ONTARIO POWER GENERATION’S
PROPOSED DEEP GEOLOGIC REPOSITORY
FOR LOW AND INTERMEDIATE LEVEL
RADIOACTIVE WASTE
BRUCE SITE, ONTARIO, CANADA

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In Fall 2006, site-specific geoscientific studies were initiated at the Bruce nuclear site, located approximately 225 km northwest of Toronto on the eastern shore of Lake Huron, by Ontario Power Generation (OPG). The purpose of these studies is to assess the suitability of the argillaceous Paleozoic sedimentary bedrock underlying the site for development of a proposed Deep Geologic Repository (DGR) for Low and Intermediate Level Radioactive waste (L&ILW).

The initiation of the site characterization studies represented the culmination of 4 years of work that, in part, established a geoscientific consensus on geologic attributes of the Bruce site favorable for the long-term isolation and containment of OPG’s operational L&ILW. This work included the application of the OECD/NEA FEPFAT, to identify, categorize and evaluate site characteristics relevant to long-term repository performance. The Bruce site (10 km²) is situated on the eastern flank of the Michigan Basin, an intra-cratonic sedimentary basin measuring 500 to 600 km in diameter. Within Ontario, the sedimentary sequence is comprised of near-horizontally bedded, weakly deformed shale, carbonate, sandstone and evaporate formations of variable thickness, Cambrian to Devonian age (354 to 543 Ma). Beneath Bruce site this sedimentary pile is ca. 850 m thick.

Through a process of community consultation which included feasibility studies for site-specific surface and sub-surface L&ILW repository designs and an Independent Impact Assessment Study of the alternative management concepts, the local community selected the DGR concept in 2005. This concept, depicted in Figure 1, envisions the DGR excavated at a depth of 660-m within the Cobourg Formation, an Ordovician argillaceous limestone, over lain by ca. 200 m of argillaceous sediments.

A key component of the DGR safety concept relates to the geometric distribution of physical bedrock properties and the apparent stability of the far-field to isolate the L&ILW for time periods relevant to demonstrating repository performance. At repository depth, the ‘layer cake’ Ordovician formations that host and enclose the repository are i) laterally continuous and predictable in occurrence for 10 to 100’s of

Figure 1: Schematic of Ontario Power Generation’s Proposed Bruce site Deep Geologic Repository.
kms, ii) possess extremely low rock mass permeabilities (< 19 m²) and effective diffusion coefficients of $10^{12}$ m² sec⁻¹, iii) contain brine pore fluids with total dissolved solids exceeding 200 gm l⁻¹, vi) yield formation-distinct isotopic pore fluid compositions ($^2$H, $^{18}$O, $^{86}$Sr/$^{87}$Sr), and v) historically have not been found to contain commercially viable economic resources. Seismically, the region in which Bruce site is located is comparable to that of the crystalline Canadian Shield.

Of particular interest is the resilience of these Paleozoic sediments and the deep seated groundwater flow domains to external perturbations. Such perturbations, for example, include the nine glacial episodes that affected the North American continent during the latter half of the Pleistocene epoch. During these glacial cycles boreal, peri-glacial (i.e. permafrost), near temperate ice-sheet cover (ca. 1700 m) and post-glacial lakes re-occurred over Bruce site. Such marked transient changes in surface boundary conditions do not appear to have influenced cross-formational groundwater migration or redox front penetration to the repository horizon and, most importantly, the preservation of a diffusion dominant solute transport regime at the selected repository horizon.

The first phase of a three phase 5-year program of geoscientific research and investigation designed to test the above conceptual understanding and explore past and future flow system evolution within the Paleozoic sediments is underway. Phase I field activities are to include the completion of 20 line kms of 2-dimensional seismic reflection surveys and coring of 2 deep boreholes (ca. 850 m) at a single location. These latter two boreholes, the first of 6, have been planned to allow dedicated investigation of the Silurian (ca. 300 m) and Ordovician to Cambrian (ca. 400 m) sediments. Significant effort within the work program is devoted to the characterization of the elemental, isotopic and noble gas composition of formational pore fluids. Subsequent to drilling, geophysical logs and straddle packer hydraulic testing will be completed prior to the installation of a retrievable Westbay multi-level casing system for long-term background hydraulic head and hydrogeochemical monitoring. The development of the site characterization work program and on-going oversight of the DGR investigation has significantly benefited from co-operation and shared experience with ANDRA and NAGRA.

While the field and laboratory studies represent a key component of a planned Geosynthesis, additional work at the regional scale has been undertaken in parallel. Among other aspects, this work program is intent on developing a constrained 3-dimensional Descriptive Conceptual Model (DSM) of a sub-sedimentary basin flow system (scale ca. 20,000 km2). This DSM will define the basin watersheds, topography, structural geology, hydrostratigraphy, and distribution of formation-specific physical and chemical hydrogeologic properties. This work will be supported through the application of the University of Toronto Glacial System Model to render possible glacial boundary conditions that repeatedly changed the landscape.

