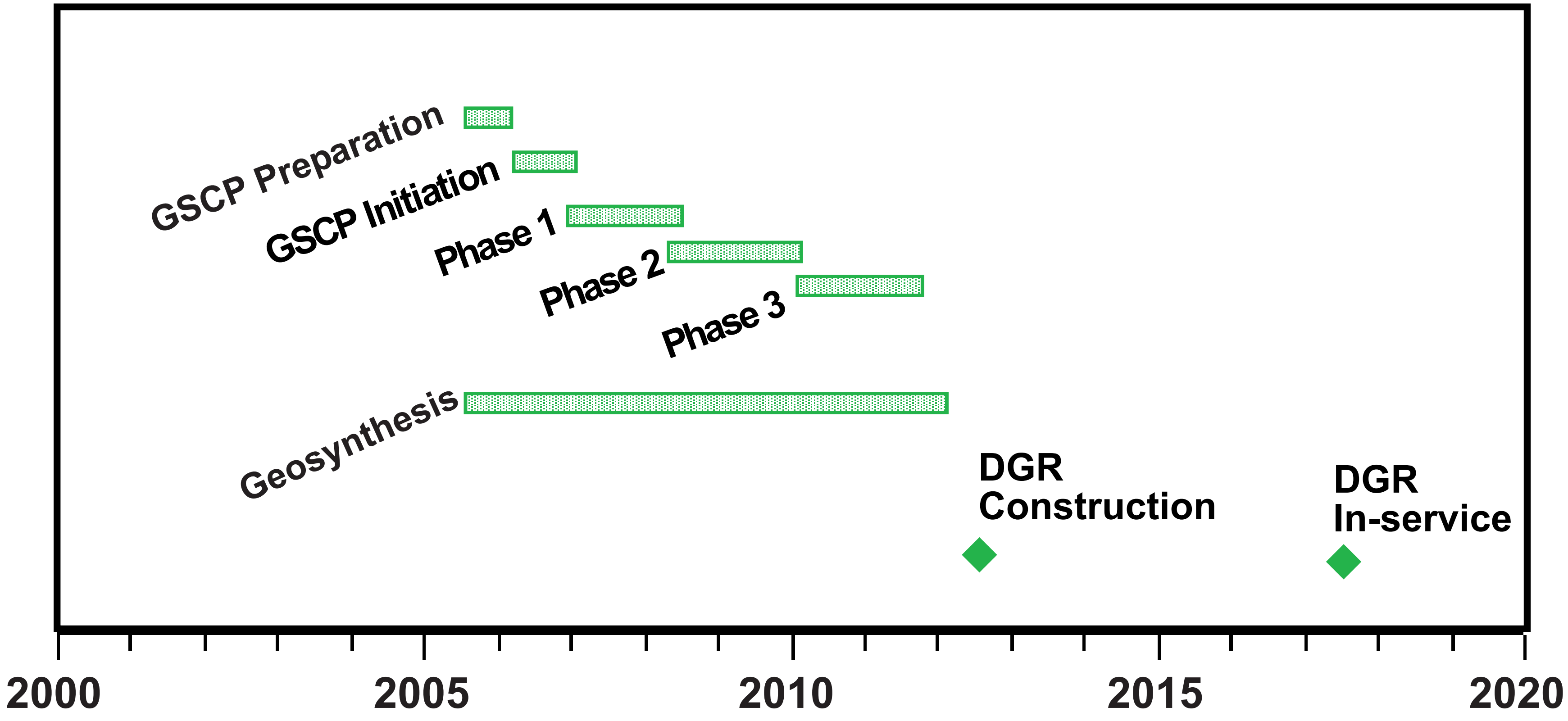
## 3.3 OVERALL PROJECT SCHEDULE

The GSCP for the DGR is comprised of three major components.

- Initiation Activities
- Site-Specific Characterization Work (3 Phases)
- Geosynthesis (Analysis and Interpretation of Data)

A tentative schedule for implementation of the GSCP and completion of initiation activities and site-specific characterization investigations for the DGR is summarized in Figure 3.1. The GSCP for the DGR is currently planned as a three phase investigative program lasting 5 to 6 years and commencing in 2006. Prior to commencement of Phase 1 site investigations, the completion of several GSCP initiation activities and tasks will need to be completed. GSCP preparation activity shown on Figure 3.1 is the work undertaken to develop the GSCP as described in this report.

The project schedule as shown in Figure 3.1 is recognized as the base case or initial time frame for completion of the GSCP. As the various activities and investigation phases within the GSCP are completed, this simplified project schedule may be modified to accommodate specific geoscientific characterization challenges of the Bruce site that may arise and cannot be anticipated based on available information. Section 8 of this report provides a more detailed schedule of initiation activities, Phase 1 site investigation activities and related geosynthesis work for the GSCP.



Schedule and Milestones of Bruce DGR Project
Geoscientific Site Characterizatin Plan for Bruce DGR

Figure 3.1
05-220-1

April 2006
SNS F3-1 Schedule and Milestones_rev2.cdr

## 3.4 WORK PHASES

As shown in Figure 3.1, the GSCP is structured into three investigative phases and required GSCP initiation activities:

1. GSCP Initiation Activities
2. Phase 1 Site Investigations
3. Phase 2 Site Investigations
4. Phase 3 Site Investigations.

The following text provides a brief description of the likely field data collection activities within each of these site investigation phases. In addition to these field data collection activities, the GSCP will include parallel geosynthesis activities (Section 7.2) that are intended to support and enhance the field data collection work and the site characterization effort.

More detailed descriptions of Phase 1, 2 and 3 site investigations are provided in Section 4, 5 and 6. Sections 4, 5 and 6 describe GSCP investigations according to the descriptive geoscience site model that the site characterization data supports (i.e., Geologic, Hydrogeologic and Geomechanics). Section 11 describes the activities and tasks required to initiate the GSCP described in this report.

## 3.5 GSCP WORK PROGRAM ORGANIZATION

As described above, it is proposed that the GSCP be conducted in three investigation phases. An outline of the site-specific characterization work program activities to be considered within each of these phases is provided below. Geosynthesis activities are not listed below, but are described in general terms in Section 7. Work program activities associated with Phase 1 can be described with greater certainty than Phase 2 and 3 as those in the later phases will be, in part, directed by the outcome of the preceding phase or phases.

The GSCP activities described below are proposed assuming that the deep bedrock units (Ordovician shales and limestones) are the primary characterization targets. However, some characterization effort must also be expended on the more permeable dolostone units in the overlying intermediate bedrock system as these formations will provide the transport pathway for any contaminants diffusing from the underlying Ordovician sediments. Characterization of the shallow bedrock system (<100 m depth) that represents the local bedrock water supply aquifer (dolostone) must also be undertaken. At a minimum, dolostone characterization would include hydraulic testing, geophysical logging and monitoring, groundwater sampling and hydraulic testing from Westbay MP multi-level casings.

### 3.5.1 Phase 1 Site Investigations

- Install 3 additional seismograph stations within 50 km of Bruce site, preferably to bedrock.
- Refurbish, monitor and sample Westbay multi-level monitoring wells in US-series boreholes to establish baseline hydrogeological conditions in shallow bedrock at site.
- Complete feasibility study for seismic surveys of Bruce site and surrounding area.
- Complete of 2-D seismic survey (several intersecting survey lines ~ 10 to 15 km total length) to assess quality of reflectors in deep Ordovician bedrock and likelihood of success of 3-D seismic surveys.

- If feasible, complete 3-D seismic survey and initial interpretation to identify structure within Ordovician shales and argillaceous limestones. These surveys would identify any sag structures at the top of the Trenton (i.e. Lindsay) limestone that show the presence of underlying dolomite traps. Such sag structures (<10m in vertical extent) should be readily discernable by seismic profiling as would the dolomite traps themselves that would appear as seismic anomalies within the massive Trenton limestones. This 3-D seismic work will also include LiDAR (Light Detection and Ranging) survey of the Bruce Site to provide an accurate digital elevation model.
- Wireline drill and core log one vertical borehole (DGR-1) to the top of Queenston shale outside of DGR footprint to confirm stratigraphic sequence and general rock quality of upper Silurian and Devonian bedrock. Rotary drill second adjacent borehole and grout casing to top of Queenston shale, to allow wireline drilling and core logging of Queenston shale to Precambrian bedrock (DGR-2).
- Undertake opportunistic groundwater sampling during drilling to obtain representative groundwater samples from permeable bedrock formations.
- Complete overcore stress testing using Deep Doorstopper Gauge System (DDGS) method within the shaley limestone Lindsay Formation at the repository horizon in DGR-2
- Collect and preserve core samples for geochemical testing, porewater extraction and testing, geomechanical testing, diffusion testing and petrophysical testing.
- Geophysical logging of boreholes, including Vertical Seismic Profiling (VSP) and other conventional logs to support interpretation of 2-D and, if feasible, 3-D seismic surveys and development of a stratigraphic model.
- Complete open-hole straddle packer hydraulic testing and other borehole hydraulic testing as necessary.
- Complete hydraulic fracturing stress measurements in DGR-2 to determine principal stresses in any massive unbedded sections of Ordovician shale and limestone.
- Complete installation of Westbay MP multi-level casings for each borehole.
- Commence pressure monitoring, groundwater sampling and hydraulic testing from Westbay casing.
- Develop specifications and work plans for GSCP Phase 2 investigations.
- Contract Phase 2 investigation works.

### 3.5.2 Phase 2 Site Investigations

- Drill and core log two vertical deep boreholes to Precambrian outside of DGR footprint to triangulate attitude of sedimentary sequence.
- Undertake opportunistic groundwater sampling during drilling.
- Consider drilling a dedicated borehole for geomechanics testing including overcore stress testing and hydraulic fracturing.
- Complete geophysical logging, and collection and preservation of samples for laboratory testing as described above.
- Expand laboratory geochemical testing program to address sorption and retardation.
- Complete open-hole straddle-packer hydraulic testing and other borehole hydraulic testing.
- Complete selected open-hole straddle-packer air injection tests in DGR formation.
- Complete installation of Westbay MP multi-level casings for each borehole.
- Continue pressure monitoring, groundwater sampling and hydraulic testing from Westbay MP casings.
- Develop specifications and work plans for GSCP Phase 3 investigations.
- Contract Phase 3 investigation works.

### 3.5.3 Phase 3 Site Investigations

- Drill and oriented core log two to three inclined boreholes (60 to 65 degrees) to Precambrian to further define bedrock stratigraphy and to investigate potential sub-vertical structures in Ordovician shales and argillaceous limestones identified from the 3-D seismic survey.
- Consider drilling one deviated sub-horizontal hole to investigate vertical structures.
- Undertake opportunistic groundwater sampling during drilling.
- Complete geophysical logging and collection and preservation of samples for laboratory testing as described above.
- Consider VSP on the additional boreholes drilled during Phase 2 and 3 and re-interpretation of the seismic survey data from Phase 1.
- Complete open-hole straddle-packer testing and other borehole hydraulic testing.
- Complete installation of Westbay MP multi-level casings for selected boreholes (note: not all boreholes need to be completed with monitoring casings).
- Consider installation of wireless EPG (Electromagnetic Pressure Gauge) or equivalent system within the sub-horizontal borehole or one inclined borehole to confirm in-situ pressures measured with Westbay MP systems.
- Continue pressure monitoring, groundwater sampling and hydraulic testing from Westbay MP casings.

It is assumed that each phase of the GSCP would only be undertaken on successful completion of preceding phase.

## 3.6 REPORTS HIERARCHY

Documentation of site characterization program results is obviously an important part of the overall program. Effective communication of GSCP results will be facilitated by defining a hierarchy of reports, with differing levels of content to address the needs of different audiences. In general, the lower levels of the hierarchy will be populated by the most technical and narrowly focused reports. Upper levels will concentrate on interpretations and synthesis of lower level reports. The reports hierarchy will include the following reports.

1. **Investigation Program Reports** – reports describing test plans defining individual components of the GSCP. These will include the following: the purpose of the test, the intended use of the resulting data, the approach to be taken, and acceptance criteria.
2. **Technical Reference Reports** – reports describing results of analysis of GSCP data and additional supporting studies. Examples of the former will include: results of hydraulic testing, stratigraphic interpretations from core logging, results of laboratory analysis of core and porewaters, and basic seismic study results. Supporting studies will consist of regional studies (hydrogeology and geochemistry) used to provide context and results of modeling studies.
3. **Milestone Summary/Synthesis Reports** – reports describing review and synthesis of data at specific project milestones, such as end of first borehole, first full seismic based stratigraphic interpretation, summary of modeling results with sensitivity and uncertainty assessments, etc. These reports will draw on and reference the lower level technical reports.
4. **Geosynthesis Report(s**) – A higher level summary and interpretation of all lower-level reports, compiled by an inter-disciplinary team of authors. The overall program geosynthesis will be in a continual state of development. There will be a single geosynthesis current at any time throughout the GSCP, which reflects the integration of

all available data, reports, and modeling results. Each revision of the Geosynthesis Report will document the state of the geosynthesis at specific date or milestone intervals. A formal process for geosynthesis development including feedback loops and audits to avoid any shared biases in the interpretation will be put in place.

# 4. GEOLOGIC CHARACTERIZATION PLAN

## 4.1 OBJECTIVES AND SCOPE

Geologic characterization activities are undertaken to develop a descriptive geologic site model of the Bruce Nuclear site and surrounding area that will directly support hydrogeologic and geomechanical descriptive site models, and will provide the necessary geoscientific site data to support Safety Assessment and Repository Engineering requirements.

Because of the phased nature of the geological characterization plan, detailed descriptions of major work elements can only realistically be provided for the Phase 1 investigations. Consequently, unless otherwise indicated, the work element descriptions provided in Section 4.2 are primarily applicable for Phase 1 tasks. Although the scope and description of Phase 2 and 3 work elements are likely to be similar to Phase 1 tasks, the final description of Phase 2 and 3 tasks will only be available following completion of Phase 1 and 2 tasks, respectively. This approach allows for adaptation and flexibility in the GSCP to define or re-focus specific work program requirements arising from acquired or emerging knowledge of site conditions relevant to the DGR Safety Case.

The following description of major work elements addresses the specific data needs and data collection methods identified in Tables 2.1 and 2.2. The following table summarizes how the data needs are met by each of the major geologic characterization work elements. Data needs are listed by numbers given in Tables 2.1 and 2.2.

**Table 4.1: Summary of Data Needs and Geologic Characterization Plan Work Elements – Phase 1 GSCP**

| *Major Work Element* | *Data Needs Met by the Work Element* |
|---|---|
| Task G.1 - Seismic Survey Feasibility Study | 1.3, 1.4, 1.5 |
| Task G.2 - 2-D Seismic Survey | 1.3, 1.4, 1.5, 6.1 |
| Task G.3 - 3-D Seismic Survey | 1.3, 1.4, 1.5, 6.1 |
| Task G.4 - Borehole Drilling and Sealing Systems | N/A |
| Task G.5 - Borehole Orientation Testing During Drilling | N/A |
| Task G.6 - Geologic Core Logging | 1.3, 1.4, 1.5, 1.6 |
| Task G.7 - Borehole Geophysical Logging | 1.3, 1.4, 1.5, 1.6 |
| Task G.8 - Laboratory Petrologic, Mineralogic and Geochemical/Isotopic Testing of Core | 1.6, 3.4, 3.6, 4.3, 5.3, 5.4, 5.5 |
| Task G.9 - Development of Descriptive Geologic Site Model | 1.1, 1.2 |

## 4.2 DESCRIPTION OF MAJOR WORK ELEMENTS

### 4.2.1 Task G.1 - Seismic Survey Feasibility Study

A component of the GSCP is the potential completion of seismic surveys to yield spatial information on the 3-dimensional internal stratigraphy and structure of the sedimentary rock mass underlying the Bruce Nuclear site. Given possible logistical and technical constraints to undertaking seismic surveys on the Bruce Nuclear site, on adjoining property and on the adjacent lake (Lake Huron), and because the size and cost of completing a large (20 to 40 km$^2$) 3-D land and water based seismic survey, a seismic survey feasibility study should be completed for the GSCP.

The feasibility study will accomplish the following.

1. Provide OPG with a descriptive outline of how a 3-D seismic survey could be conducted on Bruce Power, OPG and any off-site lands, as well as, on Lake Huron. This information will be necessary to approach Bruce Power, possibly other land owners and affected parties to assess the likelihood of approvals.
2. Set up a preliminary GIS system, acquire bathymetry data on Lake Huron, and complete mapping and identification of all exclusion areas for which seismic surveying cannot be undertaken.
3. Assess the feasibility and probable results of seismic surveys based on expert assessments and incorporating identified on-site exclusion areas.
4. If survey is judged feasible, provide OPG with a better understanding of the probable nature, costs and scheduling for the survey.

### 4.2.2 Task G.2 - 2-D Seismic Survey

A limited 2-D seismic survey consisting of several orthogonal intersecting lines (total length about 10 to 15 km) should be completed as a prerequisite to possibly completing a much more expensive and extensive 3-D seismic survey. The purpose of undertaking the 2-D seismic survey is to confirm the approach for undertaking the 3-D survey (i.e., types of seismic sources, line and shot/receiver spacing), the importance of turbine or other mechanical equipment interference on survey results, the nature of subsurface bedrock seismic reflectors, and the overall quality of geological data that would be collected from a 3-D seismic survey. Expanded 2-D seismic surveys could also be undertaken in selected areas of the site, if 3-D seismic surveys are judged to be limited benefit due to the presence of infrastructure and other impediments.

### 4.2.3 Task G.3 - 3-D Seismic Survey

Pending the successful completion of a 2-D seismic survey and a favourable outcome of the aforementioned feasibility study, a 3-D seismic survey would ideally be undertaken in the location of the proposed DGR to assist with the development of an accurate picture of bedrock stratigraphy to the Precambrian surface. In similar geologic settings such surveys have been shown to be useful in both the NAGRA (Birkhäuser et al., 2001) and ANDRA site characterization programs of deep sedimentary formations.

A seismic survey should be designed in such a way that maximum vertical and lateral resolution can be obtained, so that even faults with small throws of several metres can be mapped. The data must also support an analysis of the lateral homogeneity and continuity of the host rock for the repository and the geologic layers above.

3-D seismic surveys have the ability to produce an accurate 3-dimensional picture of the subsurface geologic layers over a specified area. It is a technology that was developed by the oil industry in the 1970's. It was initially applied on a large scale in the 1980's to map reservoirs in existing fields and has since been continuously developed and proven to be very successful.

Today it is a very mature technology that is used in the exploration, appraisal and production phase. It allows one to accurately investigate the structural configuration of the various geological layers over a large area. It also allows for the spatial mapping of variations in the rock properties.

Seismic survey results will allow better characterisation of the Bruce site geologic setting, and, in particular, the development of a constrained site-specific 3-D stratigraphic model. Such a stratigraphic model is a fundamental requirement for predictive hydrogeological and geomechanical modeling that is conducted for repository safety and engineering design purposes. A 3-D geologic model also provides an excellent tool to visualize the rock formation geometry, layering and lateral continuity and therefore facilitates communication.

To achieve all of this it is important that the 3-D seismic investigation area is large enough to allow an interpretation that is geologically significant. If discontinuities in the subsurface are known already from previous 2-D seismic data, they should be included in the 3-D seismic area.

Based on a current understanding of the subsurface geology it is proposed that the interpretable 3-D seismic area range from approximately 5 to 10 $km^2$. This area would allow inclusion of the proposed Phase 1 deep boreholes (see Section 4.2.4) within the 3-D coverage and allow an initial calibration of the seismic data. For this interpretable area, the surface survey area may be about 20 to 30 $km^2$. This survey area will of necessity include both land and lake areas.

A proposed 3-D seismic survey would have four phases: (1) planning, (2) acquisition, (3) processing and (4) interpretation.

A proposed 3-D seismic project would include the following activities.

1. Completion of LiDAR survey of Bruce site to produce accurate digital elevation model of survey area;
2. Analysis of all existing data from the area;
3. Detailed parameter analysis for the design of the 3-D field parameters;
4. Layout of an optimal seismic grid;
5. Establish a bid document for seismic acquisition contractors;
6. Bidding process;
7. Bid evaluation and contractor selection;
8. Field acquisition with real-time QC and supervision;
9. Establish a bid document for seismic processing contractors;
10. Bidding process;
11. Bid evaluation and processing contractor selection;
12. Seismic processing to a true amplitude pre-stack depth migrated volume;
13. Seismic interpretation using all modern interpretation tools;
14. Construction of a 3-D geological subsurface model; and,
15. Documentation of the work done.

A seismic survey would be complex, both in acquisition and in processing. This is because it would extend from the land into Lake Huron, which means up to three different seismic sources (i.e., vibrators, explosives and airguns shot into geophones on land and hydrophones in the water part). Specific attention would need to be given to the transition zone from land to water where special marsh phones or ocean bottom cables may have to be used.

### 4.2.4 Task G.4 - Borehole Drilling and Sealing Systems

Phase 1 drilling activities will include the completion of two boreholes, one drilled from ground surface to the top of the Queenston shale (borehole DGR-1) and one drilled through cemented casing installed to the top of the Queenston shale (borehole DGR-2) to the Precambrian basement. This drilling method will provide open sections of borehole from the bottom of the surface casing to the top of the Queenston Shale (DGR-1) and from the top of the Queenston shale to the Precambrian bedrock (DGR-2). These boreholes will allow for confirmation of bedrock stratigraphy, provide core for laboratory geological, hydrogeological and geochemical testing, and provide access for borehole hydraulic testing and future multi-level sampling, monitoring and testing. Figures 4.1 and 4.2 show the proposed drilling and casing installation sequences for boreholes DGR-1 and DGR-2. To accommodate borehole geophysical logging requirements, borehole DGR-1 will be completed 15 m into the Queenston shale, and borehole DGR-2 will be completed 15 m into the Precambrian.

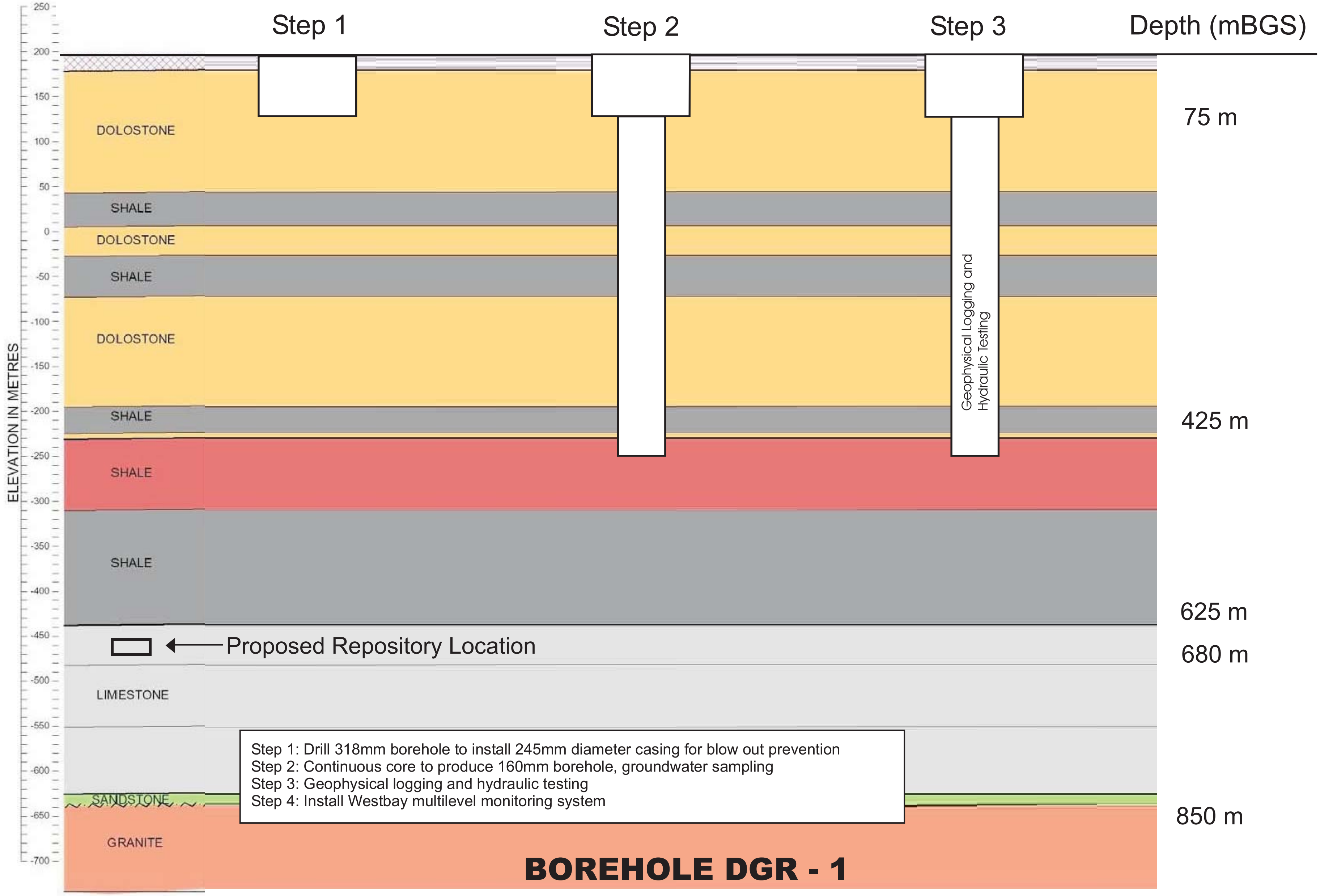
A borehole diameter of 160 mm has been selected in an effort to ensure successful completion of site characterization activities during Phase 1 site investigations while addressing potential borehole stability concerns in the shaley formations. If, during completion of the Phase 1 site activities, it is determined that a smaller diameter borehole will suffice to ensure successful completion of site characterization, a smaller diameter borehole will be considered for Phase 2 and Phase 3 site investigations.

#### 4.2.4.1 Drilling Methods

Several alternate methods for drilling deep boreholes at the Bruce site were identified and evaluated to complete the identified program. The three most common methods are diamond drilling methods, conventional oil and gas drilling and coring methods, and exploration drilling methods. The two sizes of diamond drilling methods that are most applicable to this work include HQ-3 and PQ-3. These sizes of coring equipment use wireline triple-tube core recovery methods and result in borehole sizes of 96 mm and 123 mm diameter, respectively, and core sizes of 61 and 83 mm diameter, respectively. Both of these diamond drilling methods would require the borehole to be enlarged by reaming the hole using a larger drilling bit in order to achieve the desired borehole diameter of 160 mm.

Conventional oil and gas drilling methods create a borehole of about 160 mm diameter and core size of about 90 to 100 mm diameter. With adaptations to equipment (and increased costs) these drilling methods can core continuously without removing the drill string. Most oil and gas drilling companies do not typically core continuously and would have to acquire equipment and expertise in order to complete this work.

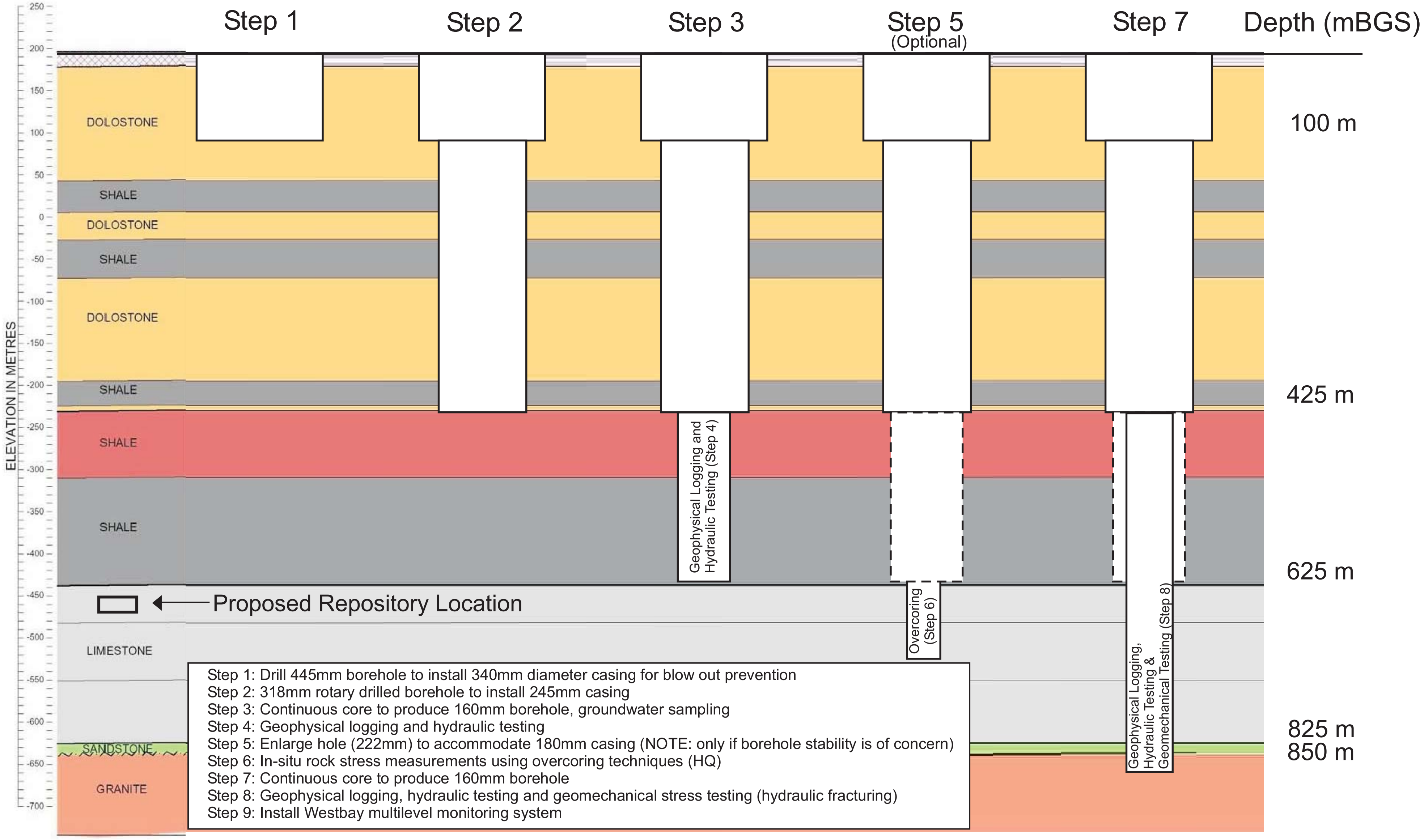
Exploration drilling methods use a specialized drilling rig which is smaller in size and more limited in depth capabilities compared to a conventional oil and gas rig. Truck-mounted exploration drilling rigs with wireline core recovery equipment are available and produce a borehole with a diameter of approximately 160 mm and a core with a diameter of approximately 76 mm and are able to drill to depths of 1000 to 1500 m below ground surface (BGS).



Step 1: Drill 318mm borehole to install 245mm diameter casing for blow out prevention
Step 2: Continuous core to produce 160mm borehole, groundwater sampling
Step 3: Geophysical logging and hydraulic testing
Step 4: Install Westbay multilevel monitoring system

Proposed Drilling and Casing Installation Sequence - Borehole DGR-1
Geoscientific Site Characterization Plan for Bruce DGR

| | |
|---|---|
| Figure 4.1<br>05-220-1 | April 2006<br>NKP F4-1 DGR1 Activity Sequence.cdr |



Step 1: Drill 445mm borehole to install 340mm diameter casing for blow out prevention
Step 2: 318mm rotary drilled borehole to install 245mm casing
Step 3: Continuous core to produce 160mm borehole, groundwater sampling
Step 4: Geophysical logging and hydraulic testing
Step 5: Enlarge hole (222mm) to accommodate 180mm casing (NOTE: only if borehole stability is of concern)
Step 6: In-situ rock stress measurements using overcoring techniques (HQ)
Step 7: Continuous core to produce 160mm borehole
Step 8: Geophysical logging, hydraulic testing and geomechanical stress testing (hydraulic fracturing)
Step 9: Install Westbay multilevel monitoring system

**BOREHOLE DGR - 2**

| | |
|---|---|
| Proposed Drilling and Casing Installation Sequence - Borehole DGR-2<br>Geoscientific Site Characterization Plan for Bruce DGR | |
| Figure 4.2<br>05-220-1 | April 2006<br>NKP F4-2 DGR2 Activity Sequence.cdr |

It is preferred to obtain a 160 mm borehole directly while coring (i.e. without reaming) in an effort to produce the highest quality borehole wall conditions for subsequent geophysical logging and packer sealing for hydraulic testing and monitoring. In our judgment, this drilling method will most effectively accomplish the goals of this site exploration program and while meeting the borehole size requirements established for Phase 1 of the GSCP.

#### 4.2.4.2 Drilling Fluids

A water-based drilling fluid will be used to drill the upper bedrock sequence above the Salina Formation. All drilling fluids will be tagged with a drill water tracer (Section 5.2.2). Brine-based drilling fluid will be used to drill the Salina Formation and all bedrock units below this formation where pore-water fluids are expected to be brine. Drilling with brine-based drilling fluids will minimize dissolution and wash-out of bedrock with extensive anhydrite and halite zones, and should minimize weathering/deterioration of the Queenston and Georgian Bay shale units.

If extensive deterioration of the borehole wall occurs during the initial drilling and testing of the Queenston and Georgian Bay shales, use of a sodium silicate drilling fluid or similarly effective new drilling fluids (Reinboth et al., 2005), to ensure borehole stability while drilling through the shale units, will be considered in subsequent deep bedrock drilling.

Detailed records must be kept during drilling activities concerning the level, density, tracer content and temperature of drilling fluid in the hole, as the drilling fluid imparts a pressure and temperature “history” to all of the formations that are penetrated and exposed to it. Accurate knowledge of the borehole pressure and temperature history will contribute significantly to defensible interpretation of subsequent pulse hydraulic tests (see Section 5.2.5-Task HG.5) conducted in the very low permeability formations expected to be present at depth at the Bruce site. Additionally, monitoring of the gas content (e.g., methane and $H_2S$) should be undertaken for worker health and safety and scientific reasons. A mud-logging sub-contractor may be retained during the drilling program to ensure independent and effective monitoring of all of these drill fluid parameters.

#### 4.2.4.3 Temporary Borehole Sealing Systems

Because the drilling program will intersect very permeable to moderately permeable rock from bedrock surface to the top of the Queenston shale and then very low permeability rock to the Cambrian sandstone and Precambrian basement, different approaches for temporary borehole sealing are proposed for these units to temporarily isolate flow zones and to minimize cross-formational fluid flow in the open boreholes.

For DGR-1 (0 to 425 m BGS monitoring interval), sections of the borehole could be sealed with bridge plugs and/or Production-Injection Packers (PIPs) following drilling and prior to the installation of Westbay multilevel systems. If zones of significant gas or water flow or borehole instability are encountered, these zones could be cemented and re-drilled.

For DGR-2 (425 to 850 m BGS monitoring interval), a mud rotary hole will be drilled to the top of Queenston shale and an appropriate size casing will be cemented in place. Drilling of the deeper bedrock units will then be completed. Because of the very low permeability expected for these units, use of temporary borehole seals are not considered necessary below the top of Queenston shale, but could be installed if warranted. For example, PIPs could be installed in the deeper borehole to contain any flowing groundwater that may be encountered in the Cambrian sandstone.

#### 4.2.4.4 Permanent Casing Sealing Systems

The need for a flexible casing concept to allow casing-off zones of borehole instability or gas and water flow is an essential requirement of the deep drilling program. Provided that a sufficiently large surface casing is installed at the start of each borehole, this casing off capability can be provided independent of the size of the cored borehole, provided allowance is made for subsequent reaming to accommodate the grouting of telescoped casing.

For the shallow borehole (DGR-1), we recommend that a 245 mm (9 5/8”) diameter casing for blow-out prevention (BOP) purposes be installed at ground surface. In order to remain compliant with MNR regulations, this 245 mm diameter casing would likely be installed to depths of about 70 m in the hole. Final depths for installation of BOP casings are determined/approved by MNR. Subsequent drilling in the shallow borehole would be completed using the exploration drilling rig methods. If borehole stability problems or gas/water flow are encountered, the hole could be reamed to accommodate grouting of 180 mm (7”) casing. Thus, the proposed casing concept for the shallow borehole would allow telescoping and grouting of major zones of borehole instability or gas/water flow.

In the event that large sections of borehole DGR-1 drilled to the top of the Queenston shale are cased with 180 mm diameter casing, this casing could later be perforated to allow installation of multi-level monitoring systems for monitoring of formation pressures.

Similarly, for the deeper borehole (DGR-2), we recommend that a 340 mm (13 3/8”) diameter BOP casing be installed from ground surface to about 100 m depth, followed by a 245 mm (9 5/8”) diameter casing cemented in place to the top of the Queenston shale. Subsequent drilling of the deeper formations could then be completed using the exploration drilling rig methods. In the event of borehole instability or gas/water flow, the hole could be reamed to accommodate grouting of 180 mm (7”) diameter casing. Final drilling of the hole would then be completed from within the 180 mm diameter casing. Thus the proposed casing concept for the deeper borehole would allow telescoping and grouting of zones of borehole instability or gas/water flow.

It should be noted that casing-off using grouted telescoping casing removes large sections of the borehole for subsequent logging, testing and monitoring. Although perforation of cemented casing may provide some access to cased-off intervals, it is not preferred for monitoring purposes and consequently, casing-off should only be undertaken if absolutely necessary. Cementing and re-drilling of zones of instability or gas/water flow is preferred over casing-off. Subsequent installation and maintenance of Westbay multiple-packer monitoring casing would also provide the MNR required sealing of zones of water and gas flow.

In the event that a borehole or monitoring well requires abandonment, the monitoring instrumentation will be removed from the borehole and the borehole will be sealed from bottom to top using low permeability bentonite cement grout tremied into place. These borehole sealing methods would meet the requirements of both MOE and MNR.

### 4.2.5 Task G.5 - Borehole Orientation Testing During Drilling

The quality of the data collected from each borehole is highly dependant on knowing the exact location of each measurement, and therefore tracking and maintaining borehole orientation during the drilling process is important. Borehole orientation should be measured periodically during drilling using a gyroscopic survey to measure the azimuth and plunge of the borehole as it is advanced. Such orientation monitoring allows for implementation of corrective measures to adjust the borehole orientation during drilling, if the deviation from required orientation becomes greater than can be tolerated. Current technologies of gyroscopic survey tools allows the borehole azimuth and plunge to be measured without requiring surface alignment or drill collar orientation and can record borehole orientation measurements at a frequency of every one metre intervals along the borehole.

Gyroscopic surveys should be completed at the end of each drilling day (after two 10-hr shifts) to provide orientation information for the section of borehole completed that day. Gyroscopic surveys of the completed borehole will be undertaken during borehole geophysical logging (Task G.7).

### 4.2.6 Task G.6 - Geologic Core Logging

Core logging for geological characterization purposes will be conducted immediately upon recovery of core from the exploratory hole. Logging will be continuous and will include detailed descriptions of the rock lithology, stratigraphy and sedimentological features, observations taken by the responsible geologist with respect to 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 fractures and other structural features (infilling, openness, roughness, planarity, staining or other evidence of water flow), and core recovery.

Recovered core should be logged in accordance with Ontario Ministry of Natural Resources subsurface stratigraphic nomenclature as opposed to outcrop nomenclature. Figure 4.3 provides a comparison of these stratigraphic nomenclatures.

The duration of time available for core logging will be dictated by the need for rapid preservation of the core for subsequent hydrogeological and geomechanical laboratory testing. As a general guide, the recovered core should be digitally photographed as soon as possible in a consistent manner following wetting by misting to enhance visibility of core features.

### 4.2.7 Task G.7 - Borehole Geophysical Logging

Geophysical logging of each borehole to collect information on geology will primarily focus on methods that will support interpretation of 2-D and 3-D seismic surveys and development of a descriptive stratigraphic geologic model for the site.

Borehole geophysical logging services are provided by three industry groups based on the application of their services:

## BEDROCK OUTCROP STRATIGRAPHIC NOMENCLATURE

PLEISTOCENE
18 SURFICIAL DEPOSITS

MIDDLE DEVONIAN
17 AMHERSTBURG FORMATION - LIMESTONE AND DOLOSTONE

LOWER DEVONIAN
16 BOIS BLANC FORMATION - CHERTY DOLOSTONE
~~~~~~ SILURIAN / DEVONIAN DISCONTINUITY

UPPER SILURIAN
15 BASS ISLAND FORMATION - DOLOSTONE
14 SALINA FORMATION
14G G MEMBER - DOLOSTONE AND SHALE
14F F MEMBER - DOLOMITIC SHALE AND SHALE
14E F MEMBER - DOLOSTONE
14D D MEMBER - SALT (ABSENT IN SITE AREA)
14C C MEMBER - DOLOMITIC SHALE AND SHALE
14B B MEMBER - DOLOSTONE AND ANHYDRITE (2m)
14A2 A2 MEMBER - DOLOSTONE, SHALY DOLOSTONE
14A1 A1 MEMBER - DOLOMITIC SHALE AND SHALE

MIDDLE SILURIAN
13 GUELPH, GOAT ISLAND, GASSPORT, ROCHESTER AND REYNALES FORMATIONS - DOLOSTONE

LOWER SILURIAN
12 CABOT HEAD FORMATION - GREY SHALE
11 MANITOULIN FORMATION - ARGILLACEOUS DOLOSTONE

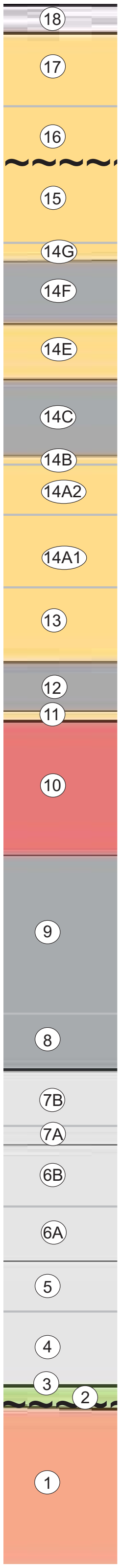
UPPER ORDOVICIAN
10 QUEENSTON FORMATION - RED SHALE AND SILTSTONE
9 GEORGIAN BAY FORMATION - GREY SHALE AND SILTSTONE
8 BLUE MOUNTAIN FORMATION - GREY SHALE

MIDDLE ORDOVICIAN
7 COBOURG FORMATION
7B UPPER MEMBER - LIMESTONE AND ARGILLACEOUS LIMESTONE
7A SHERMAN FALLS MEMBER - LIMESTONE
6 VERULAM FORMATION
6B UPPER MEMBER SHALY LIMESTONE
6A LOWER MEMBER ARGILLACEOUS LIMESTONE
5 COBOCONK FORMATION - SHALY LIMESTONE TO CRYSTALLINE LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LIKE FORMATION - SILTSTONE, SANDSTONE

CAMBRIAN
2 CAMBRIAN SANDSTONE
~~~~~~ CAMBRIAN / PRECAMBRIAN UNCOMFORMITY

PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS

NOTE:
HIGHLIGHTED TEXT INDICATES DIFFERENCES BETWEEN OUTCROPPING BEDROCK TERMINOLOGY AND SUBSURFACE BEDROCK TERMINOLOGY



## SUBSURFACE BEDROCK STRATIGRAPHIC NOMENCLATURE

PLEISTOCENE
18 SURFICIAL DEPOSITS

MIDDLE DEVONIAN
17 AMHERSTBURG FORMATION - LIMESTONE AND DOLOSTONE

LOWER DEVONIAN
16 BOIS BLANC FORMATION - CHERTY DOLOSTONE
~~~~~~ SILURIAN / DEVONIAN DISCONTINUITY

UPPER SILURIAN
15 BASS ISLAND FORMATION - DOLOSTONE
14 SALINA FORMATION
14G G MEMBER - DOLOSTONE AND SHALE
14F F MEMBER - DOLOMITIC SHALE AND SHALE
14E F MEMBER - DOLOSTONE
14D D MEMBER - SALT (ABSENT IN SITE AREA)
14C C MEMBER - DOLOMITIC SHALE AND SHALE
14B B MEMBER - DOLOSTONE AND ANHYDRITE (2m)
14A2 A2 MEMBER - DOLOSTONE, SHALY DOLOSTONE
14A1 A1 MEMBER - DOLOMITIC SHALE AND SHALE

MIDDLE SILURIAN
13 GUELPH, LOCKPORT AND REYNALES FORMATIONS - DOLOSTONE

LOWER SILURIAN
12 CABOT HEAD FORMATION - GREY SHALE
11 MANITOULIN FORMATION - ARGILLACEOUS DOLOSTONE

UPPER ORDOVICIAN
10 QUEENSTON FORMATION - RED SHALE AND SILTSTONE
9 GEORGIAN BAY FORMATION - GREY SHALE AND SILTSTONE
8 COLLINGWOOD FORMATION - GREY SHALE

MIDDLE ORDOVICIAN
7 LINDSAY FORMATION
7B UPPER MEMBER - LIMESTONE AND ARGILLACEOUS LIMESTONE
7A SHERMAN FALLS MEMBER - LIMESTONE
6 VERULAM FORMATION
6B UPPER MEMBER SHALY LIMESTONE
6A LOWER MEMBER ARGILLACEOUS LIMESTONE
5 BOBCAYGEON FORMATION - SHALY LIMESTONE TO CRYSTALLINE LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LIKE FORMATION - SILTSTONE, SANDSTONE

CAMBRIAN
2 CAMBRIAN SANDSTONE
~~~~~~ CAMBRIAN / PRECAMBRIAN UNCOMFORMITY

PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS

NOTE:
1. STRATIGRAPHIC SEQUENCE WAS DEVELOPED FROM A COMPOSITE OF THE SHALLOW BOREHOLE US-4 ONSITE AND THE DEEPER OFFSITE GAS EXPLORATION WELL TEXACO #6 IN BRUCE TWP LOT E CONCESSION IV BASED UPON A MATCH POINT AT THE AMHERSTBURG / BOIS BLANC CONTACT

Comparison of Outcrop and Subsurface Bedrock Stratigraphic Nomenclature
Geoscientific Site Characterization Plan for Bruce DGR

| | |
|---|---|
| Figure 4.3<br>05-220-1 | April 2006<br>ADG F4-3 Stratigraphic Nomenclature.cdr |

- Hydrogeological/Engineering (HE)
- Mineral Exploration (ME)
- Oil Industry (OI)

The ME industry tends to employ relatively limited suites of logs, often targeting mineralogy (electrical conductivity or magnetics) and borehole orientation. The HE community has a core suite of tools used to measure variations in lithology and/or porewater properties. However, within the HE applications and/or practitioners there are situations that require (and individuals who provide) either an extensive suite or alternatively very specific specialized tools. The OI contractors generally rely on a fairly limited core suite of technologies but often apply these with a variety of configurations. The OI geophysical loggers also tend to have access to highly specialized and exotic tools (e.g., magnetic nuclear resonance) that are justified by the value of the resource sought.

Most of the logging tools used by the HE and ME groups will fit within a 50 mm diameter borehole, while the OI, where boreholes will range from 150 to 400mm diameter, use larger diameter probes. The HE community is often trying to differentiate much smaller targets than the other two groups. Consequently, the logging speeds used by HE practitioners is typically slower and the data frequency considerably higher than what is typical in either mineral or oil exploration.

The logging speeds used in the GSCP should be kept low, varying between 0.5 and 1.5 m/min depending on the probe. Sampling frequency for those probes intended to target fine features such as fractures should be approximately 5 to 6 mm. Particular emphasis must be placed on depth accuracy and specific quality control measures should be required to address and quantify accuracy in depth measurement.

The geophysical tools proposed for identification of geological features can be divided into three categories including borehole information logs, stratigraphic information logs and fracture information logs. Borehole information logs include basic information on the diameter and orientation of boreholes. Stratigraphic information includes rock type and sequence, formation thickness and attitude while fracture information includes identification of structures intersecting or proximate to boreholes.

Table 4.2 summarizes the borehole geophysical logs intended to provide geological, hydrogeological and geomechanical information proposed for Phase 1 investigations. The following paragraphs provide descriptions of those logs that provide geological information. Descriptions of logs that provide hydrogeological and geomechanical information are provided in Sections 5.2.3 and 6.2.2, respectively.

#### 4.2.7.1 Borehole Information Logs

Information on the diameter and orientation of each borehole and the quality of the borehole walls is basic borehole information that is necessary for optimal use of each borehole for geologic, hydrogeologic and geomechanical characterization purposes. This information should be provided from borehole caliper, gyroscopic, FMI and acoustic televiewer surveys.

**Table 4.2: Summary of Recommended Borehole Geophysical Logs - Phase 1 GSCP**

| ***Borehole Geophysical Log*** | ***Geoscience Data Need*** | |
|---|---|---|
| | ***Discipline*** | ***Target Information*** |
| Gamma/Spectral Gamma | Geological | Lithology, Stratigraphy |
| Gamma-Gamma | Geological | Lithology, Stratigraphy |
| Photoelectric Effect (Lithodensity) | Geological | Mineralogy, Stratigraphy |
| Neutron | Geological<br>Hydrogeological | Lithology, Stratigraphy<br>Rock Porosity |
| Resistivity/Conductivity | Geological<br>Hydrogeological | Lithology, Stratigraphy<br>Pore-water Salinity |
| Sonic/Full Wave Form Sonic/Vertical Seismic Profiling | Geological<br>Geomechanical | Lithology, Stratigraphy, Structure<br>Bulk Modulus, Rock Competence |
| Caliper | Geological | Borehole Diameter and Zones of Instability |
| Acoustic Televiewer | Geological<br>Geomechanical | Borehole Diameter & Orientation, Fracture Occurrence & Orientation<br>Borehole Breakouts |
| FMI (Formation Macro Imaging) or equivalent imaging tool | Geological<br>Geomechanical | Borehole Diameter & Orientation, Fracture Occurrence & Orientation Lithology, Stratigraphy, Macropores<br>Borehole Breakouts |
| Video | Geological<br>Hydrogeological | Stratigraphy, Fractures, Voids<br>Flowing Fractures and Zones |
| Temperature | Hydrogeological | Water in Fractures, Vertical Water Movement in Borehole |
| Fluid Resisitivity | Hydrogeological | Groundwater Salinity, Vertical Water Movement in Borehole |
| FEC (Fluid Electrical Conductivity) Logging | Hydrogeological | Water flow from Fractures and Permeable Zones into Borehole |

#### 4.2.7.2 Stratigraphic Information Logs

Geophysical tools to collect stratigraphic information can further be divided into three categories including: radiation logs, electrical conductivity logs and acoustic logs.

Radiation logs either measure the amount of natural gamma radiation (K, U, Th) being emitted from the rocks, or expose the rock to a radiation source (i.e. gamma or neutron) and measure rock properties to infer lithology and measure porosity. The following radiation logs are proposed to be used in each open borehole section: total gamma logs, photoelectric effect (lithodensity) logs, spectral gamma logs, gamma-gamma (density) logs and neutron (porosity) logs. Radiation based tools are able to record useful measurement inside of steel casings and provide information both above and below the water table.

Electrical conductivity logs infer lithology based on a variation of clay content, the porosity/water content and the TDS of the water. Both EM-induction (resistivity) logs, which measures natural electrical conductivity of the rock formation, and conductivity logs, which emits an electrical magnetic field, are recommended for use in each open borehole section. Both tools are able to record useful measurements above and below the water table.

Acoustic logs target lithology and general rock structure characteristics of the rock formations by measuring compressional and shear wave seismic velocities. Three acoustic logs (borehole seismic surveys) are proposed to be used in each open borehole and include sonic, full waveform seismic and vertical seismic profiling (VSP). There is some redundancy with the full waveform seismic and VSP, but both surveys are proposed for the GSCP.

#### 4.2.7.3 Structural Information Logs

Although there is some overlap between geophysical tools used to measure stratigraphic changes and tools used to measure structural features (fractures), the following geophysical tools are primarily used to obtain information on fractures and are therefore proposed as part of the GSCP: FMI or equivalent imaging tool, acoustic televiewer, video log and caliper (six-arm preferred). Optical televiewer logging, which generates an oriented image of the borehole wall that is later digitally corrected, is not recommended as the performance of these logs in boreholes with dispersed clay particles is expected to be poor. Video logs which are much less expensive than optical televiewer logs, and are also affected by borehole fluid clarity, are recommended to provide real time visual inspection of borehole conditions.

With the exception of cross-hole seismic surveys, fracture identification by geophysics is limited to the immediate vicinity of the borehole. Borehole-radar reflection surveys, which under favourable conditions can provide information on fracture occurrence away from the borehole, are not recommended for the GSCP, because the signal penetration will be significantly attenuated in the high salinity and high electrical conductivity expected in the deep bedrock units at the Bruce site.

The information obtained from all of these logs (borehole, stratigraphic and fracture information) will assist in the selection of test intervals for borehole hydraulic testing and hydro-fracturing, and in configuration of the Westbay multi-level systems. Therefore all of the above mentioned geophysical logs are recommended to be used in each open borehole section immediately following drilling and flushing of drill fluid and mud from the borehole, and prior to placement of any temporary borehole seals or commencement of borehole hydraulic testing.

### 4.2.8 Task G.8 - Laboratory Petrologic, Mineralogical and Geochemical Testing of Core

Important objectives of the laboratory testing program of recovered bedrock core are to demonstrate that the pore waters within the Ordovician shale and argillaceous limestone beneath the Bruce Nuclear site are very old, i.e., > 1 million years, and that the solutes of interest, (e.g., $I^-$, $Cl^-$, Sr), have migrated only by diffusional transport. The laboratory testing program to meet these objectives includes petrologic, mineralogical and geochemical/isotopic testing of core, described here, as well as laboratory testing of groundwater (Task HG.8), laboratory extraction and testing of porewater (Task HG.9), laboratory diffusion, porosity and sorption testing (Task HG.10) and laboratory petrophysical testing (Task HG.11).

Core samples of the deep Ordovician shale and argillaceous limestone will be analyzed by optical microscopy in thin section and by X-ray diffraction to quantify the principal minerals, e.g., calcite, quartz, illite, chlorite, and pyrite, and in particular the principal pore-lining solids, in terms of their density and weight and volume percent. Scanning electron microscopy will be employed to examine rock samples for pore structure and pore-throat size and shape and recorded photographically.

X-ray fluorescence (XRF) will be used to analyze the major elements, including the concentrations and distributions of U, Th and K for calculation of 4He and 40Ar production rates and in-situ neutron fluxes for $^{129}I$ and $^{36}Cl$ in-growth calculations. Ra, Rb, Gd and other elemental concentrations will also be determined to allow estimation of naturally occurring background radioactivity and neutron flux adsorption in the deep Ordovician rocks for use in Safety Assessment. Li concentrations, not available by XRF, will be required for calculations of 3He in-growth. Organic matter may possibly be of significance in the transport of the afore-mentioned radionuclides and will be analyzed in terms of organic carbon content. Several cores will be used to determine the cation-exchange capacity and exchangeable ion populations of the shale and limestone using the methods developed by the various international groups involved in the Mont Terri geochemical program (i.e., Pearson et al., 2003, Appendix A3.6). Recent French investigations (Motellier et al., 2003; Jacquier et al., 2004) strongly recommend the measurement of ion-exchange isotherms involving $H^+$ exchange with major ions rather than the measurement of selectivity coefficients.

X-ray Absorption Spectroscopy (XAS) would provide the means to examine the porosity structure within the Ordovician shale and limestone. Computerized micro-tomography (CMT) using X-rays transmitted through cylindrical cores, coupled with scanning electron microscopy, can be used to undertake porosity mapping and three-dimensional visualization of the pore structure. Results from CMT have produced estimates of pore-size distribution and total porosity. This data can be complemented by the adsorption isotherm approach developed by Gimmi and Mazurek in Switzerland.

Diffusion cell techniques, as developed by Van Loon and colleagues (2004a, 2004b), are able to provide estimates of effective diffusion coefficients, effective porosities and retardation factors of several elements (e.g., HTO, I, Sr and Cl). For completeness, adjacent samples of core will be analysed for cation exchange capacity, exchangeable cation populations and the adsorption isotherms for use in geochemical modeling.

Table 4.3 summaries the minimum petrologic, mineralogical and geochemical testing program for recovered core. Inclusion in this table does not indicate that all tests are equally important and numbers may require amendment.

### 4.2.9 Task G.9 - Development of Descriptive Geologic Site Model

Geological data collected as part of Tasks G.1 through G.8 will be integrated to develop a descriptive geologic model of the DGR site and surrounding area. The descriptive geologic model will be developed in parallel with the GSCP and will be continually updated as new geological information becomes available. The geologic site model will describe the 3-D spatial distribution of all important geologic formations and the occurrence of all important geologic structural features within the Paleozoic and Precambrian bedrock units. The descriptive geologic model will provide a basis for geoscientific understanding of the current condition of the Bruce site, its past evolution and likely future natural evolution over the period of interest for

**Table 4.3 Summary of Minimum Core Geochemical Testing Program – Phase 1 GSCP**

| *Method* | *Targeted Formation* | *Number & Type of Tests* |
|---|---|---|
| Mineralogy of Cores | Upper Ordovician Formations | 10 (Optical Microscopy & XRD) |
| | Middle Ordovician Formations | 10 (Optical Microscopy & XRD) |
| Geochemistry of Cores | Upper Ordovician Formations | 10 (XRF, Li Digestion, Org C by IR) |
| | Middle Ordovician Formations | 10 (XRF, Li Digestion, Org C by IR) |
| Cation Exchange | Devonian & Silurian Formations | 5 (Cation Exchange Capacity, Ion Populations & Adsorption Isotherms) |
| | Upper Ordovician Formations | 5 (Cation Exchange Capacity, Ion Populations & Adsorption Isotherms) |
| | Middle Ordovician Formations | 5 (Cation Exchange Capacity, Ion Populations & Adsorption Isotherms) |
| | Cambrian Formation and Precambrian Rocks | 1 (Cation Exchange Capacity, Ion Populations & Adsorption Isotherms) |
| Pore Structure | Upper Ordovician Formations | 5 SEM (+ 3 XAS/CMT) |
| | Middle Ordovician Formations | 5 SEM (+ 3 XAS/CMT) |

Safety Assessment of the proposed DGR. The descriptive geologic site model will also provide the basic framework for the development of descriptive hydrogeologic and geomechanical site models.

## 4.3 Implementation Issues

One principal implementation issue for the geologic characterization plan is the completion of the 3-D seismic survey. There are significant infrastructure, security and other constraints to completion of this survey on OPG-controlled lands, on Bruce Power lands, on Lake Huron and off the Bruce site. These constraints need to be defined and exclusion areas identified in order to assess the feasibility of completing a meaningful 3-D seismic survey at the Bruce site in support of the GSCP. The bathymetry of the Lake off the Bruce site also needs to be defined in order to assess seismic survey feasibility on the Lake and in the difficult land-to-water transition area. All of these needs are intended to be addressed with completion of Task G.1 – Seismic Survey Feasibility Study.

There is a need for preliminary investigation of porewater extraction techniques from recovered rock core for the various analytes of interest. The methods available for extraction include crushing and leaching, centrifugation, distillation, diffusional equilibration and, more recently, advective displacement (see Section 5.2.9). Identification of preferred porewater extraction methods for core of the Ordovician shales and limestones will require trial testing of different promising methods on samples of representative core prior to commencement of Phase 1 drilling. This implementation issue is addressed with completion of Initiation Requirement I.3 (Section 11.2.3).

There may also be implementation issues related to drilling and borehole stability in the completion of deep boreholes at the Bruce Nuclear site. The Silurian and Devonian bedrock may contain anhydrite and halite layers in the Salina Formation and pinnacle reef structures in the dolostone units that may cause borehole instability. Additional drilling through the deeper Ordovician shales and limestones that may be subject to high ground stress, may also create unforeseen borehole drilling and stability problems. These potential implementation issues can be addressed by reaming and placement of permanent steel casing to isolate any zones of borehole instability.

There may also be potential for flowing groundwater conditions upon intersection of the moderately permeable Cambrian sandstone unit located immediately above the Precambrian basement. Such flowing conditions would complicate logging and testing within the deeper parts of borehole DGR-2, and 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 and with installation of temporary bridge plus or PIPs following drilling and prior to multi-level casing installation.

# 5. HYDROGEOLOGIC CHARACTERIZATION PLAN

## 5.1 Objectives and Scope

Hydrogeologic characterization activities are undertaken to develop a descriptive hydrogeologic site model of the Bruce Nuclear site and surrounding area that will provide the necessary geoscientific site data to support Safety Assessment and Repository Engineering requirements.

Because of the phased nature of the hydrogeological characterization plan, detailed descriptions of major work elements can only realistically be provided for the Phase 1 investigations. Consequently, unless otherwise indicated, the work element descriptions provided in Section 5.2 are primarily applicable for Phase 1 tasks. Although the scope and description of Phase 2 and 3 work elements are likely to be similar to Phase 1 tasks, the final description of Phase 2 and 3 tasks will only be available following completion of Phase 1 and 2 tasks, respectively. Furthermore, some hydrogeological characterization activities (e.g., in-situ air entry tests using straddle-packer assemblies, laboratory sorption testing) are only proposed for Phase 2 and/or Phase 3 investigations.

The following description of major work elements addresses the specific data needs and data collection methods identified in Tables 2.1 and 2.2. The following Table 5.1 summarizes how the data needs are met by each of the major geologic characterization work elements. Data needs are listed in Table 5.1 by numbers given in Tables 2.1 and 2.2.

**Table 5.1 Summary of Data Needs and Hydrogeologic Characterization Plan Work Elements – Phase 1 GSCP**

| ***Major Work Element*** | ***Data Needs Met by the Work Element*** |
|---|---|
| Task HG.1 – Re-Establishment of US-Series Monitoring Wells | 3.2, 3.3, 3.5, 3.6, 5.2, 5.3, 5.4, 5.5, 5.6 |
| Task HG.2 – Drill Water Tracing | 5.2, 5.3, 5.4 |
| Task HG.3 – Hydrogeologic Core Logging and Core Preservation | 1.3, 1,4, 1,5, 1.6 |
| Task HG.4 - Borehole Geophysical Logging | 1.5, 3.2, 3.4, 3.5, 5.6 |
| Task HG.5 – Borehole Hydraulic Testing | 3.2, 3.3, 3.5 |
| Task HG.6 – Design and Installation of Multi-Level Monitoring Casings | Supports Task HG.7 |
| Task HG.7 – Monitoring, Testing and Sampling of Multi-Level Monitoring Casings | 3.2, 3.3, 3.5, 3.7, 5.2, 5.3, 5.4, 5.5, 5.6 |
| Task HG.8 – Groundwater Characterization | 5.2, 5.3, 5.4, 5.5, 5.6 |
| Task HG.9 – Laboratory Porewater Extraction and Characterization | 5.2, 5.3, 5.4, 5.5, 5.6 |
| Task HG.10 – Laboratory Diffusion, Porosity and Sorption Testing | 4.1, 4.2, 4.3 |
| Task HG.11 – Laboratory Petrophysical Testing | 5.2, 5.4 |
| Task HG.12 – Development of Descriptive Hydrogeologic Site Model | 1.1, 1.2, 3.1, 5.1 |

## 5.2 DESCRIPTION OF MAJOR WORK ELEMENTS

### 5.2.1 Task HG.1 - Re-Establishment of US-Series Monitoring Wells

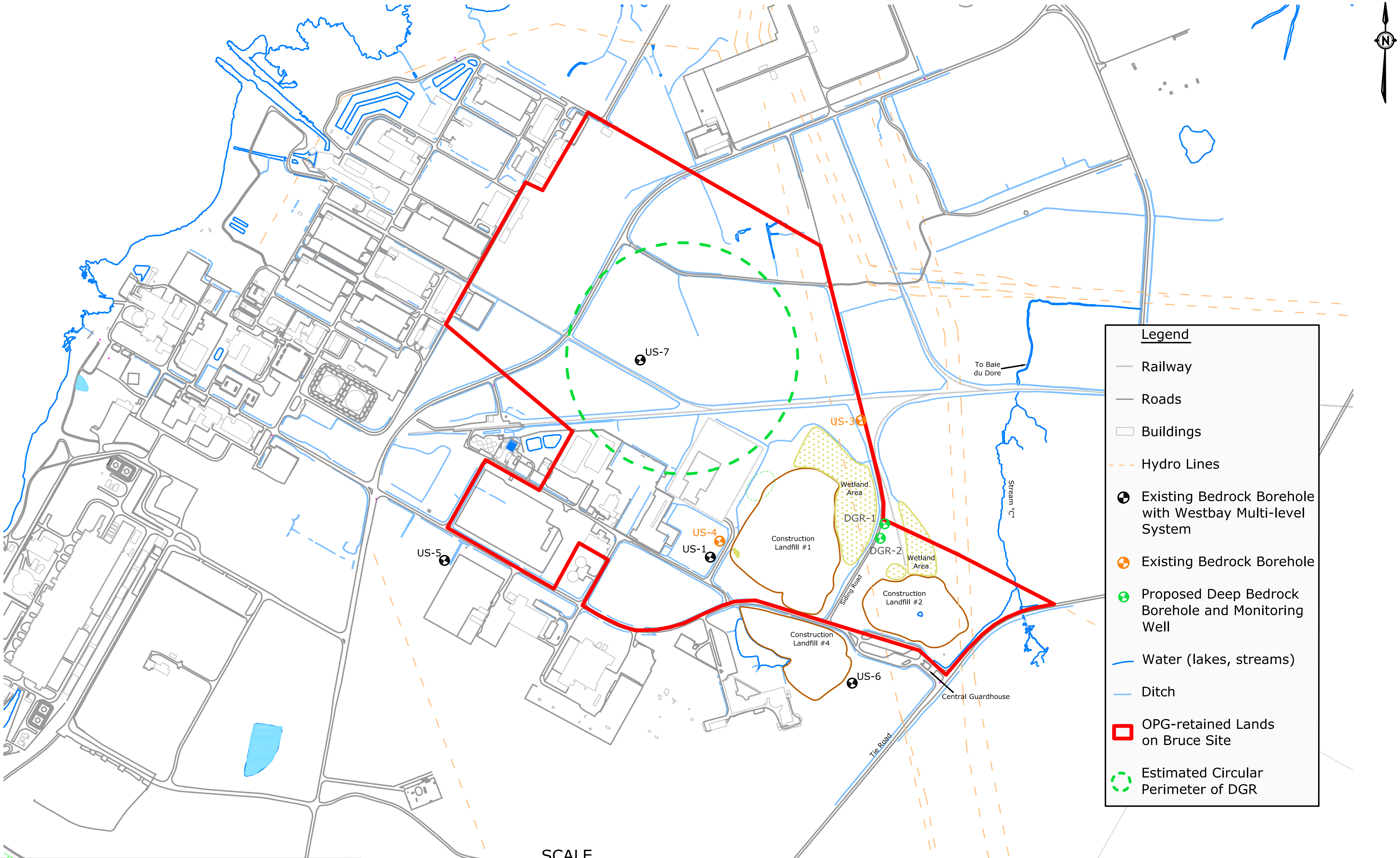
During 1986 and 1988, seven (US-1 through US-7) boreholes were drilled in the vicinity of the proposed DGR to depths of approximately 100 m BGS as part of a hydrogeological study to investigate the shallow Devonian-aged carbonate bedrock aquifer. Four of these boreholes were instrumented with plastic Westbay MP-38 multilevel monitoring systems to provide depth discrete information throughout these units and were equipped with casing packers, pumping ports and measurement ports. The intervals that were monitored by these four wells (0-100 m BGS) are strategically important because they provide historical baseline information for the upper bedrock aquifer that locally is a source of drinking water. The upper 70 to 100 m of proposed deep boreholes DGR-1 and DGR-2 will not allow access to this near surface aquifer given the requirement for installation of blow-out preventors while drilling the deeper Silurian and Ordovician aged formations. Figure 5.1 shows the location of the six boreholes that are currently accessible and indicates the four equipped with Westbay multilevel monitoring systems (US-1, US-5, US-6, and US-7), relative to the proposed DGR site within OPG retained lands.

It is proposed that the status of all six of these boreholes be investigated in terms of functionality of Westbay equipment and integrity of boreholes. Without further information, it is assumed that the Westbay multi-level casings, which are about 20 years old, will require refurbishment. As such, the Westbay equipment will be removed from the borehole by deflating packers and lifting the system using the assistance of a drilling rig. If it is determined that the equipment does not require repair and is functioning properly, the Westbay systems will be left in place.

The removal of this equipment serves several purposes: 1) the opportunity to inspect and repair/replace components of the monitoring system as necessary, 2) the opportunity to perform downhole testing within the open borehole, 3) the opportunity to reconfigure the monitoring intervals as desired and re-install the monitoring system for the ongoing investigation, and 4) the opportunity to demonstrate retrieveability of the Westbay MP system.

The packers of these Westbay systems will be deflated and the system can be removed from the borehole. In the event the packers do not readily deflate properly, they can be punctured from the inside of the Westbay casing using a tool developed by Westbay. In the worst case, the casing will be drilled out. Regardless of the method, the packers will be replaced prior to re-installing the multi-level system.

The re-established Westbay systems will be monitored for pressure/water level on a quarterly basis and sampled twice in Phase 1 to establish baseline hydrogeological conditions in shallow bedrock at site. Pressure/water level monitoring may also be completed on a more frequent basis to detect hydraulic impacts during drilling of DGR-1 and DGR-2. The analytical program for groundwater samples collected in the US-series boreholes is described in Section 5.2.9 (Task HG.8). Consideration will be given to re-establishing some of the original US-series intervals to provide continuity of historical water quality and other monitoring data for these boreholes.



OPG-Retained Land, and Existing and Proposed Boreholes and Monitoring Wells
Geoscientific Site Characterization Plan for Bruce DGR

Figure 5.1
05-220-1

April 2006
F5-1 OPG-retained land on site_Rev4.dwg

### 5.2.2 Task HG.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. 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 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 will be readily detectable in the field using a field fluorometer and will provide a wide range of detection to determine drill water contamination at sub percent levels. Na Fluorescein has been successfully used as a field-detectable drill water tracer in the NAGRA program and in other international deep drilling and testing programs. Interference with drilling muds is not anticipated to be problem. The Na Fluorescein tracer will be added to drill water that will be tested on a regular basis to determine the tracer concentrations throughout all drilling phases. Other fluorescent tracers (e.g. Lissamine FF, Eosin, Amino G acid, Pyranine, etc,) may also be used if borehole to borehole hydraulic interferences are anticipated during drilling.

The drill water tracer proposed for laboratory testing will be naturally occurring tritium. For all bedrock drilling, water from Lake Huron opposite the Bruce site will be used as the basic drilling fluid. Lake Huron water is routinely sampled and tested for tritium and averages 10 to 70 Bq/L (83 to 580 TU) depending on location. This will be an appropriate drill water tracer as testing of the bedrock in US-series boreholes at the Bruce site at depths of 50 to 90 m suggests maximum tritium contents of about 1 to 10 TU (Lee et al., 1995). Deeper bedrock should be essentially tritium free (i.e., < 1 TU).

The salinity and density of the drilling fluid will also be modified as described in Section 4.2.4.2. Routine sampling of drill water for specific conductance, HTO, $^{18}O$ and $^{2}H$ will also be undertaken to define the conductance and isotopic profiles of drilling fluids throughout the drilling program.

Should additional drilling tracers be required to evaluate cross-contamination due to hydraulic or geomechanical testing, fluorobenzoic and chlorobenzoic acids which have been employed in tracer testing at Wellenberg, Switzerland (Pearson, 1994) and at the Waste Isolation Pilot Plant in New Mexico (Meigs and Beauheim, 2001) are candidates. These halogenated benzoic acids are readily chromatographically separable and detected by liquid chromatography, on-site if necessary.

In addition to the testing of drilling-fluids, groundwater samples of opportunity will be collected during drilling for analysis of the four groups of analytes as discussed in Task HG-8.

On the basis of the analysis of the drilling fluids, the chemical properties of the opportunistic samples will be determined by measurement of tritium, $^{18}O$ and $^{2}H$. This method, originally developed for the Wellenberg boreholes (Pearson, 1994; Pearson and Scholtis, 1994) and later applied to the Benken borehole, also in Switzerland (Gimmi and Waber, 2004), uses tritium to identify modern water introduced by drilling fluids and the stable isotopes to identify evaporative losses from the sample. Further details of this operation will be addressed in the Work Plans for the Phase 1 boreholes.

### 5.2.3 Task HG.3 - Hydrogeologic Core Logging and Core Preservation

The duration of time available for core logging will be dictated by the need for rapid preservation of the core to prevent loss (or gain) of moisture, and to restrict potential oxidation of the sample, particularly when sulphide minerals are suspected of being present in the deep shale and limestone. The core will be digitally photographed and observations taken by the responsible geologist with respect to depth of recovery, fracture and bedding patterns, rock type and quality, total length recovered, texture and color, as described in Task G.6.

The cores to be used for laboratory hydrogeological testing should then be preserved immediately. Generally, the cores should be preserved in accordance with the requirements of the laboratories undertaking testing. The preferred minimum preservation technique is to place the recovered core, immediately following logging and photography (i.e., within 30 minutes of recovery at surface) into low pressure sealed core cylinders following the method used by ANDRA. The core cylinders should then be flushed with nitrogen or argon gas and maintained a low pressure differential from atmospheric to detect cylinder leakage. After preservation, the core cylinders should be stored at a temperature between 1 and 8 °C.

Any core selected for laboratory testing should be replaced in the full core sequence with a dummy of the same length, to ensure that the full core sequence that is retained in the core storage facility fully accounts for all recovered bedrock core. The dummy should identify the recipient of the core and the nature of the proposed laboratory testing of the core.

### 5.2.4 Task HG.4 - Borehole Geophysical Logging

Geophysical logging of each borehole to collect information on hydrogeology will primarily focus on methods that will identify hydraulically active fracture zones and help develop an initial descriptive hydrogeologic model to guide subsequent hydrogeologic investigations.

Although various borehole geophysical techniques mentioned previously as part of Task G.7 provide information on fracture locations, there is still the need for geophysical logs which specifically measure which of these fractures or zones are currently hydraulically active. Therefore the following geophysical logs are proposed to be used in each open borehole (DGR-1 and DGR-2) to obtain hydrogeologic information: fluid resistivity, temperature and fluid electrical conductivity (FEC).

Fluid electrical conductivity (FEC) logging would be particularly useful in the more permeable borehole DGR-1. This hydrogeologic logging method is based on replacement of the borehole fluid with a fluid of contrasting electrical conductivity (i.e., salinity) to the formation fluids, and repetitive conductivity logging of the borehole under pumping conditions to identify zones of active water inflow. The results of this logging can be used to infer hydraulic properties of the water producing zones in the borehole and help guide later borehole hydraulic testing programs. FEC logging use and application in the GSCP is further described in Section 5.2.5.2.

Prior to geophysical logging for hydrogeological purposes, it will be necessary to remove any drilling fluid effects due to mud pack on the borehole walls. It is recommended that the borehole be flushed and developed with water prior to conducting any borehole geophysical logging. The information gathered about fracture location (Task G.7) will help focus the collection of data for these fluid flow logs and therefore it is recommended that those logs are performed first.

As described in Task G.7, all of the above mentioned geophysical logs are recommended to be used in each open borehole section immediately following drilling and flushing of drill fluid and mud from the borehole, and prior to placement of any temporary borehole seals or commencement of borehole hydraulic testing.

### 5.2.5 Task HG.5 - Borehole Hydraulic Testing

#### 5.2.5.1 Test Equipment

Testing in deep boreholes to quantify the hydraulic properties of transmissivity and storativity invariably will involve the use of inflatable packers, typically set on drill tubing or rods. When the zone to be tested is at the bottom of a borehole, a single packer can be used to isolate the test zone from the higher sections of the hole. When the zone to be tested is not at the bottom of the hole, two packers connected by a perforated section of pipe will be used to straddle the test zone. In addition to the packers and tubing, a downhole shut-in valve is required to alternately open and close the test zone to the tubing. In all cases, downhole gauges will be used to measure the pressure and temperature in the test zone, the section of the borehole above the test zone, and, if present, the bottom zone of the borehole. The gauge in the test zone must be able to collect data no less frequently than every 5-10 seconds. The gauges above and below the test zone may, if necessary, be able to collect data every 1-5 minutes. For pulse tests (see below), an additional gauge can be run into the tubing to a point above the shut-in valve is also desirable, although periodic water-level measurements in the tubing can be substituted for this gauge if necessary. Test-zone lengths will be governed by the thicknesses of the strata to be tested. When practicable, entire formations will be tested. For thick formations, however, test zones will be limited to 30 m or less.

One factor that determines how long a test needs to run to provide definitive data is the volume of water that must flow or be pressurized to reach equilibrium conditions - the smaller this volume of water, the shorter the test needs to be. Hence, packers and other test tools will be set on the smallest diameter tubing or pipe that is practical, given the weight of the tools and other strength considerations. Also, solid tool volumes within test zones will be maximized to minimize the fluid volumes in those zones.

#### 5.2.5.2 Test Types

Three categories of hydraulic testing are planned: reconnaissance (or survey) testing, detailed testing, and scoping testing. The reconnaissance testing will use fluid electrical conductivity logging to identify the most permeable intervals, which may then undergo detailed testing to quantify hydraulic conductivity or transmissivity. Scoping testing may be performed on some intervals with the objective of demonstrating that hydraulic conductivity is below a defined threshold value. Recent Swiss experience in borehole hydraulic testing (Marschall et al., 2002) will be reviewed in finalizing the borehole hydraulic testing program described in this GSCP.

### *Fluid Electrical Conductivity Logging*

Fluid electrical conductivity (FEC) logging (also referred to as hydrophysical logging (e.g., Pedler et al., 1992)) will be used to identify the horizons at which the most flow is entering the borehole, which are inferred to be the horizons having the highest hydraulic conductivity. FEC logging is a two-step process. In the first step, a pipe or tubing is set to the bottom of the interval to be logged, while a pump is set at the top of the interval. A fluid (water or brine) with an electrical conductivity that contrasts with that of the natural formation water is then injected through the pipe at the bottom of the interval while pumping at the top of the interval at exactly the same rate as the injection rate. In this way, the column of water in the test interval is replaced with the contrasting fluid without inducing flow either into or out of the formation(s). In the second step, an FEC logging tool is run through the test interval to establish the initial vertical FEC profile, and then the pump is turned on at a relatively low rate to draw water into the well from the formation while making repeated logging passes with the FEC tool.

The time-dependent changes in the vertical FEC profile can then be interpreted to determine the locations at which the most water is entering the borehole, and the relative distribution of rates among these locations. If the FEC logging is performed twice, using different pumping rates, the hydraulic properties of the flowing zones can also be inferred (Tsang and Doughty, 2003). This information will be used to design and guide the detailed testing program.

### *Detailed Tests*

Three types of detailed hydraulic tests are planned in boreholes DGR-1 and DGR-2: 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 lower K. To perform any of these tests, the test zone is isolated (packers inflated, shut-in valve closed) and pressure and temperature are monitored until (ideally) they stabilize at constant values or (more typically) they have established well-defined trends towards some asymptotic values. During this equilibration period with the shut-in valve closed, enough water/drilling fluid is swabbed (or otherwise evacuated) from the tubing so that the remaining water in the tubing exerts a pressure at the elevation of the test zone that is a designed amount less (e.g., 1 MPa) than the estimated formation pressure of the test zone. The type of test performed is then determined by the sequence and time intervals of opening and closing the shut-in valve.

This difference between the pressure in the tubing when the shut-in valve is opened and the estimated formation pressure is termed the pressure differential. The pressure differential during all tests should not exceed 1 to 2 MPa to:

- avoid excessive pressure differential across packers;
- avoid/minimize gas coming out of solution; and
- avoid borehole spalling.

### *Slug Tests*

The simplest test to perform is a slug test. To initiate a slug test, the shut-in valve is simply opened, exposing the test zone to the underpressure in the tubing. Water will then flow from the formation into the test zone and up the tubing until the pressure in the tubing reaches the formation pressure. The pressure-time data collected while water is rising in the tubing are then used to calculate the transmissivity (hydraulic conductivity x thickness) of the test zone.

Uncertainty in the calculated value of transmissivity decreases the longer the test is allowed to run (i.e., as pressure recovery approaches 100 percent). Decisions to terminate slug 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. With hydraulic conductivities on the order of 1 x $10^{-7}$ m/s, slug tests should take no longer than one day to complete. Two slug tests will always be performed, with the pressure differential of one test being approximately twice that of the other.

*DSTs*

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. It therefore consists of two parts: a flow period and a buildup period (to use petroleum terminology). 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. The flow-period data can be analyzed in exactly the same manner as slug-test data but, because of the low degree of pressure recovery, will not provide a well-constrained estimate of transmissivity. The buildup data are analogous to recovery data collected after a pumping test. Uncertainty in the calculated value of transmissivity decreases the longer the buildup period is allowed to run (i.e., as pressure recovery approaches 100 percent). Decisions to terminate buildup 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 uncertainty at any time during a test. Conjunctive analysis of the flow data and buildup data allows for a better constrained estimate of transmissivity than is provided by analyzing either data set alone.

After the first DST is completed, a second DST should be performed. Because of the low degree of pressure recovery during the first DST flow period, the pressure in the tubing will still be in disequilibrium with the formation pressure at the end of the first buildup period, and the shut-in valve can be opened to initiate a second DST, which will automatically have a lower pressure differential than the first DST. With hydraulic conductivities on the order of 1 x $10^{-10}$ m/s, two DSTs should take no longer than two days to complete. However, depending on the magnitude and complexity of the pressure history imposed on the test zone since it was first penetrated by the drill bit, an equilibration period of one or more days may be necessary after the test zone is isolated before DSTs can begin.

*Pulse Tests*

To initiate a pulse test, the shut-in valve is opened only long enough for the underpressure in the tubing to be transmitted to the test zone and measured (one or two data scans), and then the shut-in valve is closed and the ensuing pressure buildup to formation pressure is monitored. A key parameter that must be measured during a pulse test is the amount of water that enters the tubing from the test zone while the shut-in valve is open. This volume of water is combined with the pressure drop observed in the test zone when the shut-in valve was opened to calculate the test-zone compressibility. No estimate of transmissivity can be obtained from a pulse test without knowledge of the test-zone compressibility. To minimize potential complications in long-term pulse tests due to osmotic effects, the fluid in the packer-isolated test interval should be of similar chemistry to that of the shale porewater.

As with slug tests, uncertainty in the calculated value of transmissivity decreases the longer the pulse test is allowed to run (i.e., as pressure recovery approaches 100 percent). At the low hydraulic conductivities at which pulse tests are the preferred testing option, the borehole pressure and temperature histories can exert a strong influence on pressure responses observed during a test. Hence, equilibration periods of several days must be scheduled between the time a test zone is isolated and testing begins, and/or the pulse tests must be allowed to reach higher levels of recovery than would be necessary for defensible parameter estimation if ideal antecedent conditions had existed. Decisions to terminate pulse 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 uncertainty at any time during a test. Two pulse tests will always be performed, with the pressure differential of one test being approximately twice that of the other test.

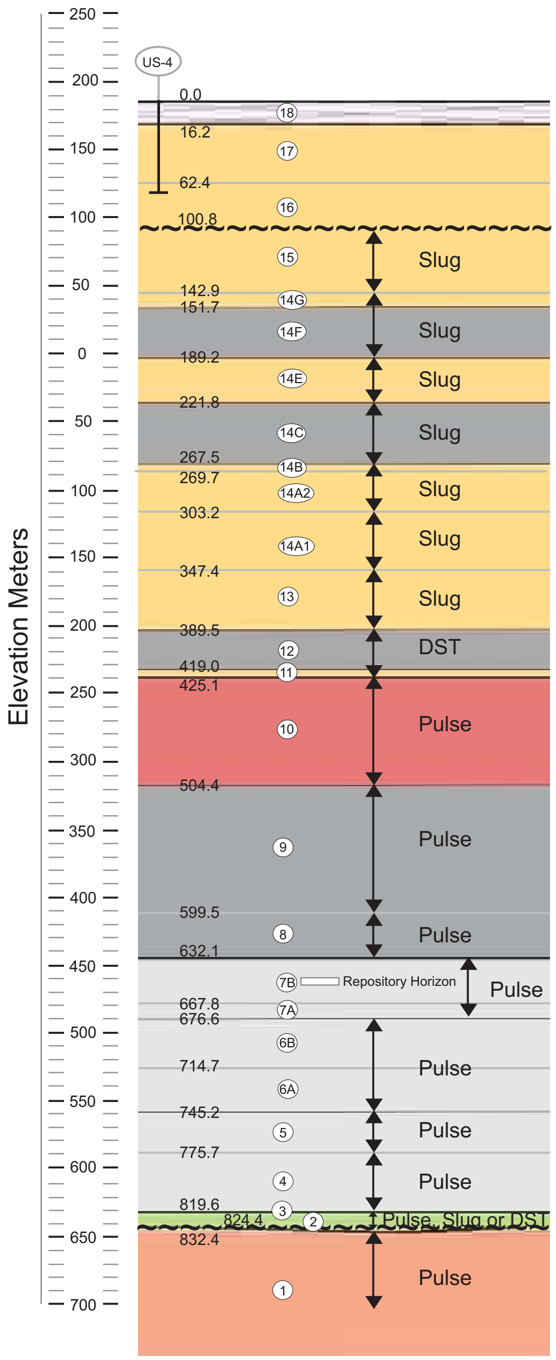
#### *Scoping Tests*

The purpose of scoping tests is to establish that the hydraulic conductivity of an interval is below some pre-defined threshold value, potentially 1 x $10^{-11}$ m/s. The threshold value will be selected to provide reasonable assurance that diffusion will dominate over advection as a transport mechanism (i.e., the Peclet number will be <<1). During the Phase 1 site investigations, simple confirmation that a formation is diffusion-dominated is needed more than precise quantification of the low hydraulic conductivities. Scoping tests will typically begin as pulse tests, but may be terminated before fully defensible hydraulic properties can be inferred if real-time analysis of the data shows that hydraulic conductivity must be below the threshold value.

### 5.2.5.3 Phase 1 Tests Planned for Borehole DGR-1

After borehole DGR-1 has been extended into the upper 15 m of the Queenston Formation and geophysical logging is complete, FEC logging will be performed over the entire open interval of the hole. The FEC logging will identify the most productive intervals in the hole, which will then be the subject of detailed testing. Based on the hydraulic conductivities estimated by Golder Associates Ltd. (2003), the Bass Island Formation is expected to contain the most permeable horizons ($K \approx 1 \times 10^{-5}$ m/s), followed by the Salina and Middle Silurian formations ($K \approx 1 \times 10^{-5}$m/s). Slug tests are expected to be the appropriate type of test for those formations. Straddle intervals for the slug tests will be based on the results of the FEC logging, but will not be longer than 30 m in any case. If some of the formations (or members beds of the Salina Formation) do not show significant flowing intervals in the FEC logging, they may nevertheless be tested to provide a more complete picture of the vertical distribution of hydraulic conductivity in the Upper and Middle Silurian strata. Figure 5.2 shows the types of hydraulic tests proposed for boreholes DGR-1 and DGR-2 based on available information. It is expected that some of the permeable intervals will be found at the contacts between formations and allowance has been made for testing of such permeable contacts.

The Lower Silurian Cabot Head and Manitoulin Formations, estimated by Golder Associates Ltd. (2003) to have hydraulic conductivities of approximately 1 x $10^{-10}$ m/s, may not show any particularly productive intervals during FEC logging. Nevertheless, DSTs will be performed on these formations as they represent the first strata above the proposed repository horizon in which advection is expected to be more significant than diffusion as a transport mechanism.



## STRATIGRAPHIC LEGEND

PLEISTOCENE
18 SURFICIAL DEPOSITS

MIDDLE DEVONIAN
17 AMHERSTBURG FORMATION - LIMESTONE AND DOLOSTONE

LOWER DEVONIAN
16 BOIS BLANC FORMATION - CHERTY DOLOSTONE
~~~~~~ SILURIAN / DEVONIAN DISCONTINUITY

UPPER SILURIAN
15 BASS ISLAND FORMATION - DOLOSTONE
14 SALINA FORMATION
14G G MEMBER - DOLOSTONE AND SHALE
14F F MEMBER - DOLOMITIC SHALE AND SHALE
14E F MEMBER - DOLOSTONE
14D D MEMBER - SALT (ABSENT IN SITE AREA)
14C C MEMBER - DOLOMITIC SHALE AND SHALE
14B B MEMBER - DOLOSTONE AND ANHYDRITE (2m)
14A2 A2 MEMBER - DOLOSTONE, SHALY DOLOSTONE
14A1 A1 MEMBER - DOLOMITIC SHALE AND SHALE

MIDDLE SILURIAN
13 GUELPH, LOCKPORT AND REYNALES FORMATIONS - DOLOSTONE

LOWER SILURIAN
12 CABOT HEAD FORMATION - GREY SHALE
11 MANITOULIN FORMATION - ARGILLACEOUS DOLOSTONE

UPPER ORDOVICIAN
10 QUEENSTON FORMATION - RED SHALE AND SILTSTONE
9 GEORGIAN BAY FORMATION - GREY SHALE AND SILTSTONE
8 COLLINGWOOD FORMATION - GREY SHALE

MIDDLE ORDOVICIAN
7 LINDSAY FORMATION
7B UPPER MEMBER - LIMESTONE AND ARGILLACEOUS LIMESTONE
7A SHERMAN FALLS MEMBER - LIMESTONE
6 VERULAM FORMATION
6B UPPER MEMBER SHALY LIMESTONE
6A LOWER MEMBER ARGILLACEOUS LIMESTONE
5 BOBCAYGEON FORMATION - SHALY LIMESTONE TO CRYSTALLINE LIMESTONE
4 GULL RIVER FORMATION - LITHOGRAPHIC LIMESTONE
3 SHADOW LIKE FORMATION - SILTSTONE, SANDSTONE

CAMBRIAN
2 CAMBRIAN SANDSTONE
~~~~~~ CAMBRIAN / PRECAMBRIAN UNCOMFORMITY

PRECAMBRIAN
1 PRECAMBRIAN BASEMENT - GRANITIC GNEISS

NOTE:
1. STRATIGRAPHIC SEQUENCE WAS DEVELOPED FROM A COMPOSITE OF THE SHALLOW BOREHOLE US-4 ONSITE AND THE DEEPER OFFSITE GAS EXPLORATION WELL TEXACO #6 IN BRUCE TWP LOT E CONCESSION IV BASED UPON A MATCH POINT AT THE AMHERSTBURG / BOIS BLANC CONTACT

Types and Locations of Borehole Hydraulic Testing Proposed for GSCP Phase 1
Geoscientific Site Characterization Plan for Bruce DGR

Figure 5.2
05-220-1

April 2006
ADG F5-2 Borehole Hydraulic Testing_Rev2.cdr

The Lower Silurian formations have an estimated aggregate thickness of approximately 36 m, comprising 30 m of grey shale of the Cabot Head Formation overlying 6 m of argillaceous dolostone of the Manitoulin Formation. Because these formations will be at the bottom of the borehole, the entire interval can be tested with a single bottom hole test tool configuration.

In the event that real-time analysis of the test data indicates a hydraulic conductivity an order of magnitude or more higher than expected, additional tests of the Manitoulin Formation alone should be performed to differentiate the properties of the two formations.

It is important to recognize that the approach to hydraulic testing, given the ability for real-time evaluation of data, allows for modification of testing protocols/procedures to obtain the best possible results. For example, an intended slug test may be converted to a DST if the initial flow response is of lower magnitude than expected, or an intended DST may be converted to a slug test if the initial response is greater than expected. Similarly, a DST flow period that shows little response will be quickly shut-in and converted to a pulse test.

#### 5.2.5.4 Phase 1 Tests Planned for Borehole DGR-2

The bedrock formations open to borehole DGR-2 are expected to have hydraulic conductivities less than 1 x $10^{-11}$ m/s (Golder Associates Ltd., 2003). Drilling of borehole DGR-2 will be temporarily suspended at the base of the Collingwood Formation, and the entire 207-m interval of the Queenston, Georgian Bay, and Collingwood Formations will be tested in a single bottom-hole test. Given reported formation hydraulic conductivities a pulse test format is likely the most appropriate method, although this will be confirmed during field testing. Furthermore, should higher than anticipated hydraulic conductivities be observed during the initial bottom-hole test, additional hydraulic tests will be perform at shorter intervals to assess formation specific hydraulic conductivity distributions. Following that test, the hole will be extended into the Precambrian (possibly after casing off the Upper Ordovician shales should borehole instability/collapse dictate).

FEC logging will then be performed over the interval from the top of the Queenston to the bottom of the hole to determine if any intervals have higher hydraulic conductivities than expected. If flowing artesian conditions are encountered in the Cambrian sandstone, FEC logging would be conducted above an installed PIP that isolates the Cambrian sandstone. Permeable intervals identified with FEC logging will be tested using whatever test method is considered most appropriate. Pulse tests will be performed over an interval of the Lindsay Formation regardless of the results of the FEC logging.

Scoping tests will be performed in the remaining formations to confirm that their hydraulic conductivities are less than the designated threshold value. Only the Shadow Lake Formation and the Cambrian sandstone will be tested together; (sections of) the other formations will be tested separately to provide baseline information on their properties. If the FEC logging provides no guidance for the selection of test intervals, they will be selected after evaluating core and geophysical logs, with the goal of testing the intervals expected to have the highest hydraulic conductivities.

As with the tests in borehole DGR-1, the type of test (pulse, slug, DST) performed in borehole DGR-2 may be modified based on real-time evaluation of the data from any interval. Based on the limited data available, the Shadow Lake/Cambrian interval appears to be the most likely candidate for alternative testing methods. Figure 5.2 shows the types of hydraulic tests proposed for borehole DGR-2.

### 5.2.6 Task HG.6 - Design and Installation of Multi-Level Monitoring Casings

Geologic and hydrogeologic data collected from previous Tasks should be used to design and select an appropriate multi-level system for long-term groundwater monitoring in both boreholes. The following factors should be considered in this system design and selection.

- Ability to ensure integrity of packer or borehole seals and monitoring system components for monitoring periods of 5 years in highly saline groundwater conditions.
- Ability to monitor casing system integrity and performance and, if necessary, the retrieval and replacement of system components.
- Ability to accurately and reliably measure formation pressures in deep, low-permeability, low-storativity, variable-density groundwater settings with the possible presence of gas.
- Ability to collect representative groundwater and dissolved gas samples under in-situ conditions with minimal disturbance.
- Flexibility in approaches and methods for hydraulic testing.
- Ability to obtain maximum amount of hydrogeologic information from maximum number of test intervals in a borehole in a cost-effective manner.
- Demonstrated track record and ability to obtain high quality data with minimal down time and ongoing system maintenance.
- Ability to retrieve multi-level casing system from borehole in event of borehole abandonment.

For the depths considered in this GSCP there are two alternatives for multi-level monitoring casings – multiple packer-standpipe/tubing systems and Westbay MP casing systems. Multiple packer- standpipe/tubing systems can be custom assembled or provided from several different manufacturers in several different borehole sizes and configurations. The major limitation of such systems is the number of intervals that can be created in a single hole, which is usually limited to 5 to 10 intervals depending upon the size of borehole, types of packers and standpipe/tubing used.

Westbay multi-level monitoring systems are available in two sizes – MP38 and MP55 systems that are installable in boreholes ranging from 72 to 225 mm diameter. Currently MP38 systems are only manufactured with plastic casing while MP55 systems can be manufactured with plastic or stainless steel casing. Plastic systems have proven performance to depths of 1000m BGS. MP38 systems are commonly installed in N- and H-size boreholes. MP55 systems are installable in P-size and conventional oil and gas boreholes.

Although no one multi-level casing system is superior on all factors identified above, the Westbay MP system is judged to provide greater flexibility and more cost-effective and superior quality data than that available from multiple packer-standpipe/tubing systems.

For boreholes DGR-1 and DGR-2 drilled in Phase 1, each borehole should be completed with approximately 20 packer-isolated test intervals. This will result in test interval lengths ranging from about 20 to 30 m. Borehole DGR-1 should use both pumping ports and pressure ports for sampling, monitoring and testing. Borehole DGR-2 should use principally pressure ports for sampling, monitoring and testing. However, if straddle-packer hydraulic testing indicates any zones of high permeability (for example, the Cambrian sandstones, if encountered) pumping ports will be installed in those intervals. Since 160 mm boreholes are proposed, the plastic Westbay MP55 system is proposed for long-term monitoring, testing and sampling.

### 5.2.7 Task HG.7 - Monitoring, Testing and Sampling of Multi-Level Casings

#### 5.2.7.1 Pressure Monitoring

Down-hole pressure monitoring is the preferred method of quantifying hydraulic heads in deep groundwater flow systems of variable fluid density. Such pressure measurements can be directly converted to equivalent fresh water heads and environmental water heads to quantify hydraulic flow potentials in horizontal and vertical directions, respectively. Water level monitoring from surface in long standpipes or tubing connected to packer-isolated test intervals does not provide such direct measurement of down-hole formation pressure. Information on the density and temperature profile of the water column in the standpipe or tubing is necessary to accurately convert water levels to formation pressures. Such density and temperature profile information is rarely known for most small diameter standpipes or tubes and cannot be easily obtained. Furthermore if gas pressures are encountered the standpipes would have to be shut-in to obtain pressure measurements, and the presence of a gas phase in the standpipe or tubing column adds additional complication and uncertainty to estimation of down-hole pressures.

There are three alternatives for down-hole pressure measurement – dedicating separate pressure transducers to individual monitoring intervals, pressure profiling using a removable pressure transducer, and continuous pressure monitoring using a dedicated transducer string.

The preferred method of pressure monitoring for the more permeable bedrock in borehole DGR-1 is using Westbay pressure measurement ports and the Westbay pressure profiling tool. Such pressure monitoring should be performed on a quarterly basis during Phase 1. This system allows the use of one pressure transducer and tool that can be easily and frequently calibrated to obtain formation pressure measurements from several multi-level monitoring wells. The preferred method for pressure monitoring the very impermeable Ordovician shale and limestone of borehole DGR-2 is continuously using a retrievable string of pressure transducers (estimated 5 probes) within the Westbay system. The apparent need for simultaneous and continuous pressure measurement in deep low permeability monitoring intervals is based on ANDRA experience that repeated accessing of intervals for pressure measurement created significant pressure disturbances and prevented the accurate measurement of representative formation pressures.

#### 5.2.7.2 Hydraulic Testing

*Test Types*

Pumping tests, slug tests and pulse tests can be performed in Westbay casing via access through pumping ports and pressure measurement ports. Given the transmissivities expected in the Silurian and older strata, only slug and pulse tests are anticipated to be performed in boreholes DGR-1 and DGR-2 after Westbay casing is installed. In Westbay casing, slug tests are performed by evacuating enough water from the central pipe to create the desired pressure differential, and then opening the pumping port of the desired test zone to the central pipe to allow water to flow from the formation. As the water rises in the central pipe, pressure is monitored using the pressure measurement tool hanging in the casing, or water levels in the casing are recorded from surface using water level tape.

Pulse tests may also be performed in Westbay casing using pressure measurement ports and the groundwater sampling and pressure measurement tool. Following establishment of an equilibrium shut-in pressure, the groundwater sampling valve in the sampling and measurement tool can be opened and closed to create an instantaneous pressure decrease in the test interval, which can be continuously monitored using the pressure measurement tool. Test interval compressibility for the test can be determined from the volume of fluid recovered in the stainless steel sampling cylinders and the magnitude of the measured pressure decrease.

Long-term pressure monitoring following drilling, casing installation and packer inflation, and future shaft excavation can also provide transient hydraulic responses that can be analyzed to determine bulk formation hydraulic properties.

The advantage of hydraulic testing in Westbay casing as opposed to using a straddle-packer assembly is that no rig or tool rental fees are accruing, so that tests can be allowed to continue for as long as useful data are being acquired. This also means that testing can be applied to lower transmissivity formations that might take weeks to months to test.

#### *Phase 1 Tests Planned for Borehole DGR-1*

Slug tests will be performed in all of the Westbay completion intervals in borehole DGR-1 to provide defensible, baseline information on their properties.

#### *Phase 1 Tests Planned for Borehole DGR-2*

Slug testing is not currently expected to be an effective way of estimating the transmissivity of the Ordovician and older strata. Slug testing may nevertheless be performed in some of the Westbay completion intervals in borehole DGR-2 if the earlier straddle-packer testing reveals higher transmissivities than expected, and/or as a way to purge drilling fluid from the hole to facilitate sampling the pore fluid of one or more formations. Such testing and sampling would only be performed following stabilization of formation pressures in borehole DGR-2. Previous experience in bedrock with such low transmissivities and storativities suggests that stabilization of formation pressures may extend to a year or more.

Pulse testing may be performed in any of the Westbay completion intervals in borehole DGR-2 for which confirmation of the open-hole test results is desired. Long-term pressure monitoring will be also be completed in several test intervals that are expected to be of very low transmissivity.

### 5.2.7.3 Groundwater Sampling

The preferred method of groundwater sampling in deep low-permeability formations is to collect representative samples with a minimum of disturbance and exposure to atmospheric influence, particularly if the samples are to be analyzed for dissolved gases (i.e., noble gases) and tritium. The elevated concentrations of atmospheric tritium at the Bruce site means that special precautions need to be taken to ensure that deep groundwater samples to be analyzed for low-level tritium content are not exposed to atmospheric tritium. Representative samples usually require that the standing water in the test interval/standpipe be purged and that drill water and other foreign water influences be reduced to the extent practicable.

For the very low permeability test intervals expected to exist in the deep Ordovician shales and argillaceous limestones at the Bruce site, the test intervals will likely produce very small quantities of groundwater, which will severely limit the ability to undertake conventional purging of isolated intervals. For these intervals it will not be possible to collect groundwater samples following conventional interval purging protocols.

The preferred approach to groundwater sampling (as opposed to porewater sampling) in these deep low permeability intervals is to collect available sample volumes using a sealed, down-hole sampling cylinder, without purging and following a suitable equilibration time of several months to perhaps a year or more to allow equilibrium pressures to be established. This equilibration time will also allow advective and diffusive exchange to occur between formation porewater and interval groundwater resulting in more representative groundwater samples when a decision is taken to sample such intervals. Given the expected time for stabilization of formation pressures and diffusive equilibration, such groundwater quality data may not be available from the low permeability intervals until early in 2008.

The Westbay groundwater sampling probe and sampling cylinders are recommended for this groundwater sampling.

#### 5.2.7.4 Demonstration of Recoverability of Multi-Level Casings

Because of concern over long-term recoverability of Westbay multi-level monitoring casings expressed by the MNR, demonstration of the recoverability of such casing systems is considered prudent. Consequently, near the end of Phase 1, the multi-level casing string installed in DGR-1 should be deflated, removed, and reinstalled to demonstrate the long-term recoverability of the Westbay multi-level casing systems at the Bruce DGR site.

### 5.2.8 Task HG.8 - Groundwater Characterization

Samples of groundwater will be collected from the shallow and intermediate bedrock flow systems in the Silurian and Devonian carbonate rock sequences, the Cambrian sandstone and the Precambrian basement. These samples will be collected from the US-series shallow boreholes, as opportunistic (i.e., “open borehole”) samples during drilling of DGR-1 and DGR-2, and later from selected Westbay multi-level intervals. They will be tested for drilling-fluid tracer concentrations (e.g., tritium, Na Fluorescein or other dyes and halogenated benzoic acids, as necessary), prior to forwarding samples to analytical laboratories for geochemical and isotope analyses.

#### 5.2.8.1 Opportunistic Groundwater Sampling

The initiating events that will cause collection of opportunistic groundwater samples will be loss of drilling-fluid circulation or at the end of a hydraulic test in which a sufficiently high permeability is measured. Consequently, it will be necessary to assemble on-site the necessary equipment for hydrogeochemical sampling, preservation and field analysis in a field laboratory that can also be employed for core preservation. Thus, the following equipment will be required: (a) submersible pump, clean sampling tubing and packer/PIP system; (b) field equipment for measurement of pH, Eh, temperature, specific conductance; (c) filtration equipment; (d) glove box for handling and transferring samples; (e) preservation chemicals; (f) specialized sampling vessels; (g) tracer analysis instruments and (h) other items associated with core handling. More detailed descriptions of the procedures and equipment to be used to complete opportunistic groundwater sampling will be provided in the Phase 1 work plans for this activity.

#### 5.2.8.2 Analytical Program

Assuming drilling-fluid contamination can be quantified in opportunistic (i.e., “open borehole sampling” as listed in Table 5.2) and other samples by the methods developed at Wellenberg (Pearson, 1994) through the analysis of Group A and B analytes (see below), groundwaters will be characterized for a suite of analytes, which will include five groups that will be the subject of both groundwater and porewater analysis:

**[Group A] Master Variables & Major Ions:** (pH, Eh, electrical conductivity, temperature) and major ions (Ca, Na, Mg, K, Sr, $SO_4$, $HCO_3$, Si, F, HS, Cl and Dissolved Organic Carbon, which may be partly anionic). These analytes will provide a charge-balanced analysis that can be used for geochemical modeling (see Section 7.2.3). 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 and Br) and environmental isotopes ($^{18}O$, $^{2}H$, $^{3}H$, $^{87}Sr$). These analytes provide information on the redox state and origin of the groundwaters and porewaters. Additional environmental isotope analytes may be added during Phases 2 and 3 including $^{13}C$, $^{37}Cl$, $^{11}B$, and $^{7}Li$.

**[Group C] Radioisotopes:** ($^{129}I$ and $^{36}Cl$ in the deep shales, $^{4}He$, $^{14}C$ and $^{36}Cl$ in the shallow bedrock). These analytes 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, He, Ar, Ne, $N_2$ and $CH_4$). These gases will provide important diffusion profiles in the Ordovician shale and argillaceous limestone and information on the redox environment.

**[Group E] Drill Water Tracers:** Fluorescein (field tested), tritium (lab) and potentially halogenated benzoic acids (lab, possibly field lab if necessary).

Table 5.2 below, summarizes the minimum groundwater and porewater analytical program recommended for Phase 1 of the GSCP.

**Table 5.2 Summary of Minimum Groundwater/Porewater Characterization Program – Phase 1 GSCP**

| ***Analytes*** | ***Targeted Formation*** | ***Number of Tests*** |
|---|---|---|
| Drill Water Tracers (Group E) | All Formations | 90 (Groundwater and Porewater) |
| Master Variables & Major Ions; Trace Elements; Environmental Isotopes (Groups A & B) | US-Series Wells | 25 (Groundwater – Open Borehole and Westbay) |
| | Drill Water | 10 |
| | Devonian and Silurian Formations | 20 (Groundwater – Open Borehole & Westbay Samples) |
| | Upper Ordovician Formations | 10 (Porewater) |
| | Middle Ordovician Formations | 10 (Porewater) |
| | Cambrian Sandstone and Precambrian | 3 (Groundwater – Open Borehole & Westbay Samples) |
| Radioisotopes<br>(Group C) | US-series Wells | 8 (Groundwater - $^{14}$C,$^{4}$He and $^{36}$Cl) |
| | Devonian and Silurian Formations | 10 (Groundwater - $^{14}$C,$^{4}$He and $^{36}$Cl ) |
| | Upper Ordovician Formations | 3 (Porewater -$^{129}$I and $^{36}$Cl) |
| | Middle Ordovician Formations | 3 (Porewater - $^{129}$I and $^{36}$Cl) |
| | Cambrian Sandstone and Precambrian | 3 (Groundwater -$^{129}$I and $^{36}$Cl) |
| Gases<br>(Group D) | Devonian and Silurian Formations | 10 (Groundwater – Open Borehole & Westbay Samples) |
| | Upper Ordovician Formations | 5 (Porewater) |
| | Middle Ordovician Formations | 5 (Porewater) |
| | Cambrian Sandstone and Precambrian | 3 (Groundwater – Open Borehole & Westbay Samples) |

In the event that only limited quantities of water are available for analyses, for example from porewater extraction, priority analytes will be those of Groups A, B and E. Group C and D analytes will be undertaken if there is sufficient quantity of water for these analyses.

### 5.2.9 Task HG.9 - Laboratory Porewater Extraction and Characterization

#### 5.2.9.1 Porewater Extraction Methods

Various methods for extracting porewater from the Ordovician shales and limestones that are the focus of this characterization program are available. Assuming a water-accessible porosity of 0.10 (Mazurek, 2004, Figure 8-2), a maximum extractable volume per unit length of HQ and PQ core is about 3 and 5.5 mL/cm, respectively.

Various approaches may be considered (Sacchi et al., 2001) and must be tested as to their appropriateness prior to the drilling of the first borehole. These approaches include:

1. mechanical squeezing;
2. whole rock crushing and subsequent aqueous leaching (“crush & leach”);
3. centrifuge extraction, possibly involving immiscible fluid displacement;
4. sequential heating to 500ºC to release dissolved and sorbed gases (“distillation”);
5. diffusional equilibration, perhaps under vacuum; and
6. forced advection.

A number of issues will need to be considered in the choice of the most appropriate method(s) for these cores. For example, it appears rather unlikely that mechanical squeezing will provide sufficient pore water to make it a suitable extraction method, particularly because it appears likely that a special high-pressure squeezer would be required by any laboratory undertaking the extraction. While the crush and leach method has been employed in the US program at Yucca Mountain and in the Swiss program, it destroys the rock sample rendering it unavailable for testing for other purposes, such as diffusion cell testing. Furthermore, water-rock interaction during the crushing and leaching process is likely to promote mineral dissolution and other changes to the water chemistry (Cave, 2005), especially when the pore water is suspected of being of such high ionic strength (~100 g TDS/L).

Centrifuge extraction, which has been in use by the British Geological Survey since the 1970s and was used to analyze the Boom Clay in Belgium, may provide a suitable and non-destructive testing process for analysis of both pore surfaces and pore-water samples. However, until samples of the Ordovician shale and argillaceous limestone are tested, the benefits and disadvantages of each method of pore-water extraction in the context of solute, isotope and gas analysis remains uncertain. All extraction methods will require a significant assessment program to determine if they can meet quality assurance standards for the analysis of isotopes, gases and major ions in these sedimentary rocks. Vacuum- or azeotropic-distillation and other extraction techniques (Sacchi et al., 2001) will likely be used in association with one or more of these principal methods, in particular for gases.

Recent developments suggest that direct equilibration of rock samples through diffusion (van der Kamp, 1996; Rubel et al., 2002) is an attractive method for the extraction of samples for isotope and noble gas analysis from clay tills and claystone rocks, such as the Opalinus Clay. Alternately, Mäder et al. (2005) have developed a procedure using forced displacement of the porewater by advection of a tracer-labeled displacing water sample. As they note: “The feasibility of the method hinges on the well connected porosity and homogeneity of most claystones that result in approximate one dimensional advective-dispersive flow [i.e., plug flow] when applying a large hydraulic gradient across the length of a cylindrical sample.” It is not clear that the Ordovician shales and limestones beneath the Bruce site are sufficiently homogeneous to allow this method to be employed, however, both it and the diffusional equilibration method merit testing with these rocks.

### 5.2.9.2 Porewater Characterization Methods

The methods of porewater characterization will depend to a certain extent on the volume of porewater that is extractable and the concentration of the target analytes within the porewater. It is anticipated that ICP/MS (inductively coupled plasma mass spectrometry), IX (ion exchange chromatography) and combustion-gas analysis will be employed for this analysis. Micro-analysis techniques may allow for pH, cation and trace element analysis on pore-water samples from the deep shales and limestones.

Alternate sections of core samples, 100-200 mm in length depending upon the pore-water yield, will be analyzed for isotopes and noble gases. $^{2}H$ and $^{18}O$ will be determined in cores from the shallow bedrock down to the Cambrian sandstone to identify the depth to which modern waters might have penetrated. If the conceptual model of connate Ordovician waters is valid, then the $^{2}H$ and $^{18}O$ signatures in pore waters from these rocks will exhibit a geochemical fingerprint of formational brine reflecting water-rock interaction rather than that of glacial melt water or modern groundwater. Stable isotope analysis of pore fluids may be achieved by direct equilibration with water vapour into a test-water reservoir of known stable isotopic composition and salinity (Rubel et al., 2002). Analytical methods must demonstrate minimal evaporative loss. Tritium contents would be quantified using low-level analytical counting methods. Ultra low-level $^{3}H$ analysis through $^{3}He$ in-growth could be considered as a check on selected sample contamination from drilling fluids and atmospheric exposure.

The purpose of the study of $^{129}I$ and $^{36}Cl$ radioisotopes with analysis by Accelerator Mass Spectroscopy (AMS) is to use their long half lives ($1.57 \times 10^{7}$ and $3.01 \times 10^{5}$ yrs, respectively) to investigate the residence times of pore waters in the stratigraphic column containing the Ordovician shale and limestone. This work began at the Bruce Nuclear site with the study of tritium and helium in the till and the shallow Devonian bedrock (Lee et al., 1995) which is located well above the Ordovician rocks at the proposed repository level. The information of apparent residence times with depth that the analysis of $^{129}I$ and $^{36}Cl$ may yield will assist in building a hydrogeological and pore-water residence time model of the sedimentary sequence including the Ordovician rocks. While it is likely that secular equilibrium for $^{36}Cl$ will fix the measured activities, because, for example, $^{36}Cl$ decay will be matched by its production from $^{35}Cl$ in-situ neutron activation, the variation in the activity of $^{36}Cl$ with depth may nevertheless provide useful information on mobility and residence times and allow minimum residence times to be estimated. Similarly, there are strong constraints on the use of $^{129}I$ in studies such as this because of uncertainties in the initial atmospheric ratio of $^{129}I/I$, in the subsurface production of $^{129}I$ by $^{238}U$ fission, and in the release of stable I by organic materials in shales (see Fabryka-Martin, 1999). Therefore, the use of these two radioisotopes will likely result in semi-quantitative ages at best and should be considered for screening purposes in Phase 1 of the DGR program.

Noble gas analyses for He, Ar and Ne should ideally be undertaken for screening purposes in Phase 1 of the DGR GSCP program. Noble gases represent important registers of pore fluid age through subsurface in-growth and through He isotope diffusion profiles established through the formations of interest. Helium concentrations should be measured in pore fluids and in the rock matrix as a measure of age through decay of U and Th (Andrews et al., 1982). He/Ar ratios, essential for interpretations of fluid age and mobility, require molar analysis by spike dilution and isotope ratio analysis. Ne concentrations (spike dilution) and isotope ratios (including $^{21}Ne$, by high resolution sector mass spectrometry, Bottomley et al., 1984) could be used for source tracing and as a comparative measure of fluid residence time.

Radioactive and stable isotopes and noble gas measurements can provide independent estimates of residence time of elements in the geosphere. Some may well give uncertain results or age dates of limited value, such as due to the secular equilibrium of 36Cl mentioned above or to the uncertainty in the initial atmospheric ratio of $^{129}I/I$. Others may not be measurable, such as $^{14}C$ or $^{3}H$ in the shallow bedrock. However, experience from the Swiss program (Rubel et al., 2002; Pearson et al., 2003; Gimmi and Waber, 2004) has shown that the results of the various methods complement one another when considered together with diffusion profiles of environmental isotopes ($\delta$O, $\delta$H, $\delta$He and $\delta$Ne) and noble gases (He, Ne, Ar). In addition, research in Canada has shown the value of using $^{129}I$ (Bottomley et al., 2002) and $^{36}Cl$ (Hendry et al., 2000) as age-dating isotopes for flow systems or aquitards with ancient groundwaters.

The geochemical program will use a variety of independent approaches to the estimation of residence times of porewater in the Ordovician rocks and of groundwater in the Silurian and Devonian rocks beneath the Bruce site. For Phase 1 work the testing of I and Cl radioisotopes and of noble gases will be completed at a screening level. If the result of these screening level analyses in Phase 1 are encouraging, additional work with these isotopes and gases will be undertaken in Phase 2 and 3 using core collected in Phase 1, 2 and 3.

Extraction of the pore water will be conducted by a primary step, e.g., diffusional equilibration, followed by stepped-heating vacuum distillation or azeotropic distillation or pyrolysis. The appropriate protocol can best be determined by trial and error using archived or available core. Stable $^{2}H$ and $^{18}O$, $^{129}I$ and $^{36}Cl$ radioisotopes will be analyzed, as well as He, Ar, Ne and $N_2$ gases in the pore waters. If diffusion in the deep shale will ultimately control the transport of the more hazardous or more mobile long-lived radionuclides contained in OPG intermediate level waste – $^{137}Ba$, $^{14}C$, $^{35}Cl$, $^{60}Co$, $^{137}Cs$, $^{55}Fe$, $^{129}I$, $^{63}Ni$, $^{106}Ru$, $^{90}Sr$, $^{99}Tc$, and $^{90}Y$ (OPG, 2004) – then the profiles of the isotopes and gases measured will be characteristic of this transport and amenable to confirmation by numerical simulation of chemical diffusion.

In order to identify a preferred method for porewater extraction and its characterization – or perhaps preferred method(s) depending upon the target analyte – it will be necessary to undertake preliminary testing with fresh core samples of the deep shale and limestone rocks obtained from off-site drilling investigations (see Requirement I.3 – Section 11.2.3).

#### 5.2.9.3 Interpretative Methods

Following preliminary testing, the geochemical program for characterizing rock core porewater will proceed through a number of steps that will conclude with geochemical modeling as the integrating step, i.e.,

- Step 1 - determine $Cl^-$ diffusion porosity from diffusion measurements;
- Step 2 - determine leachable concentrations of halide ions in cores that were carefully preserved to prevent oxidation;
- Step 3 - calculate anion contents of pore water from Steps 1 and 2;
- Step 4 - use micro-analysis technique to determine pH and the cation and trace element concentrations by inductively-coupled plasma spectrometry;
- Step 5 - determine mineralogy of core sections, in particular the identity and elemental composition of those minerals having sufficient solubility to influence pore-water chemistry, e.g., carbonates, sulphates, sulphides, halides, etc.
- Step 6 - determine the cation-exchange properties of the core, i.e., total exchange capacity at the ionic strength of the pore waters, in situ exchangeable cation populations, and by sorption isotherms for several pairs of important cations through their displacement of adsorbed protons.

- Step 7 - simulate pore-water compositions by geochemical modeling to constrain results to those consistent with dissolved solids, core mineralogy and cation-exchange processes.

The intent of this analysis should be to obtain information on the porewater geochemistry with respect to the five groups of analytes identified for groundwater characterization (i.e., Task HG.8), however it is conceded that the quality of the porewater geochemistry data is likely to be more uncertain than that of the groundwater samples, which can be recovered more readily because of their free-phase nature. However, because of the anticipated difficulty in extracting porewater from the Ordovician shale and limestone, the uncertainty at the present time on the volume of porewater that may be extractable (maximum: ~3 mL/cm of HQ core) and the geochemical complications that may be inherent in the extraction step, it is likely that limited volumes of pore water will be available for chemical analysis. Therefore, only general guidelines for prioritizing the selection of analytes are feasible at present. These guidelines are based upon the principle that it is most important to establish that transport in the Ordovician shale and limestone is diffusion dominated and that the pore waters are stagnant, stable and ancient.

#### 5.2.9.4 Required Number of Core Samples

It is proposed that five adjacent core samples, each of approximately 200 mm in length, be collected from the Ordovician shale and limestone every ten (10) meters and reserved for analysis as follows:

- Sample Set 1 - master variables, major ions and trace elements;
- Sample Set 2 - environmental isotopes;
- Sample Set 3 - $^{129}I$ and $^{36}Cl$;
- Sample Set 4 - diffusion and porosity testing (for Task HG.10);
- Sample Set 5 - dissolved gases.

Therefore, OPG would have in their possession for analysis a complete sequence of preserved samples taken every ten meters across the Ordovician shale and limestone sequence. It would not be the intent to proceed immediately with analysis of all cores, rather laboratories would each receive, extract and analyze an initial set of 10 to 20 cores collected at 20 to 40 m intervals through the shale and limestone sequence. Results from this sequence of cores would be interpreted and reviewed prior to the release of additional cores from the OPG core storage facility for further analysis.

### 5.2.10 Task HG.10 - Laboratory Diffusion, Porosity and Sorption Testing

In order to develop a complete picture of the heterogeneity of the host rock with respect to diffusion properties, measurements should be performed on samples originating from different depths throughout the Ordovician rocks (e.g., every 20 to 25 m). Because diffusion is dependent upon the interconnected porosity, the total porosity of a shale or argillaceous limestone is not identical to the effective porosity through which fluid transport takes place and in which the principal geochemical processes of concern occur, e.g., sorption and precipitation/dissolution (Pearson, 1999). Emphasis during Phase 1 of this project will be placed upon the measurement of effective diffusion coefficients for non-sorbed solutes; the measurement of sorption processes will be deferred until Phases 2 and 3.

This information as well as information on diffusion rates and radionuclide sorption can be obtained by laboratory tests on recovered core by drilling a central reservoir or well through the sample. In the NWRI method, a tracer solution is added to the reservoir and its decrease measured over time due to diffusion into the clay (van der Kamp et al., 1996). The tracer concentration in the reservoir is mathematically analyzed to yield the effective porosity of the clay and the retardation factor of the tracer by the clay (Novakowski and van der Kamp, 1996). The NWRI method was improved upon by the Paul Scherrer Institute (PSI) in Switzerland (Van Loon et al., 2004a; 2004b). PSI built a test cell allowing the confining stress to be re-imposed and developed two techniques – 'through diffusion' and 'in diffusion'. Through-diffusion tests measure the mass or radioactivity that diffuses through a piece of rock as a function of time. The in-diffusion test allows the radionuclide to diffuse from a central reservoir or well into the core 'doughnut' surrounding it as in the NWRI method but, after a certain time, the experiment is ended and the diffusion profile in the core is measured. It is used for more strongly sorbing radionuclides.

The effective diffusion coefficient and the tracer-accessible porosity for the anions tritium (HTO), $I^-$ and $Cl^-$ will be measured in through-diffusion experiments. The right choice of boundary conditions and well-defined initial conditions enable one to find an analytical solution of Ficks' second law. Analyzing the total diffused mass with time gives directly the effective diffusion coefficient and the tracer-accessible porosity (Van Loon et al., 2004a).

Because the host rock is expected to be anisotropic with respect to diffusion, diffusion studies perpendicular and parallel to the bedding should be performed. Similar kinds of measurements were performed on the Opalinus Clay (Van Loon et al., 2004a). Dr. Van Loon of PSI (personal communication with INTERA, July 13, 2005) has suggested that it would be reasonable to conduct five diffusion/retardation tests perpendicular to the bedding in the Ordovician rocks for every one test conducted parallel to the bedding planes. He further pointed out that the very high salinity that might be expected (~ 2 M NaCl) will inevitably lead to corrosion of stainless steel diffusion cylinders, therefore polymeric materials such as PEEK$^{TM}$ may need to be employed.

Table 5.3 summarizes the proposed Phase 1 GSCP laboratory testing program for diffusion, porosity and petrophysical testing described in Task HG.11. Table 5.3 identifies the test methods, analytes, parameters/information and targeted formation and number of tests.

The testing program for determination of sorption parameters in Phase 2 and 3 of the GSCP, will include reliance on batch Kd experiments for strongly sorbed elements that potentially contribute to dose estimates and some "in diffusion" testing of weakly sorbed elements. Such testing for determination of sorption characteristics in the anticipated high ionic strength porewaters may be complex and approaches and requirements may need to re-assessed based on initial results obtained in Phase 2 of the GSCP.

### 5.2.11 Task HG.11 - Laboratory Petrophysical Testing

Laboratory measurements will be conducted to determine the permeability and porosity of core samples from all of the Ordovician formations, which are the formations in which diffusion is expected to dominate over advection as a solute transport mechanism. Both gas permeability, gas entry pressure and porosity will be measured under confining-stress conditions approximating in-situ conditions. Permeability will be measured using a gas pulse decay technique. Alternatively, a synthetic pore water may be developed to allow liquid permeability

**Table 5.3: Summary of Minimum Laboratory Diffusion and Petrophysical Testing Program – Phase 1 GSCP**

| ***Method*** | ***Analytes*** | ***Parameters / Information*** | ***Formation & Number of Tests*** |
|---|---|---|---|
| Through-diffusion (Planar, i.e., vertical diffusion coefficient) | HTO and other non-radioactive conservative anions (I, Br, or organic dyes) | $D_e$, $\alpha$ [see Note Below for Explanation of Parameters] | 5 – Upper Ordovician Formations<br>5 – Middle Ordovician Formations |
| Through-diffusion (Radial, i.e., horizontal diffusion coefficient) | HTO and other non-radioactive conservative anions (I, Br, or organic dyes) | $D_e$, $\alpha$ Anisotropy & Heterogeneity of Formational Properties | 4 – Lindsay Formation (Above and Below DGR Horizon) |
| Petrophysical Testing | N/A | Gas and Liquid Permeability, Porosity | 10 – Upper and Middle Ordovician Formations |
| | | Gas-Entry Pressure | 5 – Lindsay Formation |

Note: $D_e$: effective diffusion coefficient; $\alpha$: rock capacity factor (i.e., the diffusion accessible porosity for a non-sorbing solute)

testing using a similar pulse decay method. Porosity of the samples will also be determined using standard helium techniques based on Boyle's Law. Core samples will be selected for testing based on core and geophysical logging to provide a representative set of samples, particularly from the Lindsay Formation.

### 5.2.12 Task HG.12 - Development of Descriptive Hydrogeologic Site Model

Hydrogeological data collected as part of Tasks HG.1 through HG.11 will be used, in conjunction with the descriptive geologic site model to develop a descriptive hydrogeologic model of the DGR site and surrounding area. The descriptive hydrogeologic site model will be developed in parallel with the GSCP and will be continually updated as new hydrogeological information becomes available. The hydrogeologic site model will describe the 3-D spatial distribution of the groundwater flow and radionuclide transport and attenuation processes and properties of the bedrock units that will host and overlie/underlie the proposed DGR. The descriptive hydrogeologic site model will provide the necessary information to define and describe the pathways and migration rates for any radionuclide releases from the DGR. In short, the descriptive hydrogeologic site model will provide the information necessary to support Safety Assessment and Repository Engineering design functions.

## 5.3 Implementation Issues

Other than the possible complications associated with refinement of porewater extraction methods and with borehole instability and flowing groundwater conditions identified in Section 4.3, no additional implementation issues for hydrogeologic characterization activities are evident at this time. The volumes of porewater that can be reasonably extracted from intact core (i.e., a maximum extractable volume about 3 and 5.5 mL/cm per unit length of HQ and PQ core, respectively), may limit the types of analyses that can be conducted on porewater.

# 6. GEOMECHANICS CHARACTERIZATION PLAN

## 6.1 Objectives and Scope

Geomechanical characterization activities are undertaken to develop a descriptive geomechanical site model of the Bruce Nuclear site and surrounding area that will provide the necessary geoscientific site data to support Safety Assessment and Repository Engineering requirements.

Because of the phased nature of the geomechanical characterization plan, detailed descriptions of major work elements can only realistically be provided for the Phase 1 investigations. Consequently, unless otherwise indicated, the work element descriptions provided in Section 6.2 are primarily applicable for Phase 1 tasks.

The following description of major work elements addresses the specific data needs and data collection methods identified in Tables 2.1 and 2.2. The following Table 6.1 summarizes how the data needs are met by each of the major geomechanics characterization work elements. Data needs are listed in Table 6.1 by numbers given in Tables 2.1 and 2.2.

**Table 6.1: Summary of Data Needs and Geomechanics Characterization Plan Work Elements – Phase 1 GSCP**

| ***Major Work Element*** | ***Data Needs Met by the Work Element*** |
|---|---|
| Task GM.1 – Installation of Seismograph Stations | 6.1, 6.2 |
| Task GM.2 – Geomechanical Core Logging and Preservation | 1.3, 1.4, 1.5, 1.6, 2.2, 2.3, 2,4 |
| Task GM.3 - Borehole Geophysical Logging | 1.3, 1,4, 1,5, 1,6, 2.4 |
| Task GM.4 - In-situ Stress Measurements | 2.2 |
| Task GM.5 – Laboratory Geomechanical Testing | 2.3, 2.4 |
| Task GM.6 – Rock Mass Property Characterization | 2.1, 1.3, 1.4, 1.5, 1.6, 2.4 |
| Task GM.7 – Development of Descriptive Geomechanical Site Model | 1.1, 2.1 |

## 6.2 DESCRIPTION OF MAJOR WORK ELEMENTS

### 6.2.1 Task GM.1 - Installation of Seismograph Stations

The primary seismic concern to the DGR will be the possibility of fault rupture through the repository. A secondary concern is changes in the hydraulic conductivity along seismically prone geological features. These concerns could occur due to a low-probability moderate to large event happening near the Bruce site, initiating on a pre-existing fault that was formed hundreds of millions of years ago, and which has had no significant seismic activity over the last several thousand years. The likelihood of such event is best assessed probabilistically, given the following information:

- contemporary seismicity and microseismicity within a few hundred kilometres of the Bruce site (improved knowledge of microseismicity would be very helpful); this includes the location and magnitude of all earthquakes;
- focal depth distribution of regional earthquakes; and
- distribution of faulting and fracturing in the site area, and in particular the closest approach of any significant (length>100 m) faults or fractures to the repository area.

This information can be used to enhance knowledge of the occurrence rates of earthquakes, and hence the occurrence rates of earthquake faulting, as well as provide general information on regional stress conditions from fault focal mechanisms. Small events are most common, but have very small fault lengths and are thus unlikely to rupture through the repository (unless they follow a pre-existing fault that crosses the repository). Larger events are rare, but would be associated with longer ruptures that have more potential to rupture into the repository area. The closest proximity of existing faults is relevant because the vast majority of earthquakes cause re-rupture on existing surfaces (possibly with some growth or splays) rather than initiating new fault breakage. Ground shaking due to earthquake occurrence is not normally a critical issue for an underground repository, because shaking-induced damage of underground structures strongly decreases with depth (Bäckblom and Munier, 2002). The focal depth is also relevant. Typically, earthquakes may be concentrated at depths of 5 to 15 km, in which case rupture to near-surface depths would only occur for large events. Determination of focal depth distribution and microseismic monitoring generally requires a sufficiently dense spacing of seismographic stations such that there is a station within a few tens of kilometres of every event. These conditions, however, are not met in the Bruce area.

The recommended steps to acquire the information discussed above are as follows.

- Identify significant faults and fractures within about 1 km of the repository area by means of surface mapping and seismic surveys. (Note: Tasks G.2 through G.9 address this requirement).
- Improve the local seismographic monitoring by addition of 3 new seismographic stations within 50 km of Bruce. The monitoring of low seismic events in the area will also enable us to better delineate discontinuities, if occurring, that are associated with low-level seismicity. Stations of the POLARIS type (www.polarisnet.ca) in use in southern Ontario would be ideal for this purpose, and could be sited at locations having AC power and communications (internet) to reduce costs. Placement of these new seismograph stations at locations that allow good coupling to bedrock is preferred. The data analysis function, which consists of integrating the data with those of other stations in the region to determine locations, magnitudes and depths, could be arranged through the Geological Survey of Canada.

The acquisition of this new information would allow any correlations of microseismicity (M<3) with faulting to be identified. It should be recognized that a period of at least 5 years would be required to gain enough microseismicity information to improve the correlation of seismicity with specific features, or improve estimates of local rates of seismicity; this is a consequence of the low regional seismicity rates. It is likely that hazard and fault rupture estimates would need to be made largely with currently existing data, then revised and updated in the future as the new information became available. An analysis of the implications of the microseismicity patterns is recommended after 5 years of improved monitoring, with a further review after an additional 5 years of monitoring. The microseismicity data collected from the first 5 years will contribute to the licence application for repository construction in addressing seismicity-related issues for the DGR.

### 6.2.2 Task GM.2 - Geomechanical Core Logging and Core Preservation

Core logging will be conducted immediately upon recovery of core from the exploratory hole. Logging will be continuous and will include detailed descriptions of the rock lithology and stratigraphy, any evidence of weathering or alteration, as well as the location, frequency, orientation and characteristics of fractures and other structural features (infilling, openness, roughness, planarity, staining or other evidence of water flow), as described in Task G.6.

Rock Quality Designation (RQD) will be recorded for each core run as it is recovered. Evidence of core disking will be recorded if this occurs, including relevant characteristics such as disk thickness. Provided core conditions are suitable, point-load testing may be undertaken on fresh core at intervals of about 5m, depending on lithological changes in the core, and results recorded in the drill logs, primarily as a means of indicating whether any significant changes in compressive strength are occurring. Based on these results, combined with core descriptions, limited samples will be selected for geomechanical testing (Task GM.5 - Section 6.2.5). P- and S-wave velocities will be measured parallel and perpendicular to the core axis on fresh core as a supplement to down-hole geophysical logging and as a basis for assessment of possible rock deterioration with time.

For the Phase 1 work, core preservation will be based on conventional best-practice methods for wrapping and sealing of the core to protect it from environmental degradation (drying, chemical changes, mechanical damage, etc.). For future Phases of work and depending on the results obtained in Phase 1 testing, specialized core "conditioning" methods may be utilized such as those developed by ANDRA and NAGRA to avoid the deleterious effects of total stress release. For the Phase 1 work, it will be critical to ensure that geomechanics tests on the core are conducted as soon as possible after retrieval of the core, preferably within 24 hours. This will require rapid transport of the core to the testing laboratory, followed by immediate preparation and testing.

### 6.2.3 Task GM.3 - Borehole Geophysical Logging

The borehole geophysical logs required for geomechanical characterization of the DGR site will generally include those logs required for geological characterization (Task G.7, Section 4.2.7), as well as several specific logs that have common geomechanical applications.

Borehole video, caliper, acoustic televiewer and FMI logs should be run in all open boreholes with the purpose of identifying zones of borehole breakout that may be indicative of ground stress conditions. The full suite of acoustic logs (sonic, full waveform seismic and vertical seismic profiling (VSP)) should also be run in each open borehole to estimate bulk rock modulus and rock competence for geomechanical purposes.

### 6.2.4 Task GM.4 - In-situ Stress Measurements

#### 6.2.4.1 Priorities, Data Needs and Methods

Accurate knowledge of the in-situ stresses at and above the DGR horizon is arguably the most important single geomechanics data requirement to be determined during the GSCP. Stress magnitudes and orientations are fundamental input parameters for engineering design of excavations and analysis of their short and long-term stability. However, measurement of in-situ stresses at depths of up to 660m in horizontally bedded rock formations under high stress by means of surface-based exploratory boreholes is challenging. While there are many methods that have been developed and tested under various conditions, there is no single method that can be considered as a stand-alone, fully reliable method, until such time as relevant field trials are completed. All methods have a variety of advantages and potential drawbacks. For this reason, it has become common practice to try at least two different measurement techniques for projects in which reliable knowledge of in-situ stresses is critically important.

For the GSCP investigations, the priority in-situ stress data needs are as follows:

- Magnitudes & orientations of maximum ($\sigma_H$) and minimum ($\sigma_h$) horizontal stresses at the DGR horizon (Lindsay Formation), and assessment of lateral variability across site.
- Confirmation that vertical stress ($\sigma_v$) is approximately equal to the unit weight ($\gamma_{rock}$) of the overlying rocks times the depth (z), i.e., $\sigma_v \sim \gamma_{rock}z$.
- Confirmation that orientation of the principal stresses is vertical and horizontal.
- Stress tensor in overlying units (secondary priority).

#### 6.2.4.2 Available Methods.

Two fundamental steps are essential to gain the best possible knowledge of the probable in-situ stresses at the DGR horizon:

1. Assemble and evaluate all available regional data on in-situ stresses in the Paleozoic sedimentary rocks of Southern Ontario and the Northern USA. All such data must be evaluated within the context of regional geologic and geomechanical models.
2. Undertake in-situ measurements of stresses in the GSCP exploratory boreholes at site. While there are numerous stress measurement techniques that have been proposed and tried over the years, the methods most likely to be practical and successful for a DGR in sedimentary rock at a depth of 660 m include the following.

*Deep Overcoring Methods*

The Deep Doorstopper Gauge System (DDGS), a glued borehole-bottom cell developed by AECL at the Underground Research Laboratory (URL), provides 2-D stresses in the plane perpendicular to the borehole axis. Although this method has been proposed for depths down to 1000m, currently it has not been used at borehole depths beyond 528 m. Major advantages are that no pilot hole is required and a very short length of overcore is needed, so that measurements can be made in disking (high stress) or fractured rock conditions (e.g. bedding plane partings). Potential problems include difficulties with bond performance of the glue, and lack of experience in deep sedimentary rock. Experience has shown that while this method has a good chance of success within the limestone formations, it is not likely to succeed within the shales, due to glue-bond problems. At this stage, it is recommended for trial testing in the Lindsay Formation during deep drilling of borehole DGR-2

The In Situ Stress Measurement Tool (IST), a mechanically emplaced borehole deformation gauge system developed by Sigra Pty Ltd (Australia), provides stresses in 2-D plane perpendicular to borehole axis. It was designed for depths to 1500m, and has been used to borehole depths of 750m. Advantages include rapid and easy use, rugged construction, fairly good base of experience and redundancy of diametral measurements. Potential problems include the need for fairly long overcore runs which precludes use of the method in core disking conditions, and a lack of detailed comparisons of IST data with other test methods under strict QA programs, particularly for radioactive waste management projects. If it turns out to be possible to maintain fairly long intact overcores at the DGR, then a preferable overcore method would be the Borre Probe as noted below, as this method will provide a full 3-D stress tensor.

The Borre Probe (SSPB), a glued soft-inclusion cell method developed in Sweden is also potentially applicable. The primary advantages of the SSPB are that it provides full 3-D stress information, it has been extensively tested, and it has had trial usage to ~600 m borehole depth. Potential problems include the need for relatively long, unbroken overcore (~50 cm), precluding use in core disking rock conditions, and potential glue-bond problems, particularly in shaley rock. The method also has some sensitivity to grain size variation and anisotropy of the rock.

*Hydrofracture & Sleeve Fracture Methods*

Conventional hydrofracture methods require fluid injection to cause fracture creation, opening and re-opening. This method may create disturbance to groundwater chemistry work. Test techniques are well developed due to considerable precedent experience at great depths in oil and gas industry and techniques are not limited by depth. Test results may be difficult to interpret in rock with pre-existing fractures or weakness planes (e.g. bedding). While this method is intended to measure 2-D stresses perpendicular to the borehole axis, it may only provide vertical stress information in high horizontal stress regimes, particularly in bedded rock. While it is possible that this method may have potential use to confirm vertical stress magnitude at the DGR, it is not likely to give reliable information on the more critical issue of horizontal stress magnitudes. At this stage, it will be recommended for use in the Phase 1 program only if mapping of the completed borehole DGR-2 in the Lindsay Formation indicates the presence of massive (unbedded) section of the limestone, within which hydrofracturing stress measurements are likely to succeed. It may be used in Phase 2 investigations in the event that overcore stress measurement techniques do not provide useful results in the deep shales and limestones at the DGR.

Sleeve fracture techniques are, in essence, modified hydrofracture methods, such that the high-pressure fluid is contained within a flexible bladder and does not penetrate the rock mass. Interpretation of results may be questionable as breakdown pressure and fracture re-opening pressure are often difficult to identify precisely. Effects of existing fractures/planes of weakness are also difficult to interpret. We are not aware of any substantial precedent experience at ~600 m depth in conditions similar to Bruce site, and this method is not considered to have realistic potential for use at the DGR.

#### 6.2.4.3 Phase 1 Testing

Prior to, and continuing as necessary during Phase 1, all available information on in-situ stresses at depth in these Paleozoic rock formations will be collected and evaluated as part of the assembly of precedent geomechanics data (Initiation Requirement I.4 – Section 11.2.4). These data will help to constrain the value of the stress tensor that is likely to be encountered at the DGR horizon, and will provide key information on the regional variation of the stress tensor.

As noted above, each of the available stress measurement methods has advantages and potential problems. Based on discussions with the Geoscience Review Group (GRG) and with OPG staff, a strong recommendation has been made to conduct measurement trials of the Deep Doorstopper Gauge System overcoring method during the drilling at the borehole DGR-2. These trials (5 to 10 tests) would be focused to the Lindsay Formation shaley limestone. Based on the results of such trials, a decision can then be made on whether to continue overcore stress testing using the Deep Doorstopper or other methods in Phase 2 and Phase 3 of the GSCP investigations at the Bruce site.

During drilling of DGR-2, careful examination of the Lindsay Formation will be undertaken to evaluate whether or not the formation conditions – or certain intervals within the formation – may be suitable for hydraulic fracturing stress measurements. If so, then a contract to obtain hydrofracturing equipment and services can be let at this time, during the period in which other downhole testing is being conducted (e.g., borehole geophysics and hydraulic testing). Once the other testing is completed, hydrofracture testing would be conducted, prior to final installation of long-term monitoring equipment. Thus, stress testing in Phase 1 at the Bruce site will focus on Deep Doorstopper overcoring tests in the Lindsay Formation, but may include hydrofracturing of massive sections of this Ordovician shaley limestone, depending on the evaluation of whether or not suitable test sections are present in DGR-2.

In addition, every reasonable effort will be made during Phase 1 to gather indirect information regarding stress magnitudes, including logging and description of any core disking, down-hole recording, measurement of borehole breakouts and some limited laboratory Kaiser effect testing.

#### 6.2.4.4 Phase 2 and Phase 3 Testing.

The in-situ stress measurements to be done in the Phase 2 and 3 investigations will include overcore and hydraulic fracturing tests depending on the results of Phase 1 stress testing work. Because of the difficulties involved in this work – both technical and logistical - European practice has tended towards provision of a dedicated exploration borehole for the sole purpose of stress testing. This approach will be considered for Phase 2 investigations.

### 6.2.5 Task GM.5 - Laboratory Geomechanical Testing

#### 6.2.5.1 Phase 1 Testing

For the Phase 1 site investigations, the primary objectives of the laboratory geomechanics testing are to: (a) gain preliminary information on the specific geomechanics properties of rocks of the Lindsay Formation beneath the Bruce site; (b) gain sufficient information on the geomechanics properties of the rocks in the overlying formations to confirm that these properties lie within the range of properties anticipated from precedent experience in these formations, and (c) to indicate, on a preliminary basis, if there are geomechanics parameters that will require particular emphasis and focus during subsequent Phases of site investigation. While all of the laboratory tests that will be needed to acquire the data noted below have been previously and successfully used, not all of these tests can be considered as “standard”. Relatively few laboratories in Canada will be able to perform all of the tests to the required level of Quality Assurance. Careful selection of well-qualified testing laboratory contractors will be an important pre-requisite to obtaining reliable data.

In the formations overlying the target depth, borehole DGR-1 will be cored to the top of the Queenston Shale, primarily through limestones, shales and dolostones. For geomechanical testing purposes, only limited core samples of these Devonian and Silurian rocks will be required, as these properties are not anticipated to be critical to the viability of the site. Reasonably representative stress-strain diagrams under uniaxial loading should be obtained within each major lithological horizon, and samples will be selected from appropriate horizons based on the results of core logging (see Section 6.2.2). Representative petrographic and mineralogical analyses will be required.

The Lindsay Formation, and the directly overlying Upper Ordovician shales, will be cored as part of the borehole DGR-2. The primary focus of laboratory testing for mechanical properties will be the carbonate rocks in the target horizon of the Lindsay Formation. For this initial Phase of investigation, it is important to gain an improved understanding of the stress-strain behaviour of these rocks, compared to the rather general and wide spectrum of values currently available (e.g. uniaxial compressive strength reported by Golder Associates Ltd.(2003) ranges from 25MPa to 140MPa). At this initial stage, carefully conducted and fully instrumented uniaxial compression tests will provide sufficient information i.e., triaxial testing will not be required. Uniaxial testing of the Lindsay Formation rocks should include acoustic emission measurements.

The shales of the overlying Queenston Formation have been extensively tested in other projects, notably the Niagara Tunnel Development Project at Niagara Falls, and thus there is a good deal of information available regarding the likely geomechanics performance of these rocks. It is recommended that for Phase 1 investigations only sufficient laboratory testing should be conducted to ensure that the geomechanics parameters lie within known boundaries. As these rocks degrade upon release of confining stress, drying, exposure to fresh water, and other environmental effects, it is critical that core samples from these formations are properly sealed and protected immediately upon recovery, and that the geomechanics laboratory testing is conducted as soon as possible, preferably within 24 hours of sample recovery. For the Phase 1 testing, it is not recommended to implement the sophisticated core conditioning procedures that have been developed at the ANDRA and the NAGRA projects. This will be re-evaluated for the Phases 2 and 3 work, depending on the results of Phase 1 testing. Testing will include uniaxial compression, free-swell, semi-confined swell and confined swell testing.

From a geomechanics perspective, careful assessment of the mineralogy of these rocks – particularly the clay mineralogy - will be essential. In both the Lindsay Formation and the overlying shales, basic geoscience laboratory testing will be conducted. Assessment of the mineralogy comprising petrograpic and mineralogical analyses (thin-section optical and SEM microscopy; X-ray diffraction) to gain information on the mineralogical make-up and textural relationships in the materials, particularly regarding clay minerals content, will be required (see also Section 4.2.8). Associated with the issue of clay minerals content, slake durability testing will be conducted on representative samples throughout the stratigraphic section.

For the Phase 1 investigations, the proposed (minimum) schedule of laboratory geomechanics testing is summarized in Table 6.2.

**Table 6.2: Summary of Minimum Laboratory Geomechanics Testing Program – Phase1 GSCP**

| ***Method*** | ***Targeted Formation*** | ***Number of Tests*** |
|---|---|---|
| Uniaxial Compression Test | Lindsay Formation | 20 (5 to 6 Horizons x 3 to 4 Tests/Horizon) |
| | Upper Ordovician Formations | 15 (4 to 5 Horizons x 3 to 4 Tests/Horizon) |
| | Devonian and Silurian Formations | 12 ( 4 Horizons x 3 Tests/Horizon) |
| Swelling Tests | Lindsay Formation | 6 ( Free Swell, Perpendicular to Bedding) |
| | Upper Ordovician Formations | 9 (3 Free-Swell, 3 Semi-Confined, 3 Confined) |
| | Devonian and Silurian Formations | 0 (None Anticipated) |
| Slake Durability Tests | Lindsay and Overlying Formations | 30 (Samples Selected Based on Core Logging) |
| Petrographic/ Mineralogic Tests | Lindsay and Overlying Formations | 30 (Samples Selected to be Representative of Lithologies) |

In addition to the laboratory tests noted, minor testing (in cost terms) will be conducted during the process of core logging, including point-load testing of appropriate core sample intervals, P-wave and S-wave velocity measurements, acid reactivity, etc.

#### 6.2.5.2 Phase 2 and Phase 3 Testing

Laboratory geomechanical testing in Phase 2 and Phase 3 investigations will focus on a more complete testing program to provide a full and comprehensive suite of data concerning the geomechanical properties of the DGR host rock material. These data will be required for use throughout the DGR design, construction and monitoring phases (pre- and post-closure), in order to evaluate the short and long-term response of the various rock materials to changes in:

- the stresses to which they are subjected;
- time;
- the geochemical regime;
- the moisture regime; and,
- the thermal regime (a secondary concern for LLW & ILW).

Details of the testing programs in these later Phases will depend on the results of the Phase 1 work. In general, testing may include:

### *Lithologic Description & Petrographic Analysis, Porosity, Pore and Microcrack Structure and Mineralogy, Permeability*

Complete standard descriptions and petrographic/mineralogic analyses for rock materials throughout geologic column at site, with particular emphasis on Lindsay Formation and immediately overlying shales will be required. Testing should also include representative fracture infilling materials. These data are required for geochemical analyses; sorption/diffusion calculations; mineralogical stability; evidence of previous deformation; nature of grains/boundaries, etc.

Data collection methods (see Section 4.2.8, Task G.8) should include thin-section optical microscopy; X-ray diffraction; scanning electron microscopy; radiometric dating of minerals; gas/water permeability testing.

### *Standard Index Tests*

Conventional index testing of rocks for hardness; density; abrasion resistance; soundness and slake durability will be necessary. Such testing is relevant to issues of waste-rock utilization; trafficability and wet/dry degradation. Use of standard aggregate testing methods will allow comparison with regional quarry data.

### *Strength & Deformation Parameters*

Full stress-strain curves in uniaxial compression will be required, including acoustic emission data, and longitudinal, transverse and volumetric strains under both saturated and dry conditions. Data will be used to evaluate Young’s Modulus, Poisson’s Ratio, various crack-initiation and crack-propagation parameters, various strength “thresholds” (crack initiation; cohesion loss, stable crack growth; long-term strength; peak strength, etc.).

A full suite of triaxial compression testing will also be required to evaluate appropriate strength envelopes for analysis/design purposes. Such testing should be completed on representative sample of the Lindsay and overlying Georgian Bay/Blue Mountain shales in order to determine Hoek-Brown strength parameters so that a full strength envelope under triaxial loading conditions can be defined. Testing will be required on rock cores at different orientations with respect to stratigraphy in order to assess anisotropy, using sub-coring from primary core. Sonic velocity measurements for dynamic modulus should also be collected, as should Brazilian Tests for tensile strength. Note also that deformation parameters will be determined from biaxial testing of core recovered at each overcoring stress-measurement location. Details of the testing programs in these later Phases will depend on the results of the Phase 1 work. In general, testing may include:

### *Creep Parameters (Time Dependent Straining)*

We anticipate that such testing will be required in the Lindsay Formation, sufficient to confirm expectation that creep will not be a significant design/performance issue. Creep/accelerated-creep laboratory tests are also required on rock material from overlying shales. For these tests it will be important to collect and evaluate existing data from precedent projects in these units prior to site-specific tests (see Section 11.2.4).

*Swelling/Squeezing Parameters*

Swelling/squeezing is not anticipated to be an issue in the Lindsay Formation, but limited testing is proposed to confirm this expectation. However, such lab testing will be required on rock materials from the overlying shale formations, to identify/assess shaft stability/support issues. Existing data from precedent projects in these units, should be collected and evaluate existing data prior to site-specific tests (see Section 11.2.4).

### 6.2.6 Task GM.6 - Rock Mass Property Characterization

While data regarding properties of the rock materials can be gained from laboratory tests, information concerning the geomechanical properties of the overall rock mass is more difficult to determine in a direct manner. Nevertheless, reasonable and appropriate estimates of the geomechanical properties of the overall rock mass including excavation damaged zones (EDZs) at each geological horizon of importance are necessary to provide the input parameters required for engineering analyses of the DGR facility. Evaluation of rock mass properties will be ongoing throughout all Phases of investigation.

The recent results of in-situ experiments conducted at underground laboratories at AECL, Mont Teri and Åspö (Blümer et al., 2005), suggest that the laboratory geomechanical properties of samples taken from a deep borehole may reflect the properties of EDZs for a tunnel driven in the same direction as the borehole, and not properties of the intact rock. This occurs because the stress path for the core sample is similar to the stress path experienced by the boundary of an underground opening in the same direction. (GRG, 2006). This implies that the strength and geomechanical properties of the laboratory samples will be representative of the EDZ and not of the undisturbed intact rock. Thus the main purpose of laboratory testing is to characterize the mechanical behaviour and properties of the EDZ.

The main activities of the GSCP in this regard prior to Phase 1, during Phase 1 and in subsequent Phases will focus on the following.

- Compiling and evaluating all available information on rock mass properties derived from precedent excavations in the same geological formations (Section 11.2.4), as part of the development of a regional geomechanics assessment (Section 7.2.1.5). Where appropriate, undertake additional mapping of off-site surface/quarry exposures of the Lindsay Formation to extend data on rock mass properties.
- Providing a complete description of the actual stratigraphy and lithology of the geologic column from surface to the DGR horizon.
- Developing as thorough a description as possible of the discontinuities associated with each geologic unit, based on core logging and downhole geophysical logging data. This will include analysis of discontinuity occurrence (location, frequency and spacing, orientation) and engineering characteristics (roughness, aperture, continuity, planarity, surface mineralogy and alteration, infilling). Collectively, this information is essential to allow for the use of standard rock mass classification systems and empirical correlations as part of the engineering design of the shaft and tunnel facilities (Tunnelling Quality Index, Q; Rock Mass Rating, RMR; Geological Strength Index, GSI).
- Data on the shear strength and stiffness of discontinuity sets, particularly bedding planes, which occur within the DGR horizon will be required as input to performance analyses of the DGR openings.

- Data on the geomechanical properties of discontinuities will also be needed as input to various hydrogeological and transport analyses.
- Providing data from direct measurement of in-situ geomechanics properties for the rock mass, where such measurements can be practically and usefully obtained. Examples would include use of geophysical techniques to obtain data on density and mass modulus.

### 6.2.7 Task GM.7 - Development of Descriptive Geomechanical Site Model

Geomechanical data collected as part of Tasks GM.1 through GM.7 will be used, in conjunction with the descriptive geologic site model to develop a descriptive geomechanic model of the DGR site and surrounding area. The descriptive geomechanic site model will be developed and continually updated as new geomechanical information becomes available. The geomechanic site model will describe the 3-D spatial distribution of all relevant geomechanics parameters, such as in-situ stresses, rock peak and residual strength parameters, elastic parameters; swell and creep parameters; joint orientations and characteristics; and rock mass classification ratings, etc. In short, the descriptive geomechanic site model will provide the information necessary to support Safety Assessment and Repository Engineering design functions.

An essential complement to the descriptive geomechanics site model will be the development of behavioural geomechanics models (Section 7.2.2.3). The iterative process of geomechanical modelling – parameter sensitivity studies – design studies – performance modeling – refinement of input data, etc. will be ongoing throughout all Phases of investigation.

## 6.3 Implementation Issues

The principal implementation issue for the geomechanics characterization plan is the collection of in-situ stress data. The difficulties of obtaining representative and reliable information on the state of stress in the deep shales and argillaceous limestones beneath the Bruce site from surface-based drilling is well documented and is discussed in Section 6.2.4 – Task GM.4. There are no easy answers to this implementation issue, as there are no readily identifiable superior methods for measurement of in-situ stresses in deep boreholes in horizontally bedded rock formations under high horizontal stress – which are the conditions anticipated to exist in the formations of interest. As noted, it is strongly recommended that field trials of the AECL Deep Doorstopper method should be completed during drilling of DGR-2 as part of the Phase 1 investigations. If these tests are successful, Deep Doorstopper testing will be retained for Phase 2 and 3 testing. If these tests are unsuccessful in Phase 1, alternate overcore test methods will be evaluated in Phase 2 and 3.

Preliminary discussions with the Polaris Consortium, potentially responsible for installation of the three new seismograph stations near the Bruce site, indicates that these new stations may need to be installed in the spring of 2006, as current schedules may not allow installation in the summer of 2006.

# 7. GEOSYNTHESIS

## 7.1 Objectives

The geosynthesis task of the GSCP provides the overall integration of all project data and the development of a descriptive site geosphere model(s) consistent with all the acquired data and information that are necessary for preparation of the DGR Environmental Assessment and regulatory site preparation and/or construction licence application. The geosynthesis for the GSCP is intended to develop and present the overall geoscientific understanding of the site, the host rock and the geological barrier system, its present state and future evolution, as well as the geoscientific data base for Safety Assessment and Repository Engineering.

Geosynthesis is an essential component in the development of a basis to understand the long-term performance of the DGR concept. It is an activity that is conducted throughout the entire site characterization work program and involves the coordinated and collaborative efforts of specialists from all relevant disciplines.

Geosynthesis typically (GRG, 2005a) must address both local and regional geoscientific understanding of the following.

- Characterization of the undisturbed system and behaviour of the site.
- Assessment of repository-induced disturbances (e.g., excavation damage zone properties, gas generation from repository waste and gas release from the repository, oxidation effects in repository, high pH cement water and host rock interactions, repository re-saturation, etc).
- Assessment of geological long-term evolution of the site (e.g., glaciation, erosion, tectonic activity, etc.).
- Development of a realistic and defendable reference geoscientific data set for use in Performance Assessment and Repository Engineering work.

The description of geosynthesis activities that follows is based primarily on characterization of the undisturbed system, including the site, the host rock and the geological barrier system. Characterization to support assessment of repository disturbances, long-term evolution of the host rock, and development of a geo-data set are described in only limited terms in this GSCP (e.g. addressed in part in Section 7.2.1.6 – Repository Gas Migration and in Section 7.2.1.7 – Long-Term Climate Change). It is recognized that site characterization requirements to support these other geosynthesis components will need to developed as OPG Repository Engineering and Performance Assessment programs evolve for the Bruce DGR project. However, it is anticipated that much of the site characterization data required to support these other geosynthesis components will be collected as part of the site characterization data that is proposed to be collected as part to of both detailed on-site and complementary off-site studies that are described in this GSCP.

An important activity that needs to be completed early in the GSCP geosynthesis task is the development of a geoscience attribute list for argillaceous limestones following the similar NEA FEPCAT list developed for argillaceous materials (Mazurek et al., 2003). Initiation Requirement I.6 – Section 11.2.6 describes this need. Once this list is developed, GSCP data needs should be screened against both these geoscience attribute lists for the undisturbed system, repository-induced effects and long-term evolution of the site. This screening will ensure that the GSCP addresses all of the geosynthesis components listed above.

## 7.2 DESCRIPTION OF MAJOR WORK ELEMENTS

### 7.2.1 Task GS.1 - Complementary Geoscientific Studies

Complementary off-site studies are recognized as powerful tools to communicate evidence of how a site may behave under certain scenarios by studying the behaviour of sites with similar geology and geologic history. Such information can provide indirect evidence of site behaviour over geologic time frames relevant to Safety Assessment, and also assist in the interpretation of GSCP data. Use of complementary geoscientific studies will be an important component of the GSCP strategy, which can contribute significantly to geosynthesis. The following sub-sections describe recommended complementary studies for the GSCP.

#### 7.2.1.1 Regional Geologic Framework

Developing a regional scale geologic and structural geologic understanding of the deep sedimentary formations surrounding the Bruce site is an essential element of site-specific DGR geosynthesis. This would include establishing existing geologic knowledge as it relates to basin history, sedimentology, formation sediment source areas, formation thermochronology and depth of burial, tectonics and structural fracture framework models for the Paleozoic sedimentary sequence found at the DGR site. These studies can provide meaningful context to the on-site characterization work planned as part of the GSCP, through, for example, improving the basis to understand regional predictability and homogeneity of the DGR host and overlying bedrock formations, and to rationalize extrapolation of site conditions beyond the Bruce site.

#### 7.2.1.2 Regional Hydrogeologic Modeling

Regional modeling of groundwater flow within the Paleozoic sedimentary sequence underlying southwestern Ontario (e.g., Niagara Escarpment to the Lake Huron) would yield a reasoned basis to explain aspects of groundwater flow patterns, rates and quality relevant to conveying an understanding of DGR safety. Such regional scale groundwater flow modeling should be founded on a geologically constrained understanding of basin hydrostratigraphy and structural fracture network geometry as determined through interpretation of oil and gas and other deep drilling records, water well resource studies and structural/fault mapping. Given knowledge of formation specific brine hydrogeochemistry, it should also consider variable density groundwater distributions. Such modeling would provide a regional context and framework to hydrogeologic investigations of the DGR. This work program could also serve as a basis for “what-if” or illustrative modeling that would, for example, simulate perturbations created by long-term climate change and glacial isostasy.

#### 7.2.1.3 Regional Petroleum Geology Assessment

Regional understanding of the oil and gas resources of the Bruce site and surrounding area in southwestern Ontario should be developed. Such a study will provide regional scale information on sedimentary structural traps and cap rock properties of specific formations that may be important to demonstrating long-term safety of the DGR. As a minimum, such a regional study would provide an assessment of the potential for oil and gas resources near the DGR, the potential for future human intrusion for resource exploitation, and an understanding of the integrity and longevity of structural sedimentary (i.e., shale) traps.

#### 7.2.1.4 Regional Hydrogeochemical Assessment

The available hydrogeochemical groundwater information for the Paleozoic sedimentary sequence in southwestern Ontario that is relevant to the Bruce DGR, should be assembled, documented and interpreted. This complementary regional hydrogeochemical assessment should be focused to investigate evidence for cross-formational groundwater flow in the context of regional structural and stratigraphic models. Early results from this study would assist in defining chemical concentrations for drill water intended to minimize formation disturbances and interactions during drilling of DGR Phase 1 boreholes.

#### 7.2.1.5 Regional Geomechanics Assessment

All available information on formation-specific in-situ stresses and geomechanical properties in the Paleozoic rock formations of southern Ontario and northern USA must be collected and evaluated as part of the development of a regional geomechanics assessment. These data will help to constrain the value of the stress tensor that is likely to be encountered at the DGR horizon, and will provide key information on the regional variation of the stress tensor with geological conditions.

#### 7.2.1.6 Repository Gas Generation and Migration

Issues of generation of gas within the DGR and it potential for migration along excavation damage zones (EDZs) and room and shaft seals appear to be important. Although some limited laboratory and field testing for gas entry pressures and gas permeability are planned for Phase 1 and Phase 2 GSCP activities, additional review and assessment work is necessary in this area to support the GSCP. Such additional work should include review of reservoir pressure histories and sealing for Paleozoic rocks in southwestern Ontario, a multidisciplinary effort, including modeling, to assess EDZ gas migration for the DGR, and participation in various international experimental programs (i.e., NAGRA and ANDRA) investigating these issues.

#### 7.2.1.7 Long-Term Climate Change

Understanding of the long-term effects of climate change on hydrogeological, hydrogeochemcial and geomechanical properties of host rock and the DGR is a central aspect of site geosynthesis. Within the northern latitudes long-term climate change during the latter half of the Pleistocene (0-1 Ma) has resulted in marked change of surface conditions. Within this time period, long-term climate change has resulted in nine glacial events each with duration of approximately 115,000 years. During each event it is estimated that peri-glacial (permafrost) and glacial ice-sheet conditions could exist at a hypothetical DGR site for approximately 90,000 years. As surface conditions change from present day boreal to peri-glacial, variable ice-sheet thickness cover and then rapid glacial retreat (8-10 ka), coincident transient geochemical, hydraulic, mechanical and temperature conditions will influence groundwater flow system evolution and stability.

An important aspect related to such boundary condition change is the magnitude and rate of change in groundwater flow rates, fracture-matrix fluid chemistry and stress magnitude and orientation; and how such change may influence crystalline flow system evolution (e.g. redox front migration; end member chemistry mixing, depth of penetration by recharge) and repository performance (e.g., fracture rejuvenation/propagation/generation; stress re-orientation/magnitude change) at repository depths. A key goal of these studies will be to define a long-term climate scenario(s) and uncertainty in support of illustrative hydrogeological and geomechanical modeling to assess the resilience of the geosphere at repository depths to external perturbations both in the past and future.

### 7.2.2 Task GS.2 - Site Specific Numerical Analyses

Site specific numerical modeling and analyses will be an important element contributing to geosynthesis activities. Such analyses can be directed such that they:

- provide a structured and systematic framework for the analysis, integration and interpretation of spatially and temporally variable multidisciplinary geoscientific data sets;
- provide an illustrative and more quantitative method to communicate geoscience concepts relevant to understanding long-term DGR safety; and
- provide a basis to explain and illustrate the influence of parameter and scenario uncertainty (as limited by realities of site characterization) on predicted long-term geosphere barrier performance (i.e., parameter/boundary condition sensitivity analyses).

A description of discipline specific numerical analyses is provided below.

#### 7.2.2.1 Hydrogeologic Modeling

Numerical analyses are integral both to the assembly and explanation of how acquired parameter distributions and correlation are realized within the conceptual hydrogeologic flow system model. Through this structured process inconsistencies within the integrated flow system understanding can be revealed. This significantly contributes to an interpretative process that is transparent and traceable.

The hydrogeologic model will evolve as GSCP data becomes available. The following describes possible model iterations.

1. The initial scoping model will be a site scale (~10 km) and will incorporate the geologic features reflecting the current system conceptualization: flat layered geology with approximate estimates of hydraulic conductivity. There are no natural flow-divides or apparent boundary conditions within this scale of model. Consequently, initial external boundary conditions will have to be estimated or extracted from regional modeling results (Section 7.2.1.2). Steady-state (constant porewater properties) simulations will be performed with the goal of estimating advective velocities in the system.
2. At the conclusion of Phase 1 drilling, the model geology will be updated as indicated by core logging. Hydraulic conductivity estimates will be refined based on hydraulic testing

results. Porewater analyses will help establish salinity profiles for variable density simulations.

3. Seismic results will be used to further define geology and to infer variations in geologic/hydrogeologic properties. The location and magnitude of vertical/sub-vertical fault systems (if any) may also be incorporated. Vertical head profiling results will provide additional guidance.
4. Subsequent boreholes and associated seismic re-interpretations will allow refinement of the geologic structure and property variability. Measured horizontal hydraulic gradients will allow validation of vertical boundary conditions.
5. Incorporation of results of long-term climate change modeling as changing boundary conditions to assess some coupled thermal, hydraulic and mechanical effects for hydrogeologic models.

The hydrogeologic model will also be useful in simulating the evolution of the flow system. Various conceptual models are available to describe flow system evolution and for explaining salinity and porewater isotopic compositions. Flow modeling can assist in discriminating between conceptual models by simulating and comparing system response under various scenarios. We anticipate that flow and transport modeling will be performed using FRAC3DVS. This provides consistency with regional modeling and with likely performance assessment modeling codes.

#### 7.2.2.2 Geochemical Modeling

The Swiss experience during the Mont Terri study indicates that the information obtained by rock and porewater analyses was necessarily integrated through the use of geochemical models that allowed evaluation of uncertainties. Pearson et al. (2003) used PHREEQC, a simulator capable of one-dimensional ground-water and solute-diffusion flow and geochemical reactions, to model the genesis of the porewater in the Opalinus Clay by dilution of the original seawater with the diffusion of freshwater over time. The analysis allowed the assessment of precipitation-dissolution reactions, such as those related to quartz, pyrite, calcite and dolomite, and ion-exchange reactions associated with the concentrations of major ions in the porewater (e.g., Ca, K, and Sr). Furthermore, geochemical modeling was used (Pearson et al., 2003) to determine the internal consistency of the analytical data, to compare different samples of groundwater and to interpret batch sorption data with results from diffusion testing. Because of the anticipated high ionic strength of the pore waters from the Ordovician rocks of southern Ontario, it is likely that a version of the PHREEQ code using the Pitzer database will necessarily be employed.

#### 7.2.2.3 Geomechanical Modeling

Conceptual design work for the proposed underground repository must be carried on in parallel with the site characterization process, in order to ensure that site investigations are constantly focused, or re-focused, on obtaining relevant data for the design parameters of greatest importance. In particular, the use of appropriate geomechanical models will be necessary from the earliest stages of site investigation to evaluate whether the proposed conceptual designs are fitted to the actual site conditions, as these conditions are determined. As a corollary, the results of such modeling will identify and prioritize those geomechanics parameters that are critical to the viability or optimization of the repository design.

The highest priority in geomechanical modeling will be the assessment of the stress/strength/ displacement relationships and resulting behaviour of the rock mass around the repository openings, including the shafts. Modeling of the short and long-term development, and potential for sealing of the Excavation Damaged Zone (EDZ) will be an important component of the modeling exercise, providing critical input to other facility performance models. Modeling will require input values for the in-situ stresses, and appropriate short and long-term constitutive relationships for the materials in the various rock formations that enclose the repository. Initially, input parameters will be based on ranges of estimated values in order to evaluate the sensitivity of proposed designs to various geomechanical parameters. The results will help guide site characterization activities, and this process will be constantly updated and iterated as site characterization proceeds.

### 7.2.3 Task GS.3 - Scientific Data and Model Visualization

Three-dimensional visualization of GSCP data and of geosynthesis modeling results will provide the most directly accessible method of confirming the descriptive geosphere site model. Static and animated visualizations will be useful to the GSCP project team and to external stakeholders. Seismic interpretation and borehole core-logging will provide the geologic surfaces and (possibly) fault zones that will form the large scale framework of all visualization. Geologic cut-away and color scales applied to rock types will provide distinct indications of geologic layers and contacts. Borehole locations and borehole data, mapped to location using visual cues such as color and symbol size allow the viewer to visually integrate three-dimensional results. Surface features should be included in the visualization to provide reference.

An appropriate geoscience visualization system (GVS, see Section 10.1.4) will be used to provide integrated display of all site data. Data to be displayed include: site surface mapping and bathymetry, geologic contacts and fracture/fault features, borehole location and borehole related data. Numeric modeling results from other geosynthesis tasks will also be displayed using the GVS.

### 7.2.4 Task GS.4 - Overall Site Model Geosynthesis

In many ways the final purpose of the GSCP for the DGR and the goal for geosynthesis is to develop an overall descriptive geosphere site model that provides consistency of geoscience understanding amongst individual descriptive geologic, hydrogeologic and geomechanic site models and consistency with other complementary and supporting geoscience studies and projects undertaken to build confidence in site suitability and the safety case. Such complementary and supporting studies include ongoing regional geologic and hydrogeologic assessments of the Paleozoic sequence in Ontario, natural analogue studies, ‘what-if’ numerical studies of geosystem barrier performance, precedent experience in investigation and excavation of these geologic formations elsewhere, and international experience in similar geologic formations.

## 8. PROJECT SCHEDULE

Figure 8.1 shows the detailed schedule for the GSCP Phase 1 investigations, the activities necessary to implement Phase 1 investigations, and general completion dates for Phase 2 and 3 investigations. Figure 8.1 includes the planning and preparatory work to conduct the Phase 1 field investigations, the performance of Phase 1 field investigations including seismic surveys, drilling of the deep boreholes DGR-1 and DGR-2, borehole testing, sampling and monitoring, and completion of the laboratory testing programs. The project schedule also includes the analytical and interpretative work required to develop descriptive geoscience site models of the Bruce DGR and surrounding area, completion of the site geosynthesis based on Phase 1 GSCP results and the development of work plans and contracting for Phase 2 site investigations.

The activities listed in Figure 8.1 cover GSCP initiation activities and the Phase 1 tasks defined in the geologic, hydrogeologic and geomechanics site characterization plans. In order to simplify the schedule for presentation on one page in this report, the tasks listed in Figure 8.1, do not precisely correspond with work elements or tasks listed in Sections 4, 5, 6, 7 and 11 of this report. The following table provide a summary of the correspondence between Figure 8.1 tasks and tasks listed in Sections 4, 5, 6, 7 and 11 of this report.

**Table 8.1: Summary of Figure 8.1 Tasks and Section 4, 5, 6, 7 and 11 Work Elements - Phase 1 GSCP**

| *Figure 8.1 Schedule ID and Task* | *Phase 1 GSCP Work Element* |
|---|---|
| 4 Requirement I.1: Project Quality Plan | Requirement I.1 |
| 5 Requirement I.2: Establish Project Data Warehouse/GIS | Requirement I.2 |
| 6 Requirement I.3: Refinement of Core Porewater Extraction and Simulation Methods | Requirement I.3 |
| 7 Requirement I.4: Assembly of Precedent Geoscientific Data | Requirement I.4 |
| 8 Requirement I.5: Definition of Scientific Terminology | Requirement I.5 |
| 9 Requirement I.6: Assessment of GSCP against Argillaceous Limestone Geoscience Attributes | Requirement I.6 |
| 10 Requirement I.7: Preparation of Phase 1 Work Plans | Requirement I.7 |
| 11 Requirement I.8: Establish Site Infrastructure | Requirement I.8 |
| 14 Task 1: Complete Feasibility Study for 3-D Seismic Survey | Task G.1 |
| 21 Task 2: 2-D Seismic Survey | Task G.2 |
| 25 Task 3: 3-D Seismic Survey | Task G.3 |
| 44 Task 4: Installation of 3 Additional Seismograph Stations | Task GM.1 |
| 45 Task 5: Refurbish US Series Boreholes | Task HG.1 |
| 50 Task 6.1.1: Coring DGR-1 to Top of Queenston Shale | Tasks G.4, G.5, G.6, HG.2, HG.3, HG.8, GM.2 |
| 51 Task 6.1.2: Borehole Geophysics in DGR-1 | Tasks G.7, HG.4, GM.3 |
| 52 Task 6.1.3: Hydraulic Testing In DGR-1 | Task HG.5 |
| 53 Task 6.1.4: Installation of Westbay Multilevel Monitoring System | Task HG.6 |

**Table 8.1 Cont'd: Summary of Figure 8.1 Tasks and Section 4, 5, 6, 7 and 11 Work Elements- Phase 1 GSCP**

| ***Figure 8.1 Schedule ID and Task*** | ***Phase 1 GSCP Work Element*** |
|---|---|
| 54 Task 6.1.5: Initiate Pressure Monitoring, Sampling and Testing | Tasks HG.7, HG.8 |
| 56 Task 6.2.1: Rotary Drill DGR-2 and Set Casing to top of Queenston Shale | Tasks G.4, G.5, HG.2 |
| 59 Task 6.2.2: Coring DGR-2 from Top of Queenston Shale to Precambrian | Tasks G.4, G.5, G.6, HG.2, HG.3, HG.8, GM.2 |
| 60 Task 6.2.3: DDGS Overcore Stress Measurements in DGR-2 | Tasks GM.4 |
| 61 Task 6.2.4: Borehole Geophysics in DGR-2 | Tasks G.7, HG.4, GM.3 |
| 62 Task 6.2.5: Hydraulic Testing in DGR-2 | Task HG.5 |
| 63 Task 6.2.6: Hydro-fracturing Stress Measurements in DGR-2 | Task GM.4 |
| 64 Task 6.2.7: Installation of Westbay Multilevel Monitoring System | Task HG.6, |
| 65 Task 6.2.8: Initiate Pressure Monitoring, Sampling and Testing | Task HG.7, HG.8 |
| 66 Task 7: Laboratory Testing Program | Tasks G.8, HG.8. HG.9, HG.10, HG.11, GM.5, GM.6 |
| 88 Task 8: Development of Descriptive Geoscientific Site Models | Tasks G.9, HG.12, GM.7 |
| 90 Task GS-1: Complementary Geoscientific Studies | Task GS.1 |
| 97 Task GS.2: Site Specific Numerical Analyses | Task GS.2 |
| 101 Task GS.3: Scientific Data and Model Visualization | Task GS.3 |
| 102 Task GS.4: Overall Site Model Geosynthesis | Task GS.4, |

| ID | Task Name |
|---|---|
| 1 | **OPG award geoscientific site characterization contract and start up meeting** |
| 2 | |
| 3 | **REQUIREMENTS OF SCP INITIATION** |
| 4 | Requirement I.1: Project Quality Plan |
| 5 | Requirement I.2: Establish Project Data Warehouse/GIS |
| 6 | Requirement I.3: Refinement of Core Porewater Extraction and Simulation Methods |
| 7 | Requirement I.4: Assembly of Precedent Geoscientific Data |
| 8 | Requirement I.5: Definition of Scientific Terminology |
| 9 | Requirement I.6: Assessment of SCP against Argillaceous Limestone Geoscience Attributes |
| 10 | Requirement I.7: Preparation of Phase 1 Work Plans |
| 11 | Requirement I.8: Establish Site Infrastructure |
| 12 | |
| 13 | **PHASE 1 SITE INVESTIGATIONS** |
| 14 | **Task 1: Complete Feasibility Study for 3-D Seismic Survey** |
| 21 | **Task 2: 2-D Seismic Survey (Several Intersecting Survey Lines ~ 10 to 15 km Total Length)** |
| 25 | **Task 3: 3-D Seismic Survey (20 to 30 km^2)** |
| 44 | **Task 4: Installation of 3 Additional Seismograph Stations** |
| 45 | **Task 5: Refurbish US Series Boreholes (US-1 through US-7)** |
| 48 | **Task 6: Borehole Investigations DGR-1 and DGR-2 (Vertical Boreholes)** |
| 49 | Task 6.1: Drilling and testing DGR-1 |
| 50 | *Task 6.1.1: Coring to top of Queenston shale (~425 m BGS)* |
| 51 | *Task 6.1.2: Borehole geophysics in DGR-1* |
| 52 | *Task 6.1.3: Hydraulic testing - 8 slug tests (2 days each) and 1 DST (4 days)* |
| 53 | *Task 6.1.4: Installation of Westbay multilevel monitoring system* |
| 54 | *Task 6.1.5: Initiate pressure monitoring, groundwater sampling and hydraulic testing of Westbay system* |
| 55 | Task 6.2: Drilling and testing DGR-2 |
| 56 | *Task 6.2.1: Rotary drill and set casing to top of Queenston Shale (~425 m BGS)* |
| 59 | *Task 6.2.2: Coring from top of Queenston shale to Precambrian (~425-850 m BGS)* |
| 60 | *Task 6.2.3: DDGS overcore stress measurements* |
| 61 | *Task 6.2.4: Borehole geophysics in DGR-2* |
| 62 | *Task 6.2.5: Hydraulic testing - 9 scoping pulse tests (1 week each)* |
| 63 | *Task 6.2.6: Hydro-fracturing stress measurements* |
| 64 | *Task 6.2.7: Installation of Westbay multilevel monitoring system* |
| 65 | *Task 6.2.8: Initiate pressure monitoring, groundwater sampling and hydraulic testing of Westbay system* |
| 66 | **Task 7: Laboratory Testing Program (Geological, Hydrogeological, Hydrogeochemical, and Geomechanical)** |
| 88 | **Task 8: Development of Descriptive Geoscientific Site Models** |
| 89 | **Task 9: Complete Site Geosynthesis** |
| 90 | Task GS.1: Complementary geoscientific studies |
| 97 | Task GS.2: Site specific numerical analyses |
| 101 | Task GS.3: Scientific data and model visualization |
| 102 | Task GS.4: Overall site model geosynthesis |
| 103 | **Task 10: Develop SCP Phase 2 Specifications and Work Plans** |
| 104 | **Task 11: Contract Phase 2 Investigation Works** |
| 105 | |
| 106 | **PHASE 2 SITE INVESTIGATIONS (Spring 2010 Completion)** |
| 108 | **PHASE 3 SITE INVESTIGATIONS (Fall 2011 Completion)** |

Figure 8.1 Proposed GSCP Phase I Schedule
Geoscientific Site Characterization Plan for Bruce DGR

| Task | Progress | Milestone | Summary |
|---|---|---|---|
| ▨ | ▬ | ◆ | ▬ |

## 9. QUALITY PLAN

All GSCP activities will be performed under the control of a DGR Project Quality Plan (PQP). Although there is no formal regulatory guidance on quality management and quality assurance (QA) in site characterization work, the CNSC discussion paper on site characterization recognizes that QA is a “critical aspect of site characterization”.

OPG will be managing the overall project, but will contract large work scopes to external contractors. In addition to the GSCP work scope, there will be Safety Assessment (SA), Repository Engineering (RE), and Environmental Assessment (EA) components of the overall project.

OPG’s Nuclear Waste Management Division (NWMD) operates under a system of governance that embodies a quality management system. It has been developed in compliance with CSA N286 and consists of a series of procedures that governs work performed by NWMD staff. Defined procedures are both global and specific, with all employees and operations subject to global procedures. Specific procedures are provided to govern particular work activities.

OPG will be developing a set of project-specific procedures to govern various aspects of the DGR project, including work to be carried in the GSCP. These procedures will be developed under the control of a predefined OPG-NWMD process to provide a consistent structure and to ensure compliance with OPG-NWMD governance. The new procedures would be intended to augment, rather than replace, existing OPG-NWMD procedures.

OPG expects that any contractor retained to conduct work on the DGR project will operate under their own internal quality management system. However it will be a condition of contract award that lead contractors also develop a PQP that specifically addresses their work program on the DGR project. The contractor’s plan would be required to comply with the overall DGR PQP and would list the DGR project-specific procedures to be used in their work program. The DGR quality management system will help ensure all products and services meet the stated or implied needs and expectations of stakeholders in the project.

# 10. DATA MANAGEMENT

The GSCP Data Management System (DMS) will consist of software systems designed to store, manage, integrate, and visualize acquired data. Additionally, the DMS will assist the QA process by providing tools to track and identify data. The DMS will not be a single integrated system, but instead will consist of several commercial-off-the-shelf systems (COTS), with overall integration provided by a custom data warehouse system.

## 10.1 Software Selection

There will be four major types of data produced during execution of the GSCP: borehole related, seismic data, mapping data, and geoscience interpretations of seismic and borehole logging. These data types and their associated management tools are described in the following sub-sections.

### 10.1.1 Borehole Data Management

Borehole data consists of all data which are spatially and temporally related to a single borehole or to a borehole interval. As the GSCP describes a borehole driven sub-surface program, it is not surprising that this is the most significant data type from a data management perspective. Borehole related data that needs to be managed includes the following.

1. Continuous core logging – on-site geologist's narrative description of core, core intervals and depths, drilling time, core identification for storage, geologist name, digital images of core.
2. Drilling fluid testing – physical-chemical properties of the drilling fluid (e.g., density, viscosity, temperature, tritium and stable isotope measurements) and measured tracer concentrations over time.
3. Continuous borehole logs – multiple sets of depth continuous (or discontinuous) results from standard borehole and geophysical logs; identified by log type, date performed, sub-contractor/contractor staff, depth and time of opportunistic samples of groundwater and their field and laboratory analysis.
4. Core sample identification - identification of core subsets extracted for lab analysis, date of subset and method(s) of preservation.
5. Core sample extraction – criteria for selection of core for pore-water extraction, extraction procedures performed to obtain pore-water samples, analyses to be performed on both solid and aqueous phases, methods and conditions of analysis, and results of analyses in terms of exchangeable ions, dissolved gases and isotopes, diffusion tests and sorption measurements.
6. Hydraulic testing intervals – location of tested intervals, location of packers for each interval tested, date performed, test equipment used, sub-contractor/contractor staff, and raw testing results (pressure, temperature, flow rate).
7. Well completion details – location of sampling ports, packers (Westbay), date installed, sub-contractor/contractor staff and raw testing results.
8. Long-term monitoring results – hydrogeochemical analyses, pressure measurements, date installed, interval tested, and results.
9. Geochemical simulations of borehole data – date of simulation, version of simulator, documentation of input and output files.

Many of these data will be initially acquired using separate and task-specific data acquisition systems. For example hydraulic testing results will be recorded by the DAS operated by the testing contractor (i.e., a MiniTroll system). Typically DAS results will then be converted to a more commonly useable format such as Excel spreadsheets. Ideally, all phases of the data processing should be captured for GSCP project records.

QA information associated with borehole data needs to be incorporated in the Borehole DMS. Consequently, the Borehole DMS should be based on a flexible data base architecture that will allow user-configuration to add QA fields such as the QA Control ID (CID, see Section 10.2) associated with each data component.

There are several available COTS systems that are suitable for use in the GSCP. HydroGeo Analyst (Waterloo Hydrogeologic, http://www.waterloohydrogeologic.com/software/Hydrogeo_ Analyst/ Hydrogeo_analyst_ov.htm) and ViewLog (ViewLog systems, http://www.viewlog.com/ viewlog/ Default.htm) are two widely used systems which will meet most GSCP requirements. The choice of a specific system should be made by the GSCP contractor based on previous use, familiarity and availability of trained staff

### 10.1.2 Seismic Data

3-D seismic survey and, to a lesser extent, 2-D seismic surveys, will generate vast quantities of data. We do not see a requirement for the GSCP to manage or internally process these data (although a copy of the raw processed data should be provided to the GSCP for archive/QA purposes). We anticipate that interpreted seismic results will be provided by the seismic sub-contractor. These should be in a form compatible with the project geoscience visualization system (see Section 10.1.4). Individual formation contact surfaces and fault surfaces should also be provided in forms compatible with the project GIS (see Section 10.1.3) and for use in modeling and visualization pre-processors.

### 10.1.3 Geographic Information Systems

Taken in isolation, the mapping/GIS requirements of the GSCP program are minimal. Although nearly all GSCP data will be geo-referenced, GIS are not the primary visualization tools for geologic data. However, GIS/mapping applications are suitable for display of traditional 2D representations of GSCP data such as isopachs of formation contacts and bathymetry, as well as for planning documents such as borehole locations at surface, proposed seismic lines, etc.

Integration of GSCP data with data from concurrent EA programs will be facilitated if a common mapping standard is established across all DGR related programs. We believe that OPG should establish a general mapping specification for all elements of the DGR project. The specification should be supported by a mapping services group, either within OPG or provided by a contractor/sub-contractor with recognized mapping skills. The mapping services group would be responsible for maintaining base map data (cultural features, ortho-photo, etc) and for supplying base map files in appropriate formats for use by GSCP, EA, and other contractors. Mapping data generated by GSCP and EA contractors would be provided back to the mapping organization for QA and archive purposes. This resource should be established early in the program, during the GSCP implementation phase.

### 10.1.4 Geoscience Visualization Systems

Geoscience visualization systems (GVS) will be a significant tool to both support geosynthesis of GSCP data and to support communication of GSCP results to stakeholders. In general, a geologic visualization system can be defined as a system for the presentation and analysis of three-dimensional geo-referenced data, defined as volumes, surfaces or lines. It will have the capability to display and analyze geologic contacts, fault systems and to present ancillary data such as borehole location and repository features as well as providing basic display of surface mapping information. A useful additional feature is the capability of displaying numeric modeling results using the native model discretization.

There are a number of commercial systems that will meet GSCP requirements. These include VULCAN (Maptek Pty Ltd, www.vulcan3D.com), EarthVision (Dynamic Graphics Inc. www.dgi.com/earthvision/index.shtml), EVS (CTech Development Corp, www.ctech.com), GOCAD (Earth Decision Sciences, www.t-surf.com), GeoGraphix (Halliburton, www.geographics.com) and mView (Intera Engineering Ltd, http://www.interaeng.ca/tech _mview.htm). VULCAN is oriented towards mining industry requirements, while EarthVision and GeoGraphix primary markets are hydrocarbon exploration and production. GOCAD supports both mining and hydrocarbon exploration, while EVS is oriented to environmental applications. mView's primary purpose is visualization of numeric model results, but has a complete capability for displaying and analyzing imported geologic and repository features.

Any of these systems are suitable for meeting the majority of geoscience visualization requirements. The choice of a specific system should be made by the GSCP contractor based on previous use, familiarity, and availability of trained staff.

## 10.2 Software Specification – Project Data Warehouse

Management and use of technical data will be facilitated if there is a single point of access and a single mechanism for data identification and retrieval.

We propose development of a database management system geared to managing many disparate data types. The system will be integrated with the PQP. Although PQP procedures for archive and control of scientific data and interpretations have yet to be defined, we have assumed that the mechanism will include a QA Control Identifier (CID) which uniquely identifies any particular baselined (i.e. approved/reviewed data submitted to QA control) data set. The identifier will include alphabetic and numeric elements which provide broad definition of the data type, date, and revision status. For example, the CID: HT070056.000 might refer to revision 000 of hydraulic testing results from the 56th test conducted in 2007. The actual naming criteria will be developed during the GSCP Implementation Phase.

The Project Data Warehouse (PDW) will be implemented as a directory structure based on the data CID. The structure may be flat, or may be hierarchical, depending upon the final form and format of the CID. Each directory will contain metadata describing the data. At a minimum the metadata will consist of a readme.doc file, although a preferred alternative would use a common XML schema for data descriptions. All associated data files will be stored under the main CID based directory, using further subdirectories if necessary. The format used to store data will be entirely data dependent. Preference will be given to open formats, such as XML. In general, use of proprietary binary formats will be discouraged, although common binary formats such as Microsoft Word and Excel will be acceptable.

Data in the PDW system will be accessed through a project web-page.  Read access will be allowed by all authorized users, while write access will be limited to PQP administrative staff. Restrictions on data access and use will be enforced by other PQP procedures.

The PDW will require IT systems and staff support, either from within the site contractor organization or from OPG.

# 11. REQUIREMENTS FOR GSCP INITIATION

## 11.1 OBJECTIVES

Several activities for initiation of the GSCP need to be completed prior to commencement of Phase 1 GSCP investigation in fall, 2006. These activities include: work elements related to developing GSCP PQP procedures; developing project glossary of accepted scientific terminology; assessment of GSCP against geoscience attributes for argillaceous limestone; establishment of data management systems; refinement of uncertain test procedures and methods; assembly of relevant geoscientific data; establishing site infrastructure; preparation of detailed procedures and test plans for Phase 1 investigations; and tendering for GSCP Phase 1 work These activities have the objective of reducing uncertainty in the outcome of Phase 1 GSCP investigations, and assuring that these investigations are performed in a cost-effective manner.

## 11.2 DESCRIPTION OF MAJOR REQUIREMENTS

### 11.2.1 Requirement I.1 - Project Quality Plan

The initiation phase of the PQP involves writing the actual procedures that will govern project work. The GSCP contractor will refer to OPG project procedures and develop any additional procedures deemed necessary. Each procedure will provide sufficient detail so that GSCP work products can be objectively assessed for procedural compliance.

### 11.2.2 Requirement I.2 - Establish Project Data Warehouse/GIS

The Project Data Warehouse system will be implemented by OPG or an IT contractor in the early phases of the project. In the GSCP initiation phase, the GSCP contractor may assist OPG in system testing. System testing will include use and verification of QA procedures related to the PDW.

The GIS resource will be established by OPG. The GSCP contractor will assist in verifying map coverage and will determine GSCP specific map layers to be generated. The GSCP contractor will also verify the usability of PQP procedures related to GIS data updating and retrieval.

### 11.2.3 Requirement I.3 - Refinement of Core Porewater Extraction and Simulation Methods

The most promising methods available for porewater extraction include crushing and leaching, centrifugation, diffusional equilibration and, more recently, advective displacement (see Section 5.2.9). Due to the uncertain properties of the Ordovician rocks and, in particular, the effect that the various porewater extraction processes have on the analytes to be determined, it is necessary to undertake a detailed study prior to drilling the first borehole at the DGR site.

In the absence of such preliminary testing, a significant fraction of the core from the first OPG borehole might be expended in assessing appropriate porewater extraction methods and thereby delaying the overall project. Therefore, it is recommended that OPG undertake a preliminary assessment of porewater extraction with fresh core samples of the Ordovician formations of interest that may be collected from drilling at an off-site location. Such core samples would preferably be collected from a shallow location east of the Niagara Escarpment and within an area of brackish to saline groundwater. Several promising sites are known to exist in southeastern and southcentral Ontario. It is proposed that these studies be undertaken at research laboratories that are currently equipped and established to complete such tests.

Even after an extraction technique has been developed specifically for the Ordovician rocks at the Bruce Nuclear Site, the analytical data derived from the extraction of pore waters will require extensive geochemical interpretation using geochemical codes such as PHRQPITZ. Consequently, the geochemistry of the pore waters will be indirectly determined by simulation rather than directly by analytical chemistry. Therefore, an assessment of geochemical codes capable of simulating pore waters from the Ordovician host rocks should be undertaken prior to the commencement of site characterization.

### 11.2.4 Requirement I.4 - Assembly of Precedent Geoscientific Data

Precedent geoscientific data for the sedimentary sequences of interest at the DGR need to be assembled, reviewed and evaluated to ensure the GSCP benefits from the precedent experience in investigation, testing and excavation of these rocks. Precedent geological, hydrogeological, hydrogeochemcial, petrophysical and geomechanical data need to collected, and reviewed.

For geomechanics this work is distinct from regional geomechanics assessment as part of geosynthesis, in that it focuses on practical experiences in undertaking geomechanics testing in the rocks of interest. While some of these data and experience have been summarized in the Geotechnical Feasibility Study, and some will be addressed as part of complementary off-site studies (e.g., Sections 7.2.1.2, 7.2.1.4 and 7.2.1.5), there is a specific need to assemble precedent geomechanics data prior to start of the Phase 1 GSCP. Information on in-situ stresses, geomechanical rock properties and rock mass properties from precedent investigations needs to be assembled and reviewed. In particular, results of standard index tests from regional quarries and rock stress and strength data from the recent Niagara Tunnel Development Project in the Queenston shale at Niagara Falls should be reviewed.

A similar need exists to assemble precedent hydrogeological, hydrogeochemical and petrophysical information related to the groundwaters of the Michigan Basin in southern Ontario, the mineral assemblages that constitute the principal rock formations and the physical-chemical properties that will constrain fluid flow and transport in the Ordovician host rocks. The work of Mazurek (2004) is of course a survey of this information, however much additional information may be obtained from the Geological Survey of Canada, Ontario Ministry of Natural Resources, Ontario Geological Survey, OPG and the various academic research groups cited by Mazurek.

### 11.2.5 Requirement I.5 - Definition of Scientific Terminology

The GRG (2005b) recommended that potentially ambiguous scientific terminology (e.g., porosity, Pearson, 1999, stratigraphy – see Figure 4.3) be defined early in the GSCP to avoid confusion in subsequent stages of the GSCP. Provision of uniform set of scientific terms and definitions for use in the GSCP is an initiation requirement that should be completed prior to implementation of GSCP Phase 1 investigations. It is likely that a project technical glossary will be established under control of a project specific QA procedure. The GSCP contractor will assist OPG in generating and reviewing glossary terms.

### 11.2.6 Requirement I.6 - Assessment of GSCP Against Argillaceous Limestone Geoscience Attributes

Although screening of GSCP data needs against the NEA features events and processes catalogue (FEPCAT, Mazurek et al., 2003) for argillaceous media for the undisturbed system was completed (INTERA, 2005), the GSCP should be screened against a similar catalogue of geoscience attributes prepared for limestone and the DGR site. Since no such attribute list currently exists for argillaceous limestones, it is recommended that such a limestone and site-specific geoscience attribute list be prepared and included in the GSCP. Such a list may include dolomitized fault zones (Carter et al., 1996), shaley interbeds, orthogonal joint/fracture systems, solute transport through fractures, retardation by matrix diffusion, etc.). The assessment should consider not only the undisturbed system, but also repository-induced effects, and long-term evolution of the host and barrier rocks, including the DGR. This assessment should be completed early in the Bruce DGR project.

### 11.2.7 Requirement I.7 - Preparation of Phase 1 Work Plans

Prior to any Phase 1 GSCP work commencing, there will be a requirement to prepare detailed test and control procedures and work plans for all the major tasks to be completed in the GSCP. These procedures and plans must be developed in accordance with the PQP and the DMS requirements. These procedures and plans will define how Phase 1 GSCP work will be conducted, how data quality will be ensured and how results will be generated, interpreted and managed.

Phase 1 work plans will also address issues of worker Health and Safety, well head gas monitoring at drill sites, contingency plans in the event of a site incident or emergency, and on-site control and management of produced fluids and other wastes.

### 11.2.8 Requirement I.8 - Establish Site Infrastructure

Several site related activities must be undertaken prior to commencement of Phase 1 GSCP work. These include establishment of an on-site core storage and handling facility, acquisition of on-site office space to accommodate OPG and GSCP implementation staff, development of a drill site and drill pad and provision of site services (roadway, electrical) to the drill site. Some of these infrastructure requirements may have long lead times to implement.

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# APPENDIX A: Geoscience Data Collection Methods

## CONTENTS

**Page**

## A.1 Geological Setting and Framework

**Table A.1.1 Data Collection Methods – Existing Geological Information**

| **Collection Method** | |
|---|---|
| Published OGS/GSC Maps & Reports | ***Description -*** Published maps and reports by the Ontario Geological Survey (i.e., Maps P2314, P.2315, P.2316) and the Geological Survey of Canada (i.e., Map 1194A) on quaternary and bedrock geology, bedrock structure, drift thickness and bedrock topography in Bruce area. |
| | ***Cost –*** Low |
| OGS Petroleum Resources Maps | ***Description -*** Structural surface and isopach maps (i.e., P2759, P.2814, P.2825, P.2900, P.3018 and P.3040) of Rochester, Devonian Carbonate and Guelph Formations in Bruce County |
| | ***Cost –*** Low |
| Published MNR and Other Reports on Deep Sedimentary Sequence Geology | ***Description –*** Maps and reports (e.g., Golder 2005 Report on Hydrocarbon Resource Assessment of the Trenton Black River Thermal Dolomite Play in Ontario) on dolomitized fault zones and other geologic structures in the deep sedimentary sequence, available from MNR's Oil Gas Salt Resources Library, London. |
| | ***Cost –*** Low |
| Maps and Geologic Logs of Oil and Gas Wells in Bruce County | ***Description -*** Map of well locations and electronic geological logs of all 109 oil and gas wells drilled in Bruce County available from MNR's Oil Gas Salt Resources Library, London. |
| | ***Cost –*** Low |
| Geophysical Logs of Oil and Gas Wells in Bruce County | ***Description -*** Geophysical logs can be purchased for selected wells from data brokerages in Calgary |
| | ***Cost –*** High |

**Table A.1.2 Data Collection Methods – Existing Geophysical Information**

| **Collection Method** | |
|---|---|
| Seismic Refection Surveys | ***Description -*** Existing 2-D and occasionally 3-D seismic reflection data sets acquired as part of oil and gas exploration in Bruce and Huron Counties in the 1970s to 1990s are available for purchase from data brokerages in Calgary. Closest coverage to Bruce site appears to be 2 intersecting lines about 8 to 10 km southeast of Bruce. |
| | ***Cost -*** High, Seismic data is typically sold for about 20 to 40 % of acquisition costs. |
| Regional Geophysical Data Sets | Description - Regional aeromagnetic total field and gravity surveys for the Bruce area are available from the Geological Survey of Canada and the Ontario Geological Survey. |
| | ***Cost –*** Low |

**Table A.1.2 Data Collection Methods – Existing Geophysical Information**

| **Collection Method** | |
|---|---|
| Bathymetric Surveys of Lake Huron | ***Description -*** Depth of water within the adjacent Lake Huron should be collected from Bruce and OPG sources and Canadian Hydrographic Service to support Lake-based seismic surveys |
| | ***Cost –*** Low |

**Table A.1.3 and A.1.4 Data Collection Methods – Stratigraphic Sequence, Formation Thicknesses and Attitudes**

| **Collection Method** | |
|---|---|
| Borehole Drilling and Core Logging | ***Description -*** Continuous collection of rock core collected using wireline techniques while drilling that can be logged by on-site geologist for changes in lithology. Allows for visual inspection of rock. Provides the only tangible evaluation of geological environment without larger excavations. Obtain photographic record of all core. |
| | ***Cost -*** Expensive – includes cost of drilling rig and crew ($150 to $200 per metre) |
| Borehole Geophysical Testing | ***Description -*** Lowering geophysical tools down borehole after drilling is complete and collecting measurements pertaining to rock properties allowing differentiation between varying stratigraphic units. Borehole geophysical information is primarily representative of a limited distance from the borehole walls (except for some cross hole surveys if boreholes are spaced relatively close to each other, i.e., ~ 100 m). Tools useful for identification of stratigraphic sequence and formation thickness and attitude include:<br>**Gamma** - Records amount of gamma radiation emitted by the rocks surrounding the borehole and therefore infers varying clay content;<br>**Spectral Gamma** – detection of gamma radiation emitted from the formation and used to differentiate potassium, uranium and thorium content to infer lithology based on clay mineral content;<br>**Gamma-Gamma (Density)** – measurement of electron density obtained by exposing formation to gamma radiation from a source in the probe and infers lithologic contacts and porosity;<br>**Neutron (Porosity)** – measurement of hydrogen content by exposing formation to neutrons from a source on the probe and infers lithologic contacts, water content and porosity;<br>**EM-Induction (Resistivity)** – records the electrical conductivity (resistivity) of the rocks and water surrounding the borehole which are effected by porosity and clay content of rocks and TDS of the water;<br>**Conductivity** – measurement of variations is electromagnetic field induced by a transmitter in the probe and used to infer lithology in terms of electrical conductivity (i.e., water/clay content);<br>**Full Waveform Seismics** – measurement of the compressional, shear and Stoneley seismic velocities using a probe source(s) and detectors (transducers);<br>**Vertical Seismic Profiling** – measurement of shear and compressional seismic velocities using a surface source and borehole detectors (geophones) to calculate bulk modulus and infer general rock competence and lithology;<br>**Cross Hole Seismic Profiling (Tomographic Survey)** – measurement of shear and compressional seismic velocity of the formation between two boreholes, one of which contains sources(s) and the other detectors(s) and used to determine general rock competence (calculates bulk modulus). |

**Table A.1.3 and A.1.4 Data Collection Methods – Stratigraphic Sequence, Formation Thicknesses and Attitudes**

| **Collection Method** | |
|---|---|
| | ***Cost -*** Low to Moderate – specialized equipment necessary |
| 2-D Seismic Surveys | ***Description -*** The variations of speed and time for sound waves produced by explosives, vibrating plates, and air guns (sleeve guns) to be reflected and measured by receivers can indicate changes in lithology at a particular depth. 2-D seismic surveys have receivers oriented in a line. These surveys produce information over a larger area than boreholes and can offer more detail by simply reducing the spacing between receivers and geophones. They are minimally intrusive but usually require borehole information and borehole vertical seismic profiling to improve interpretation. Changes in reflection rates of sound waves indicate a change in material properties (i.e., density) but do not indicate the lithology, this information must be inferred from core collected while drilling and from vertical seismic profiling of boreholes. These surveys can indicate the level of continuity of larger reflective features such as tops of formations, major bedding planes and other flat-lying stratigraphic features. Cannot directly identify strata or features dipping greater than 45 degrees |
| | ***Cost -*** Moderate: ~$100K to 200K per 5 km of survey line. |
| 3-D Seismic Surveys | ***Description -*** Similar to a 2-D survey, however the receivers are oriented in a grid format (i.e., multiple 2-D seismic lines with offset lines that are orthogonal to each other) which allows for a 3-D interpretation of the data. Produces information over a larger area than boreholes and can offer more detail by simply reducing the spacing between receivers and geophones. The collection of data over offset lines and on an orthogonal grid generates a 3-D interpretation of bedrock layering and structure. Similar to 2-D surveys they cannot directly identify strata or features dipping greater than 45 degrees. They are also minimally intrusive but usually require borehole information and borehole vertical seismic profiling to improve interpretation. More steeply dipping strata or features require interpretation of vertical offsets in sub-horizontal layering. Coverage may be limited by Bruce infrastructure. |
| | ***Cost -*** Expensive: ~$3 to 4 Million depending on size of survey area |
| Mineralogical | ***Description –*** see A.1.6 |
| | ***Cost -*** Low |

**Table A.1.5 Data Collection Methods – Structural Framework**

| **Collection Method** | |
|---|---|
| Borehole Drilling and Core Logging | ***Description -*** Continuous collection of rock core while drilling that can be logged by on-site geologist for bedding plane contacts between different layers and structural features such as faults, fractures zones, smaller fractures or joints, as well as taking note of water producing/losing zones as drilling progresses. Allows for visual inspection of rock, the breaks in the core and any chemical alterations on these fracture surfaces which indicates hydraulic activity at some time. Is the only tangible evaluation of geological environment without larger excavations. Interpolation is required for extending structure between boreholes. Sampling of vertical structure is limited in |

**Table A.1.5 Data Collection Methods – Structural Framework**

| Collection Method | |
|---|---|
| | vertical to sub-vertical boreholes. Unless borehole is drilled at a sub-vertical angle there is difficulty in orienting the core and therefore the core fractures. Mechanical breakage of core during collection process is sometimes difficult to differentiate from natural features |
| | ***Cost -*** Expensive – includes cost of drilling rig and crew ($150-$200 per metre) |
| Borehole Geophysical Testing | ***Description -*** Lowering geophysical tools down borehole after drilling is complete and collecting measurements pertaining to rock mass and fracture properties allowing identification of structures intersecting or proximate to boreholes. With the exception of borehole radar and tomographic cross-hole seismic surveys, the identification is limited to the immediate vicinity of the borehole. Tools useful for structural identification and mapping include:<br>**Acoustic Televiewer** – highly detailed measurement of borehole diameter obtained by timing the return reflection of an acoustic pulse of the borehole wall back to the probe; primarily used to infer fractures and there orientation, borehole diameter and borehole orientation;<br>**Optical Televiewer** – collects an oriented image of the borehole wall which undergoes “restoration” to correct for optical distortion and creates a “virtual core”; primarily used to indicate fracture location but also provides some lithologic information;<br>**FMI** – Formation Macro Imaging, provides a high resolution image of the borehole wall, that is of superior quality to that provided by optical or acoustic televiewer. This is an oil and gas tool requiring a 160 mm diameter hole.<br>**Video** – video camera (VHS and SVHS) recording down length of borehole; used to visually inspect locations of fractures and voids, and large water movement zones;<br>**Caliper** – mechanical measurement of borehole diameter based on the extension of 3 or 4 caliper arms;<br>**Borehole-Radar Reflection** – records the reflected wave amplitude and transit time of high-frequency EM waves using a pair of downhole transmitting and receiving antennas; used to determine the location and dip of fractures and lithologic changes and to estimate the radial extent of such features beyond the borehole (3 to 10 m radial penetration dependent on the electrical resistivity of the rock and water surrounding the borehole);<br>**Cross Hole Seismic Profiling (Tomographic Survey)** – measurement of shear and compressional seismic velocity of the formation between two boreholes, one of which contains sources(s) and the other detectors(s) and used to determine general rock structure in the panel that exists between two holes.<br>**Fluid Resistivity** – measures the electrical resistivity (which is related to the dissolved solids concentration) of the water in a borehole; used in conjunction with temperature and flowmeter logs to infer locations of fractures based on flowing water;<br>**Temperature** – direct measurement of borehole fluid temperature to within 0.001 degrees C used to detect water movement through and between fractures; provides insitu temperature data needed for diffusion parameter definition at DGR depth;<br>**Heat Pulse Flowmeter** – measures time required for a temperature pulse to travel from a source to thermistors above and below probe and used to determine low levels of vertical water movement in open boreholes and infer locations of significant fractures or changes in flow conditions;<br>**Impeller Flowmeter** – measures vertical flow with an impeller and used to identify high levels of vertical water |

**Table A.1.5 Data Collection Methods – Structural Framework**

| Collection Method | |
|---|---|
| | movement in an open borehole and locate significant fractures or changes in flow conditions;<br>**EM-Flowmeter** – records the direction and rate of vertical flow in a borehole by measuring the voltage gradient generated by the flow of water through an induced magnetic field. |
| | ***Cost -*** Moderate – some specialized equipment necessary |
| Open-Hole Hydraulic Testing | ***Description -*** Hydraulic testing with dual (or more) packer tool on work-over rig. Successive intervals in borehole can be tested to reliably identify transmissive and permeable structural features of importance to the site characterization effort. |
| | ***Cost -*** Moderate – some specialized equipment necessary |
| Surface Seismic Surveys | ***Description -*** The variations of speed and time for sound waves produced as surface by explosives, vibrating plates, and air guns (sleeve guns) to be reflected and measured by surface receivers can also indicate changes in rock quality due to structure at a particular depth. Surveys can be produce information in 2-D (lines) or 3-D (grid). They produce information over a larger area than boreholes and can indicate the level of continuity of larger structural features such as tops of formations, major bedding planes, faults. These surveys will not indicate smaller features such as fractures or joints. They are minimally intrusive but usually require borehole information and borehole vertical seismic profiling to improve interpretation. More steeply dipping structures require interpretation of vertical offsets in sub-horizontal layering. Coverage may be limited by Bruce infrastructure. |
| | ***Cost -*** Moderate: ~$100K to 200K per 5 km of 2-D survey line; Expensive: 3-D surveys ($3 to $4 Million) |
| Gravity Surveys | ***Description –*** High-resolution airborne or ground measurement of gravity and/or vertical gravity gradient to detect changes in subsurface densities of rock units. These surveys have typically been used too map deep lithologic and structural features and some shallow geological features including ore bodies, kimberlite pipes and geologic structures associated with hydrocarbon accumulations. They may have application in mapping strike-slip dolomotized fault zones in the deeper Ordovician argillaceous limestones, provided the differential gravity signature is strong and overlying Devonian and Silurian bedrock is relatively homogeneous gravimetrically. However both of these conditions are unlikely and therefore gravity surveys are unlikely to be useful. |
| | ***Cost -*** Moderate |

**Table A.1.6 Data Collection Methods – Bedrock Petrography and Mineralogy**

| Collection Method | |
|---|---|
| Core Logging | ***Description -*** Logging of recovered drill core by on-site geologist for changes in rock type, texture, mineralogic composition, layering, hardness, etc. Allows for visual and physical inspection of rock to determine changes in rock type, texture, hardness, and mineralogy. Is the only tangible evaluation of geological environment without larger excavations |
| | ***Cost -*** Low – does not include costs associated with drilling and core collection |

**Table A.1.6 Data Collection Methods – Bedrock Petrography and Mineralogy**

| **Collection Method** | |
|---|---|
| Optical Microscopy | ***Description –*** Conventional analyses of thin sections using microscope to identify petrography and mineralogy of rock samples |
| | ***Cost -*** Low |
| X-ray Diffraction Mineralogy (XRD) | ***Description -*** Laboratory analysis which provides quantitative determination of all rock-forming and clay/phyllosilicate minerals including weight percent, volume percent, grain density. A rock thin section is also needed for this analysis. |
| | ***Cost -*** Low (~$400 per sample) |
| Scanning Electron Microscopy (SEM) | ***Description –*** Laboratory evaluation of porosity, pore connectivity and pore throat size, shape, and roughness by preparing rock core samples and obtaining high-quality black and white photomicrographs at various magnifications. |
| | ***Cost -*** Low (~$300 per sample) |
| X-ray Fluorescence (XRF) | ***Description -*** Laboratory analysis of the major elements, including the concentrations and distributions of U, Th, and K. Allows for calculation of $^{4}$He and $^{40}$Ar production rates and in-situ neutron fluxes for $^{129}$I and $^{36}$Cl in-growth calculations |
| | ***Cost -*** Low |
| Borehole Geophysical Testing | ***Description -*** Lowering geophysical tools down borehole after drilling is complete and collecting measurements pertaining to rock properties allowing differentiation between varying stratigraphic units. Tools useful for determining bedrock petrography and mineralogy include:<br>**Gamma** - Records amount of gamma radiation emitted by the rocks surrounding the borehole and therefore infers varying clay content;<br>**Spectral Gamma** – detection of gamma radiation emitted from the formation and used to differentiate potassium, uranium and thorium content to infer lithology based on clay mineral content;<br>**Gamma-Gamma (Density)** – measurement of electron density obtained by exposing formation to gamma radiation from a source in the probe and infers lithologic contacts and porosity;<br>**Neutron (Porosity)** – measurement of hydrogen content by exposing formation to neutrons from a source on the probe and infers lithologic contacts, water content and porosity;<br>**EM-Induction (Resistivity)** – records the electrical conductivity (resistivity) of the rocks and water surrounding the borehole which are effected by porosity and clay content of rocks and TDS of the water;<br>**Conductivity** – measurement of variations is electromagnetic field induced by a transmitter in the probe and used to infer lithology in terms of electrical conductivity (i.e., water/clay content).<br>**Photoelectric Effect (Lithodensity)** – density logging tool that measures absorption of low-energy gamma rays, and is a sensitive indicator of mineralogy. Particularly useful for identification of dolomitized zones in limestone units. |
| | ***Cost -*** Low to Moderate – some specialized equipment necessary |

## A.2 Geomechanical Setting and Rock Properties

**Table A.2.1 Data Collection Methods – Existing Geomechanical Information**

| **Collection Method** | |
|---|---|
| In-situ Stress Database | ***Description -*** Database on Canadian Crustal Stresses maintained by the National Earthquake Hazard Program, Geological Survey of Canada, Ottawa |
| | ***Cost –*** Low, but database will need to be sorted to extract information for sedimentary rocks |
| Ground Stress and Geomechanical Rock Properties | ***Description -*** Data from OPG, K.Y Lo reports/papers and from other engineering projects (i.e., aggregate quarries, tunnel project and other underground openings) completed in the same or similar formations in southern Ontario (e.g. Goderich Sifto Mine) and northern US. |
| | ***Cost –*** Low |

**Table A.2.2 Data Collection Methods – In-Situ Stress Regime**

| **Collection Method** | |
|---|---|
| Deep Doorstopper Gauge System (DDGS) | ***Description -*** Developed by AECL, a deep overcoring method that uses a glued borehole bottom-cell that provides 2-D stresses in plane perpendicular to the borehole axis. |
| | ***Advantages -***<br>• Does not require pilot hole to be drilled, therefore advantageous in disking or highly fractured rocks<br>• Very short length of overcore required |
| | ***Disadvantages -***<br>• Effectiveness of glue to adhere stress cell to bottom of borehole in deep boreholes filled with water is questionable<br>• Never used below 528 m borehole depth<br>• Performed while drilling, therefore slows rate of drilling and creates standby charges for drilling crew |
| | ***Cost –*** Moderate relatively inexpensive for equipment alone but time and effort of all involved make this a moderately expensive technique. |
| In Situ Stress Measurement Tool (IST) | ***Description -*** Borehole deformation gauge that is secured in borehole by spring loaded pins. Developed by Sigra Pty Ltd based in Australia, and provides 2-D stress information in plane perpendicular to borehole axis. |
| | ***Advantages -***<br>• Does not rely on glue to ensure stress gauge is secure<br>• Rapid and easy to use, rugged construction<br>• Has been used at depths of 750 m BGS |
| | ***Disadvantages -***<br>• Need for fairly long overcore (1 m in length) creates problems where core disking or highly fractured rocks are encountered. |

**Table A.2.2 Data Collection Methods – In-Situ Stress Regime**

| Collection Method | |
|---|---|
| | • Limited data available for comparison to other tests under appropriate quality assurance plans. |
| | ***Cost -*** Moderate |
| Borre Probe (SSPB) | ***Description -*** Glued soft cell inclusion method developed in Sweden. |
| | ***Advantages -***<br>• Provides 3-D stress information;<br>• Has been used at depths of 600 m BGS |
| | ***Disadvantages -***<br>• Need for fairly long overcore (50 cm in length) creates problems where core disking or highly fractured rocks are encountered<br>Sensitive to grain size variation and isotropy of rock |
| | ***Cost -*** Expensive |
| Hydro-fracturing | ***Description -*** Fluid is injected between two straddle packers to a level that causes fracture creation or re-opening of existing fractures. Theoretically new fractures are created at an orientation perpendicular to the minimum principal stress and the stabilized fluid injection pressure required to prop open the fracture is a measure of this stress. |
| | ***Advantages -***<br>• Hydrofracturing is commonly used technique in oil and gas industry and thus this method has a long history of use.<br>• Not limited by depth of application.<br>• Can be done independently of advancing the drill hole. |
| | ***Disadvantages -***<br>• May create disturbance to groundwater chemistries due to fluid injection.<br>• May be difficult to interpret in rock with pre-existing fractures or weakness planes (i.e., horizontal bedding)<br>• May only provide vertical stress information in high horizontal stress regimes and horizontally layered rocks as likely exist at Bruce. |
| | ***Cost*** – Moderate |
| Sleeve Fracturing | ***Description –*** Similar to hydro-fracturing except the high pressure fluid is contained within a flexible bladder or gland, between the injection packers, and hence the injected fluid does not penetrate the rock mass. |
| | ***Advantages -***<br>• Similar advantages to hydro-fracturing, major advantage is that fluid is not injected into the formation. |
| | ***Disadvantages -***<br>• Interpretation of results is often difficult as identification of breakdown and fracture re-opening pressure is difficult to precisely identify.<br>• Effects of existing fracture/planes of weakness are also difficult to interpret.<br>• No substantial precedent experience at the 600 m depth in sedimentary rocks similar to Bruce. |

**Table A.2.2 Data Collection Methods – In-Situ Stress Regime**

| Collection Method | |
|---|---|
| | ***Cost*** – Moderate |
| Laboratory Core Testing | ***Description –*** Laboratory geomechanical testing of recovered core to determine orientation and magnitude of in-situ stresses (e.g., Kaiser effect testing). |
| | ***Advantages -***<br>• Provides 3-D state of stress using conventional intact bedrock core, and hence does not interfere with costly additional field drilling and borehole testing methods |
| | ***Disadvantages -***<br>• Evidence showing comparable results to other accepted test methods (i.e, overcoring), is limited and not compelling. |
| | ***Cost -*** Moderate |

**Table A.2.3 Data Collection Methods – Rock Material Properties**

| Collection Method | |
|---|---|
| Lithologic and Petrographic Analyses | ***Description -*** Standard descriptions and petrographic/ mineralogic analyses of rock materials (see Table A.2.4) based on inspection and laboratory testing of recovered core. |
| | ***Cost –*** Low |
| Standard Index Tests | ***Description -*** Conventional aggregate industry index tests including hardness, density, abrasion resistance, soundness, slake durability used to assess issues of waste-rock utilization, trafficability and wet/dry degradation. Use of standard aggregate testing methods allows for comparison with regional quarry data. |
| | ***Cost –*** Low |
| Strength & Deformation Parameters | ***Description -*** Full stress-strain curves in uniaxial compression required, incl. acoustic emission data, longitudinal, transverse and volumetric strains under both saturated and dry conditions. Data used to evaluate Young's Modulus, Poisson's Ratio, various crack-initiation and crack-propagation parameters, various strength "thresholds" (crack initiation; cohesion loss, stable crack growth; long-term strength; peak strength, etc.). Full suite of triaxial compression testing required to evaluate appropriate strength envelopes for analysis/design purposes (Hoek-Brown, Modified Hoek-Brown, Mohr-Coulomb, etc.). Testing required on rock cores at different orientations with respect to stratigraphy in order to assess anisotropy, using sub-coring from primary core. Sonic velocity (P and S wave) measurements for dynamic modulus should be completed on fresh intact cores, parallel and perpendicular to core axis, and possibly repeated after 1 month to assess deterioration due to weathering. Brazilian Tests for tensile strength. Note also that deformation parameters will be determined from biaxial testing of core recovered at each overcoring stress-measurement location. |
| | ***Cost -*** Moderate |

**Table A.2.3 Data Collection Methods – Rock Material Properties**

| **Collection Method** | |
|---|---|
| Creep Parameters | ***Description -*** Anticipate that testing will be required in the Lindsay Formation, sufficient to confirm expectation that creep will not be a significant design/performance issue. Creep/accelerated-creep laboratory tests required on rock material from overlying shales. Collect and evaluate existing data from precedent projects in these units prior to site-specific tests. |
| | ***Cost -*** Moderate |
| Swelling/ Squeezing Tests | ***Description -*** Not anticipated to be an issue in the Lindsay Formation, but require limited testing to confirm. Laboratory testing will be required on rock materials from overlying shale formations, to identify/assess shaft stability/support issues. Collect and evaluate existing data from precedent projects in these units prior to site-specific tests. |
| | ***Cost -*** Low |
| Thermal Properties | ***Description -*** Limited testing for coefficient of linear expansion; thermal conductivity and thermal diffusivity of rock |
| | ***Cost -*** Low |

**Table A.2.4 Data Collection Methods – Rock Mass Properties**

| **Collection Method** | |
|---|---|
| Borehole Core Logging | **Description -** Continuous collection of rock core while drilling that can be logged immediately by on-site geologist for bedding plane contacts between different layers and structural features such as faults, fractures zones, smaller fractures or joints as well evidence of weathering or chemical alteration, rock quality designation (RQD) and evidence of core disking. |
| | ***Cost –*** Low – does not include costs associated with drilling and core collection |
| Borehole Geophysical Surveys | ***Description -*** Lowering geophysical tools down borehole after drilling is complete and collecting measurements pertaining to rock mass properties. The following borehole geophysical logs are useful for defining rock mass properties for geomechanical purposes:<br>**Acoustic Televiewer** – highly detailed measurement of borehole diameter obtained by timing the return reflection of an acoustic pulse of the borehole wall back to the probe; primarily used to infer fractures and there orientation, borehole diameter and borehole orientation. Successive logging can identify borehole deformation due to creep and borehole breakouts due to high rock stress;<br>**Optical Televiewer** – collects an oriented image of the borehole wall which undergoes “restoration” to correct for optical distortion and creates a “virtual core”; primarily used to indicate fracture location but also provides some lithologic information;<br>**Acoustic Velocity** – measurement of the velocity of acoustic energy (seismic waves produced by a downhole sonde) in the material adjacent to the borehole; used to infer lithology variations and fracture locations;<br>**Caliper** – mechanical measurement of borehole diameter based on the extension of 3 or 4 caliper arms. Similar |

**Table A.2.4 Data Collection Methods – Rock Mass Properties**

| **Collection Method** | |
|---|---|
| | application to acoustic televiewer re mapping creep and stress breakouts.<br>**Borehole-Radar Reflection** – records the reflected wave amplitude and transit time of high-frequency EM waves using a pair of downhole transmitting and receiving antennas; used to determine the location and dip of fractures and lithologic changes and to estimate the radial extent of such features beyond the borehole (3 to 10 m radial penetration dependent on the electrical resistivity of the rock and water surrounding the borehole);<br>**Full Waveform Seismics** – measurement of the compressional (P), shear (S) and Stoneley seismic velocities using a probe source(s) and detectors (transducers) is useful for estimation of Poisson's ratio and Young's shear and bulk modulus.<br>**Vertical Seismic Profiling** – measurement of shear and compressional seismic velocities using a surface source and borehole detectors (geophones) to calculate bulk modulus and infer general rock competence and lithology.<br>**Cross Hole Seismic Profiling (Tomographic Survey)** – measurement of shear and compressional seismic velocity of the formation between two boreholes, one of which contains sources(s) and the other detectors(s) and used to determine general rock competence (calculates bulk modulus). |
| | ***Cost -*** Moderate – some specialized equipment |
| Open-Hole Hydraulic Testing | ***Description -*** Hydraulic testing with dual (or more) packer tool on work-over rig, successive intervals tested. Provides integrated measure of bulk rock hydraulic conductivity and hence assessment of likelihood of fracturing. |
| | ***Cost -*** Moderate – relatively specialized equipment |
| Laboratory Testing of Rock Material Properties | ***Description -*** Laboratory testing of shear strength parameters of bedding plane features within DGR horizon to provide needed data for design considerations |
| | ***Cost –*** Low |

## A.3 Hydraulic Properties and State

**Table A.3.1 Data Collection Methods – Existing Hydrogeological Information**

| **Collection Method** | |
|---|---|
| Municipal Groundwater Study, Bruce & Grey Counties | ***Description -*** Mapping and assessment of groundwater resources (quantity and quality) in Grey and Bruce Counties as part of MOE-sponsored municipal groundwater studies. Identifies, characterizes and maps groundwater sources of drinking water in Bruce County based on MOE water well records, and available overburden and bedrock geology mapping |
| | ***Cost –*** Low |
| Hydraulic Information from Other Off-Site Studies | ***Description -*** Results of laboratory testing and deep borehole hydraulic testing programs and hydraulic head monitoring in Westbay completions undertaken in similar bedrock formations in Ontario and the Michigan Basin as part of other studies (i.e., UN-2 at Darlington, OHD-1 at Lakeview, MDMW-1 at Sarnia, Niagara Falls). Also inflow data from excavations and tunnels in similar bedrock formations. |
| | ***Cost –*** Low |
| Hydrogeologic Information from On-Site Studies | ***Description -*** Results of borehole drilling, hydraulic testing and monitoring completed in the overburden and shallow bedrock at the Bruce site. For example water level and hydraulic conductivity data collected from OPG intermediate depth bedrock monitoring wells US-1, US-5, US-6 and US-7 (Westbay MP completions) and US-3 and US-4 (open boreholes), including 1995 work described in AECL Report COG-95-248. |
| | ***Cost –*** Low |

**Table A.3.2 Data Collection Methods – Rock Mass Hydraulic Conductivity**

| **Collection Method** | |
|---|---|
| Single-Packer Bottom-hole Testing | ***Description -*** Hydraulic testing concurrent with drilling through the drill stem (through-the-bit) or after drill string withdrawal and insertion of a single packer on tubing |
| | ***Advantages -***<br>• Minimizes effect of borehole history, simplifies analyses<br>• Provides information quickly |
| | ***Disadvantages -***<br>• Disrupts drilling<br>• Testing decision must be made with no knowledge of what lies deeper (that may be of more interest)<br>• Presence of drilling fluid complicates testing and analyses<br>• No opportunity to develop well (reduce skin effects) |
| | ***Cost –*** Expensive; increases rig crew standby time |

**Table A.3.2 Data Collection Methods – Rock Mass Hydraulic Conductivity**

| **Collection Method** | |
|---|---|
| Open-Hole Straddle Packer Testing | ***Description -*** Hydraulic testing with dual (or more) packer tool on work-over rig, successive intervals tested. Can perform slug, DST, and/or pulse tests |
| | ***Advantages -***<br>• Can preferentially test zones of interest identified from core examination and borehole geophysical logging<br>• Drilling fluid can be purged |
| | ***Disadvantages -***<br>• Borehole history effects necessitate longer recovery/stabilization times to estimate hydraulic head<br>• Multiple intervals are left commingled for some period of time, leading to mixing of fluids<br>• Borehole stability can be an issue |
| | ***Cost –*** Moderate; relatively specialized equipment |
| Testing in Multi-level Monitoring Casings (i.e., Westbay) | ***Description -*** Testing in predefined isolated intervals |
| | ***Advantages -*** Convenient, limited equipment required |
| | ***Disadvantages -***<br>• Intervals must be selected prior to casing installation – no possibility of modification after<br>• Compliance effects more severe, reliance on multi-level seals (i.e., packers)<br>• Testing options (types) limited |
| | ***Cost -*** Low ; does not include costs associated with multi-level monitoring equipment and it's installation |
| Pumping Tests | ***Description -*** Pumping from isolated interval using bridge plugs and packers |
| | ***Advantages -***<br>• Provides properties representative of greater volume of rock than other methods<br>• Standard equipment required<br>• Single fluid (formation water) in both borehole and formation<br>• Can estimate storativity if observation well(s) nearby |
| | ***Disadvantages -***<br>• In well open to multiple intervals, multiple trips in and out of hole required to set bridge plugs, pump and packer<br>• Not practical in low-permeability media<br>• Water disposal can be an issue<br>• Hole stability can be an issue.<br>• |
| | ***Cost –*** Moderate; fairly extensive equipment required, plus manpower intensive |

**Table A.3.2 Data Collection Methods – Rock Mass Hydraulic Conductivity**

| **Collection Method** | |
|---|---|
| Laboratory Core Permeability Tests | ***Description -*** Laboratory testing of intact rock core for hydraulic conductivity under confining pressure using constant head flow tests or pressure transient pulse testing |
| | ***Advantages -***<br>• Can provide estimates of anisotropy in hydraulic properties of intact rock under controlled laboratory conditions<br>• Provides a matrix permeability for comparison to insitu field tests (assists in defining field tests that may exhibit effects of fractures) |
| | ***Disadvantages -***<br>• Unloading of rock cores can induce micro-fracturing, that may be irreversible and hence overestimate permeability<br>• Testing should be done with representative pore water chemistry |
| | ***Cost –*** Moderate, specialized equipment required |

**Table A.3.3 Data Collection Methods – Hydraulic Heads**

| **Collection Method** | |
|---|---|
| Electromagnetic Pressure Gauge (EPG) sensors | ***Description –*** A dedicated wireless pressure sensor that measures hydraulic pressures in low permeability environments that is sealed in a borehole using a dedicated packer system and low permeability cement plug. Developed and used successfully as part of the ANDRA Program |
| | ***Advantages -***<br>• Equilibrium pressure in very low permeability environments is quickly achieved (within 6-12 months);<br>• No concern over effective seals of packers on the borehole walls<br>• Demonstrated to provide the highest quality estimate of static (undisturbed) formation pressure in very low permeability formations. |
| | ***Disadvantages -***<br>• Prevents further monitoring in the section of borehole where the sensor and low cement are installed;<br>• Battery life is approximately 3 to 5 years<br>• Cannot remove sensor to recalibrate or move to another location<br>• Sensor must be within 70 m of steel casing, therefore preventing dual use of Westbay casings and EPGs in same hole |
| | ***Cost –*** Expensive; highly specialized equipment required (~$200K per installed sensor) |

**Table A.3.3 Data Collection Methods – Hydraulic Heads**

| **Collection Method** | |
|---|---|
| Pressure Monitoring in Multi-level Westbay Casings | ***Description -*** Pressure sensor(s) lowered at a selection of monitoring intervals within a multi-level system (such as the Westbay MP system) will collect continuous or point data over time in order to evaluate transient and static hydraulic heads within all of the bedrock units |
| | ***Advantages –***<br>• Readily commercially available<br>• Pressure transducers can be removed and recalibrated or redistributed to other intervals<br>• Allows for vertical interference testing and reliable long-term pressure monitoring |
| | ***Disadvantages -***<br>• Pressures within a multi-level packer system may take a longer time to equilibrate than cemented in pressure gauges isolated with packer and cement plug (i.e., EPG completion).<br>• Borehole conditions must be good, requires an effective seal between packers and borehole walls |
| | ***Cost -*** Expensive |
| Pressure or Level Monitoring in Multi-Packer Standpipe Completions | ***Description –*** Surface monitoring of water levels (via dedicated standpipes or tubing) or pressures (via signals from dedicated pressure transducers) in intervals created by a series of inflatable packers with feed-through assemblies. |
| | ***Advantages –***<br>• Packer pressures can be monitored if inflation lines extend to surface providing confidence in borehole interval seals<br>• Allows for vertical interference testing and reliable long-term pressure monitoring |
| | ***Disadvantages -***<br>• Requires larger diameter boreholes.<br>• Number of intervals is limited by borehole diameter, Typically limited to maximum of 4 to 6 intervals per borehole<br>• Density profile of water column in standpipe or tubing is required to convert water levels to hydraulic heads |
| | ***Cost -*** Expensive |

**Table A.3.4 Data Collection Methods – Total and Effective Rock Matrix Porosities**

| **Collection Method** | |
|---|---|
| Conventional Oven Drying Method | ***Description –*** Total or 'water-content' porosity is determined from the difference in weight between an oven-dried and water-saturated rock specimen. |
| | ***Advantages –*** Low cost |

| **Table A.3.4 Data Collection Methods – Total and Effective Rock Matrix Porosities** | |
|---|---|
| **Collection Method** | |
| | ***Disadvantages -*** From experience at Mont Teri this porosity estimate will likely overestimate both the solute diffusion and the geochemical porosities (see Pearson, 1999, What is the porosity of a mudrock?) |
| | ***Cost -*** Low |
| Mercury –Injection Porosimetry Methods | **Description** - Based on the intrusion of mercury into a porous structure under stringently controlled pressures. Since mercury does not wet most substances and will not spontaneously penetrate pores by capillary action, it must be forced into the pores by the application of external pressure. The required pressure is inversely proportional to the size of the pores, only slight pressure being required to intrude mercury into large macropores, whereas much greater pressures are required to force mercury into micropores. With accurate pressure measurements, the resulting pore size data is very accurate. Measures the pore size distribution and allows estimation of the capillary pressure curve and ultimately enables the $N_2$/brine relative permeability curves to be developed. This is a destructive technique, therefore further testing on sample specimen is not permitted. |
| | ***Advantages –*** Proven method for measuring pore-throat sizes and variability |
| | ***Disadvantages –***<br>• Very long injection periods must be anticipated in order to allow Hg to penetrate to relatively high saturations and therefore measure a significant number of pore throats.<br>• Tests may not access smaller pores.<br>• Concern expressed by Horseman of BGS that Hg injection causes damage to small pores. |
| | ***Cost -*** Low-moderate (more costly than the other porosity determination methods, but also provides pore-size distribution information) |
| Gas Expansion and Boyle's Law Method | ***Description –*** By filling the pores of a rock core sample with an ideal gas such as He, and measuring the pressure of the gas, the volume (therefore porosity) can be measured by applying Boyle's Law. |
| | ***Cost –*** Low; during WIPP program estimate $30.00 per sample. |
| Diffusion-Cell Testing | ***Description –*** An estimate of the effective or solute diffusion porosity is obtained from through-diffusion or out-diffusion tests in the laboratory. |
| | ***Advantages –***Tests likely to give a meaningful estimate of porosity for diffusion and geochemical modeling |
| | ***Disadvantages –*** Relatively expensive |
| | ***Cost –*** Expensive |
| $H_2O$ and $N_2$ – Adsorption – Desorption Isotherm | ***Description –*** Measurement of $H_2O$ and $N_2$ – adsorption – desorption isotherms is used to estimate physical porosity |
| | ***Cost –*** Moderate, |

**Table A.3.5 Data Collection Methods – Fracture/Fault Hydraulic Properties**

| Collection Method | |
|---|---|
| Single-Packer Bottom- hole Testing | ***Description -*** See discussion in Table A.3.2 for details. |
| Open-Hole Straddle Packer Testing | ***Description -*** See discussion in Table A.3.2 for details. |
| Testing in Multi-level Monitoring Casings (i.e., Westbay) | ***Description -*** See discussion in Table A.3.2 for details. |
| Pumping Tests | ***Description -*** See discussion in Table A.3.2 for details. |
| FLUTe™ Hydraulic Conductivity (FHC) Profiler | ***Description -*** The rate of descent while installing a blank FLUTe™ liner can be measured and recorded electronically which can then be used to calculate the rate at which water is displaced into the rock formation |
| | ***Advantages -***<br>• Continuous hydraulic conductivity profile in a section of borehole that can then be tested more precisely using conventional straddle packer testing equipment |
| | ***Disadvantages -***<br>• Not effective in low permeability environments<br>• Borehole water is displaced into the rock fractures/matrix, therefore chemical alteration may be a concern |
| | ***Cost –*** Moderate |

**Table A.3.6 Data Collection Methods – Gas-Brine Flow Properties**

| Collection Method | |
|---|---|
| In-Situ Gas-Entry Tests | ***Description -*** Below or between packers, replace drilling fluid with gas while maintaining constant pressure. Then increase gas pressure until pressure rise deviates from unit-slope line, indicating end of wellbore storage period and gas entry into formation. |
| | ***Advantages -*** Provides measurement of gas-entry pressure |
| | ***Disadvantages -*** Possible borehole skin and fluid incompatibilities may lead to questionable data |
| | ***Cost –*** Moderate — relatively specialized equipment |
| Laboratory Petrophysical Testing | ***Description -*** Single phase flow tests (absolute permeability) followed by gas breakthrough testing on core samples. Standard techniques used in oilfield analyses. |
| | ***Advantages -*** Widely available, well understood tests for porosity and permeability. |
| | ***Disadvantages -*** Laboratories may not be equipped to perform tests on very low permeability materials. |
| | ***Cost –*** Low to Moderate |

**Table A.3.7 Data Collection Methods – Groundwater Densities**

| **Collection Method** | |
|---|---|
| Laboratory Analysis of Groundwater/ Porewater | ***Description -*** Laboratory measurements of fluid weight or calculated from measured total dissolved solids. |
| | ***Cost –*** Low |

## A.4 Diffusion and Sorption Properties

**Table A.4.1 and A.4.2 Data Collection Methods – Effective Diffusion Coefficients and Effective Diffusion Porosities**

| **Collection Method** | |
|---|---|
| Free-water Diffusion Coefficients | ***Description –*** Free-water diffusion coefficients are available in the literature at selected temperatures and in dilute aqueous solutions. Values at other temperatures and in saline solutions can be calculated using relationship principally dependent on water viscosity. |
| | ***Cost –*** Low |
| "In Diffusion" Laboratory Tests | ***Description -*** The "in diffusion" test allows the radionuclide to diffuse from a central reservoir or well into the core "doughnut" surrounding it. After a certain time the experiment is ended and the diffusion profile in the core is measured. This technique is used for more strongly sorbing radionuclides. Combined with information of the concentration evolution in the reservoir, both the effective diffusion coefficient and the rock capacity factor can be derived for the radionuclide employed. Without the reservoir information, only an apparent diffusion coefficient can be extracted from the profile. |
| | ***Advantages -*** Suitable for strongly sorbing radionuclides, e.g., $^{60}$Co, $^{90}$Sr and other hydrolysable cations |
| | ***Disadvantages -*** Long experimental times required, e.g., one year. Small core sample size may be a disadvantage if sample is smaller than representative elementary volume (REV). |
| | ***Cost –*** Moderate |
| "Through-Diffusion" Laboratory Tests | ***Description -*** A section of core is cut in cross section to produce a rock wafer which is then placed in a diffusion cell with two reservoirs on either end, each maintained at the same pressure. One reservoir is filled with a known concentration tracer solution and the other reservoir is filled with a fluid of similar ionic strength but lacking the tracer. The concentrations in both reservoirs are measured over time and the rate of diffusion is measured. This method provides an effective diffusion coefficient and effective diffusion porosity as well as the retardation factors for weakly-sorbing radionuclides. |
| | ***Advantages -*** Suitable for weakly sorbing radionuclides, e.g., I, Cl and Tc and other anions |
| | ***Disadvantages –*** Small core sample size may be a disadvantage if sample is smaller than representative elementary volume (REV). |
| | ***Cost –*** Moderate |
| In-Situ Diffusion Tests | ***Description -*** Developed at ANDRA's Bure site in France using deep drilling methods from ground surface, a pilot hole is drilled at the bottom of the borehole into which a radial diffusion experiment is performed (in the intact rock). After a sufficient time has elapsed, the reservoir is overcored and the resulting rock specimen is sampled and the diffusion profile measured. Combined with information of the concentration evolution in the reservoir, both the effective diffusion coefficient and the rock capacity factor can be derived for the radionuclide employed. Without the reservoir information, only an apparent diffusion coefficient can be extracted from the profile. |
| | ***Advantages -*** In-situ measurement are performed under more representative stress and chemical conditions. Encouraging results from Mont Terri and ANDRA experiments. |

**Table A.4.1 and A.4.2 Data Collection Methods – Effective Diffusion Coefficients and Effective Diffusion Porosities**

| Collection Method | |
|---|---|
| | ***Disadvantages -*** High cost and potential interferences by drilling. Although theory is well established, methods for conducting tests at large borehole depth need standardization and international acceptance. Does not necessarily provide a better estimate than laboratory values. |
| | ***Cost -*** Expensive – due to specialized equipment development, time consuming procedures and potential for problems working at large depths |
| Laboratory Formation Factor | ***Description:*** Electrical resistivity measurements are performed in the laboratory on core plugs. The constant of proportionality relating the resistivity of the core plug and its saturating fluid is called formation factor (>=1). Performed after matrix porosity determination. Matrix tortuosity can be calculated as the reciprocal of the product of formation factor and matrix porosity. The effective diffusion coefficient of the solute in the matrix can be calculated as the product of tortuosity and solute free-water diffusion coefficient. |
| | ***Advantages -*** The advantage of this method is that formation factor determinations are inexpensive allowing determination of diffusion properties at multiple locations and lithologies at relatively low cost. |
| | ***Disadvantages –*** The correlations between electrical resistivity and tortuosity are not well established, and hence the estimates of effective diffusion coefficients is only approximate. |
| | ***Cost –*** Low |

**Table A.4.3 Data Collection Methods – Sorption Parameters**

| Collection Method | |
|---|---|
| Laboratory Batch Tests | ***Description -*** Add a known amount of solute to a known amount of rock and allow concentration to come to equilibrium. Measuring the equilibrium concentration will allow determination of amount of solute sorbed onto rock. Varying the initial concentration will allow a plot of equilibrium concentration vs. mass adsorbed which can be fit to a model to determine $K_d$ and allow any concentration dependence to be determined. These results can be compared with diffusion testing results. |
| | ***Advantages -*** Obtains first approximations of radionuclide retention that will allow comparison with $K_d$ values from retardation factors. |
| | ***Disadvantages -*** Requires robust conceptual model of pore-water geochemistry that will allow appropriate experiments to be conducted with specified amounts of sorbent of specified surface area and specified anion competitors. |
| | ***Cost -*** Low in themselves, but the geochemical modeling to set up the tests will be considerable |

**Table A.4.3 Data Collection Methods – Sorption Parameters**

| **Collection Method** | |
|---|---|
| Accelerator Mass Spectrometry (AMS) | ***Description -*** An ultra-sensitive technique for measuring isotopic ratios of the abundant to rare isotopes of beryllium, carbon, aluminum, chlorine, iodine etc.. For the Bruce site, the concentration of $^{129}$I and $^{36}$Cl in different solid phases is essential for characterizing radioiodine and radiochlorine partitioning, for assessing anion ages for these fluids in the Ordovician shale and limestone, and for assessing the mobility of these radionuclides in the geosphere. Allows the use of a smaller sample, provides faster analysis times and greater sensitivity than other mass spectrometry or decay counting techniques. Furthermore, extraction of the sorbed and crystallographic fractions by pyrolosis of the solid phases is essential to establish the immobile phase of these radionuclides. Proposed to be conducted on a relatively small number of samples (each sample requires 1-10mg of iodine or chlorine). |
| | ***Advantages -*** Extreme sensitivity for $^{129}$I and $^{36}$Cl |
| | ***Disadvantages -*** Mass required may be limiting in some cases |
| | ***Cost –*** Expensive |
| Organic Carbon Determination | ***Description -*** Measures the amount of organic matter in a rock sample will be analysed for total kerogen and bitumen and for their elemental compositions in terms of C, O, N, S, and H. |
| | ***Cost –*** Low |
| Cation Exchange Capacity (CEC) | ***Description -*** Measures the ability of the rock to adsorb and exchange cations and therefore provides an indication of how much potential there is for sorption of cations. Important for reconstructing geochemical model of groundwater evolution. Will also provide cation occupancy data, i.e., exchangeable cations. |
| | ***Cost –*** Moderate |
| Adsorption Isotherms | ***Description –*** Measurement of ion-exchange isotherms involving H$^+$ exchange with major cations. Preferred over measurement of selectivity coefficients. Important for reconstructing porewater chemistries from limited porewater characterization data and in part will contribute to determination of sorption parameters. |
| | ***Cost –*** Expensive |

## A.5 Groundwater/Porewater Characterization

**Table A.5.1 Data Collection Methods – Existing Hydrogeochemical Information**

| **Collection Method** | |
|---|---|
| Municipal Groundwater Study, Bruce & Grey Counties | ***Description -*** Mapping and assessment of groundwater resources (quality) in Grey and Bruce Counties as part of MOE-sponsored municipal groundwater studies. Identifies, characterizes and maps groundwater quality in Bruce County based on MOE water well records, and available overburden and bedrock geology mapping |
| | ***Cost –*** Low |
| Hydrogeochemcial Information from Other Off-Site Studies | ***Description -*** Results of groundwater sampling and laboratory analytical testing of deep boreholes and monitoring in Westbay completions undertaken in similar bedrock formations in Ontario and the Michigan Basin as part of other studies (i.e., UN-2 at Darlington, OHD-1 at Lakeview, MDMW-1 at Sarnia, Niagara Falls). |
| | ***Cost –*** Low |
| Hydrogeochemical Information from On-Site Studies | ***Description -*** Results of groundwater sampling and laboratory analytical testing of monitoring wells completed in the overburden and shallow bedrock at the Bruce site. For example, hydrogeochemcial and isotopic data collected from OPG intermediate depth bedrock monitoring wells US-1, US-5, US-6 and US-7 (Westbay MP completions), including 1995 work described in AECL Report COG-95-248. |
| | ***Cost –*** Low |

**Table A.5.2 and A.5.3 Data Collection Methods – Major Ion, Trace Element and Isotope Chemistry**

| **Collection Method** | |
|---|---|
| Groundwater Sampling During Drilling | ***Description -*** Groundwater samples can be collected during the drilling process by stopping drilling and pumping from drill rods via submersible pumps, with or without single packers installed through the drill bit or on the bottom of the drill rods. This method of groundwater sampling is preferred for the Silurian and Devonian bedrock where the higher bedrock permeabilities will allow recovery of drill fluids from permeable horizons or zones of lost or reduced drill fluid circulation. Such opportunistic sampling may provide the best chance of obtaining representative groundwater samples from the deeper parts of the Devonian and Silurian bedrock that may have lower hydraulic heads and hence may be subject to extensive drill fluid and cross-formational fluid contamination during drilling and while the hole stays open. |
| | ***Cost*** - Expensive |
| Temporary Borehole Sealing using Bridge Plugs or PIPs | ***Description –*** Bridge plugs or production-injection packers (PIPs) can be remotely set at different depths in a borehole to prevent the cross connection of fluids (leading to cross contamination of formation waters) after a section of borehole is completed drilling. Bridge plugs and PIPs provide excellent seals and can seal against high pressure or gas producing zones |
| | ***Cost –*** Expensive |

| **Table A.5.2 and A.5.3 Data Collection Methods – Major Ion, Trace Element and Isotope Chemistry** | |
|---|---|
| **Collection Method** | |
| Tracers for Drilling Operations | ***Description -*** A Na Fluorescein solution can be added to all drilling fluids to allow rapid laboratory and field identification of drill fluid contamination of rock samples from which the pore-water is to be extracted and of groundwater samples to be collected from Westbay multilevel installations or during pumping tests of open boreholes during drilling. Other fluorescent dyes may also be used as drill water tracers. Furthermore as the source of drilling fluid will be Lake Huron water opposite the Bruce site with elevated tritium concentration, tritium will also be used as a drill water tracer. However because of the elevated tritium content in atmosphere at the Bruce site, special care will need to be taken to ensure that deep groundwater samples are not contaminated with atmospheric tritium. Tritium requires laboratory analysis of drill water samples to determine potential drill water contamination levels. |
| | ***Cost –*** Low to Moderate |
| Groundwater Sampling from Multilevel System | ***Description -*** Collecting groundwater samples from depth discrete monitoring intervals pre-determined by the configuration of the multilevel monitoring system (i.e., Westbay system). Sampling tool is lowered to selected port and attached to sampling valve which allows groundwater to flow into a sealed sampling container that is raised to surface for analyses (water flows based on pressure difference between sample container and formation). Samples can be collected at in-situ pressures, therefore minimizing de-gassing and subsequent changes in chemistry. Water between Westbay casing and the borehole wall must be purged prior to sample collection, therefore low K borehole intervals will present problems for sample collection. |
| | ***Cost -*** Low (same equipment used for multiple sampling ports), however does not include costs associated with multilevel monitoring equipment and its installation |
| Preservation of Rock Cores (Teflon-lined bags flushed with $N_2$ gas) | ***Description -*** Cores are preserved in Teflon-lined aluminized bags that are then flushed with $N_2$ gas, vacuum-extracted, and then heat sealed in the field. |
| | ***Advantages –*** Minimizes oxidation of analytes. |
| | ***Disadvantages -*** Potential for loss of dissolved gases. |
| | ***Cost –*** Moderate |
| Preservation of Rock Cores (wrapping with plastic, aluminum foil and wax) | ***Description -*** Cores are preserved by immediately wrapping a section in two layers of plastic wrap, followed by two layers of aluminum foil followed by a 1-cm thick layer of wax. |
| | ***Advantages –*** Minimizes loss of dissolved gases, oxidation of analytes, evaporation of pore fluids |
| | ***Disadvantages –*** Labour intensive, potential loss of seal over long-term (> several months) |
| | ***Cost –*** Low |
| Preservation of Rock Cores in Sealed Cylinders | ***Description -*** Cores are preserved by placing in sealed cylinder, flushing the cylinder with nitrogen or argon gas, imposed a minor pressure differential on the cylinder to allow detection of any cylinder leakage. |
| | ***Advantages –*** Very effective in reducing long-term (> several months) loss of dissolved gases, oxidation of analytes, evaporation of pore fluids |
| | ***Disadvantages –*** Labour intensive |

**Table A.5.2 and A.5.3 Data Collection Methods – Major Ion, Trace Element and Isotope Chemistry**

| **Collection Method** | |
|---|---|
| | ***Cost –*** Expensive |
| Pore-fluid Extraction by Centrifuge Extraction | ***Description -*** Core sections can be centrifuged to allow drainage of porewaters or their displacement with CFC-113 or other suitable inert, dense liquid. Rock is required to have water content > 4% and well-interconnected porosity (i.e., high effective porosity), otherwise it will be necessary to crush the rock first. |
| | ***Advantages -***<br>• Provides a high quality water sample that is both representative of the chemical and isotopic composition of the *in-situ* porewater. 25 years of experience in UK sedimentary rocks with this technique.<br>• Drainage centrifugation is non-destructive and would allow core samples to be used for additional testing. |
| | ***Disadvantages -***<br>• Labor intensive. The method will not be suitable for highly indurated or low moisture content samples.<br>• Control of redox conditions is more difficult compared to mechanical porewater squeezing and crushing/leaching techniques.<br>• Requires well interconnected porosity to work without crushing first.<br>• Displacement centrifugation is destructive. |
| | ***Cost –*** Moderate |
| Pore-fluid Extraction by Crushing Core and Aqueous Leaching | ***Description -*** Crushed core material is centrifuged in the presence of de-ionized water, filtered then preserved for analysis |
| | ***Advantages -*** In cases in which the rock is of low porosity and strongly lithified, this may be the only approach possible to extract porewaters. If there are a series of samples taken from contiguous depths ranges (i.e., >10 m) then data processing techniques are available to allow rock water interactions to be removed and good estimates of the major ion chemistry can be obtained (Na, K, Ca, Mg, $HCO_3^-$, Cl, $SO_4$) with possibilities of mapping down hole porewater concentration profiles. In the worst case a good estimate of the chloride content of the porewater will be obtained |
| | ***Disadvantages -***<br>• Rock-water interactions – dissolution of fresh mineral surfaces, dissolution of fluid inclusions – can make the data difficult to interpret. Information on the stable isotopic composition of the porewater will not be able to be measured.<br>Relies on crushing of core; therefore a destructive technique that does not allow further testing of specimen. |
| | ***Cost –*** Low |
| Pore-fluid Extraction by High-Pressure Squeezing | ***Description -*** For argillaceous material with a moisture content > 4% and not excessively stiff, porewater can be obtained from the rock core sample by squeezing the core in a mechanical squeezing rig for between approximately 7 and 21 days, until sufficient porewater is collected to enable full chemical characterization. The extracted porewater may either be treated as a single bulk sample, or, assuming sufficient sample can be collected from each core, as a series of sequential fractions which may be used to study porewater fractionation. If the core material is redox sensitive (presence of pyrite), it will be necessary to use a specially designed nitrogen-filled |

**Table A.5.2 and A.5.3 Data Collection Methods – Major Ion, Trace Element and Isotope Chemistry**

| Collection Method | |
|---|---|
| | chamber. If moisture content < 4%, re-hydrating the core material (clay) with deionised water and then squeezing the resulting mixture has been shown to provide estimates for the true in-situ composition however information on trace elements and isotopic composition was not obtained. |
| | ***Advantages -*** Where the moisture content is very low, this may be the best method of obtaining a representative sample of *in-situ* porewater and being able to determine the stable oxygen and hydrogen isotopic data. A new high duty squeezing cell will become available in September 2005 at BGS. This heavy duty squeezer will have a similar design to the standard system but will provide squeezing pressures up to 350 MPa, more than three times as much as the standard system allowing the extraction of pore-waters from very low moisture content (3-4 %) samples although this will be dependant on the their mineralogy and structure. |
| | ***Disadvantages -*** The method may not be able to extract porewater from highly indurated or low moisture content samples |
| | ***Cost –*** Expensive |
| Diffusive Exchange | ***Description –*** Based upon the van der Kamp method for clay tills. A test water of known isotopic ($\delta^{18}O$ and $\delta^{2}H$) concentration is brought into contact with a small quantities of rock in a water-tight tin-plate container and allowed to equilibrate. After 10-20 days the test water is analyzed and the change in $\delta^{18}O$ and $\delta^{2}H$ reported |
| | ***Advantages –*** Good estimate of stable O and H isotopes within 10-20 days |
| | ***Disadvantages –*** May require some correction for $\delta^{2}H$ due to the addition of NaCl to minimize vapor loss and isotope fractionation |
| | ***Cost –*** Low |
| High-Pressure Fluid Displacement | ***Description*** – Using triaxial confining cell, an immiscible liquid like CFC-113, other suitable inert, dense liquid, or tracer-tagged synthetic pore-water is driven through the rock sample and collected in the reservoir beneath |
| | ***Advantages –*** By using an inert dense liquid it may be able to minimize dissolution of minerals during extraction |
| | ***Disadvantages –*** Displacing liquid can be toxic and the core cannot be used for additional testing |
| | ***Cost –*** Low-Moderate |

**Table A.5.4 Data Collection Methods – Dissolved Gases**

| Collection Method | |
|---|---|
| Downhole Sampling Using Pressurized Copper Tubing | ***Description –*** 9.4mm (3/8”) polyethylene tubing with a 1.3 m long 9.4mm (3/8”) OD copper tube fitted with a check valve is lowered into the borehole to the desired depth and pressurized using a hand pump or a compressor. The sample is raised to surface and the copper tube is clamped at each end and transported to the laboratory for analysis. |
| | ***Advantages -***<br>• Easy operation |

**Table A.5.4 Data Collection Methods – Dissolved Gases**

| Collection Method | |
|---|---|
| | - Sample can be collected in an open borehole or in a Westbay casing<br>- Proven techniques by AECL and INTERA |
| | ***Disadvantages -***<br>- Lowering equipment with clamped joints into the borehole/multilevel system has opportunity to disconnect<br>- Allowing formation water to enter into Westbay casing will "cross contaminate" over the length of the casing and therefore could pose an issue for future sampling from other zones |
| | ***Cost* –** Low |
| Groundwater Sampling during Drilling and from Westbay System | ***Description -*** See discussion in Table A.5.2 and A.5.3 for details. |
| Extraction of Dissolved Gases in Porewater by Sequential Heating (Vacuum/Azeotropic Distillation) | ***Description -*** Sub sample of core is sealed within an stainless steel high-vacuum container that is evacuated to $10^{-5}$ torr and 25˚C and then heated sequentially from 30 to 500˚C with the concentration of helium extracted being measured at each heating step. Procedure previously successful on clay rich aquitards from Saskatchewan for He, Ne, Ar, and $N_2$ |
| | ***Cost* –** Moderate |

**Table A.5.5 Data Collection Methods – Redox States**

| Collection Method | |
|---|---|
| Measurement of Redox Conditions | ***Description -*** Measurements of Pt electrode potential (Eh), methane and hydrogen sulphide gases, identification of sulphide minerals and sedimentary organic carbon will be used to define the redox environment present within the porewaters. |
| | ***Advantages -*** Simple and inexpensive means of characterizing the general redox environment |
| | ***Disadvantages -*** Not amenable to quantitative definition of redox potential because of lack of sufficient quantities of electroactive pairs |
| | ***Cost* –** Low |
| X-ray Absorption Near Edge Spectroscopy (XANES) | ***Description -*** Using the Canadian Light Source in Saskatoon, this technique will allow the determination of formal oxidation states and complexes of many elements, in particular I and Cl. It is proposed to use the XANES spectroscopic technique on well characterized rock samples containing sufficient quantities of I or Cl (tens of ppm) to obtain information regarding the formal oxidation states of these anions and associated complexes. The |

**Table A.5.5 Data Collection Methods – Redox States**

| **Collection Method** | |
|---|---|
| | capability to conduct these measurements on rock samples is valuable since both the oxidation state and species of iodine can directly affect the degree to which iodine is sorbed to mineral and organic surfaces and thus retarded, thereby influencing the “conservative” nature of dissolved iodide ($I^-$) or iodate ($IO_3^-$) in groundwater systems. |
| | ***Advantages -*** The capability to conduct these measurements on rock samples is invaluable since both the oxidation state and species of iodine can directly affect the degree to which iodine is sorbed to mineral and organic surfaces and thus retarded, thereby influencing the “conservative” nature of dissolved iodide ($I^-$) or iodate ($IO_3^-$) in groundwater systems. |
| | ***Disadvantages -*** Innovative and therefore subject to peer-review criticism |
| | ***Cost –*** Expensive |

**Table A.5.6 Data Collection Methods – Water Physical Properties**

| **Collection Method** | |
|---|---|
| Borehole Geophysical Testing (Porosity, Salinity) | ***Description -***<br>**EM-Induction (Resistivity)** – records the electrical conductivity (resistivity) of the rocks and water surrounding the borehole which are effected by salinity of the water; helps to estimate sorption parameters;<br>**Fluid Resistivity** – measures the electrical resistivity (which is related to the dissolved solids concentration, therefore salinity) of the water in a borehole; helps to estimate sorption parameters;<br>**Temperature** – direct measurement of borehole fluid temperature to within 0.001˚C which helps to estimate advection and diffusion rates; |
| | ***Cost -*** Moderate – specialized equipment |
| Downhole Measurements in Westbay System | ***Description -*** Measurement of in-situ temperature and pressure at time of groundwater sampling using the sampling probe provided with Westbay system |
| | ***Cost –*** Low |
| Laboratory Analysis on Groundwater / Porewater Samples | ***Description -*** Laboratory measurements of fluid density (comparing to unit weight of pure distilled water) and dynamic viscosity (measuring time for a known volume of fluid to flow through a known diameter capillary tube). Calculations of density from major ion analyses. |
| | ***Cost –*** Low |

## A.6 Seismicity

**Table A.6.1 Data Collection Methods – Map Significant Local Faults**

| **Collection Method** | |
|---|---|
| Map Faults within 1 km of DGR | Description - See Table A.1.5 (Structural Framework) |
| | Cost - Low to Expensive |

**Table A.6.2 Data Collection Methods – Local Seismographic Monitoring**

| **Collection Method** | |
|---|---|
| Seismographic Stations | ***Description -*** Add 3 new seismographic stations within 50 km of Bruce. POLARIS type (www.polarisnet.ca) stations in use in Southern Ontario would be ideal for this purpose, and could be sited at locations having AC power and communications (internet) to reduce costs. |
| | ***Cost -*** 200K for installation, $6K annual operating costs, $10K annual processing costs |