Phase I Bruce site investigation and Geosynthesis activities are schedule for completion in summer 2008. This paper will present an overview of the DGR concept and an update on Bruce site geoscientific work program progress.
DESIGN AND REALISATION
OF THE PRACLAY EXPERIMENTAL
GALLERY AT THE HADES URF

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SUMMARY
The PRACLAY demonstration & confirmation experiments contribute to the Belgian research, development
and demonstration programme to assess the safety and feasibility of geological disposal of radioactive waste
in Boom Clay. Within this programme, the large scale PRACLAY heater experiment aims to verify that
Boom Clay is suitable to host heat emitting radioactive waste. The experiment will study the large scale
 thermo-hydro-mechanical and chemical response of the Boom Clay to the excavation of a disposal gallery
and to a large scale thermal load. For this purpose, a blind gallery about 45 m long will be excavated using a
tunnelling machine, the diameter will be 2.5 m. The design needs to meet very specific requirements related
to the PRACLAY experiment. The construction of the gallery will allow optimising the tunnelling tech-
nique, to simulate a stop of the excavation progress due to technical problems, and to further characterise the
hydro-mechanical behaviour of Boom Clay. The present paper will detail the design and realisation of the
dedicated gallery. The results of the instrumentation programme (mine-by test) will be discussed.

THE PRACLAY GALLERY
The PRACLAY gallery is a horizontal drift of about 45 m long, perpendicular to the connecting gallery.
Owing to this configuration, the excavation of the PRACLAY gallery should provide information
concerning the anisotropy in the horizontal plane of Boom Clay properties and the in-situ stress stress state.
Moreover, direct observation of the clay around the connecting gallery is possible during gallery
construction, providing a unique opportunity to further characterise the EDZ and sealing phenomena
around the connecting gallery. Figure 1 shows the lay-out of the gallery.

Before the PRACLAY gallery can be constructed, a local reinforcement of the connecting gallery is
necessary. A steel reinforcement structure with an internal diameter of 3.5 m will be installed at the

![Diagram of PRACLAY gallery and lay-out](image)

Figure 1: Lay-out of the PRACLAY gallery.
crossing of the two galleries. Due to the limited capacity of the access shaft, the reinforcement structure is composed of 11 cast steel segments that will be bolted together on site. Once this structure is properly installed, the tunnel opening can be realised through the lining of the connecting gallery.

Afterwards, the tunnelling shield will be assembled inside the reinforcement structure. Therefore, no starting chamber is foreseen. An open face shield will be used; the clay face will be excavated by means of a roadheader. To move forward, the shield is equipped with hydraulic jacks that push against the previously installed lining (except during the start-up phase).

The lining of the PRACLAY gallery consists of unbolted, unreinforced concrete segments (compressive strength C80/95), having an internal diameter of 1.9 m for an external diameter of 2.5 m. The wedge-block technique is used; this implies that the lining is expanded against the excavated tunnel wall, limiting convergence of the clay just behind the tunnelling shield. Another measure taken to limit the disturbance of the host rock is imposing a minimal progression rate of 2m/24h (excavated and lined), at this rate delayed convergence is no longer significant.

In total, 81 rings are envisaged and each ring is 0.5 m wide. After placing 79 rings, a stop test will realised to simulate a stop of the tunnelling machine in case of technical problems and to assess the consequences. The tunnelling progress will be stopped and the face will be stabilised; the convergence of the clay around the shield is monitored. About one week later, an attempt will be made to overcome the friction between the shield and the converged clay around it. If successful, the excavation will restart for 2 additional rings.

Unlike most underground galleries, the PRACLAY gallery is not only designed to withstand the pressure from the surrounding rock mass. The temperature increase during the heater test (up to ~95°C at the lining intrados) imposes an additional loading of the lining. In order to allow some thermal dilation of the lining and keep stresses below an acceptable level, compressive materials will be introduced between the lining segments at various locations. To this end, material testing and selection was carried out. Several materials will be used: polypropylene, silicone rubber, and stainless steel foam panels.

At the end of the works, the tunnelling shield will remain in place; all recoverable components will be removed. The final face will be given a hemi-spherical shape and a concrete end plug will be installed.

SCIENTIFIC PROGRAMME
In the frame of the PRACLAY heater experiment, an extensive instrumentation programme has been developed. Measured parameters include pore water pressure, total stress, displacements, temperature, hydraulic conductivity, pore water chemistry and seismic properties of the rock. The majority of the sensors monitoring the host rock were already installed in boreholes drilled from the connecting gallery. Consequently, they are already available during the construction of the gallery and they will register the HM response of the Boom Clay during the excavation.

The crossing of the two galleries will be instrumented as well, providing insight in the complex stress redistribution that will occur at that location. Furthermore, an important part of the lining rings of the PRACLAY gallery will be instrumented; both short and long term evolution of the interaction between the host rock and the lining will be monitored. Finally, a systematic observation of the excavation face and sidewalls will be performed; geological features and excavation induced fractures will be mapped.

PLANNING AND REALISATION
The excavation of the PRACLAY gallery is scheduled to start at the beginning of August 2007 and will need some 4 to 5 weeks. At the moment of writing the abstract, the preparation of the construction site is in progress and the construction and test assemblies of the main components (reinforcement structure, tunnelling equipment and gallery lining) are being finalised.

If no major problems are encountered, the gallery will be realised just before the Lille 2007 meeting and the first results of the scientific programme will be available.

Once the PRACLAY gallery is finished, the equipment for the PRACLAY heater Experiment will be installed. The heating phase is scheduled from 2009 to 2019.
EXTENSION OF THE MONT TERRI ROCK LABORATORY AND EXPERIMENT PROGRAMME

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GALLERY 08
The Mont Terri project partners have discussed the future extension of the Mont Terri rock laboratory. They have decided to create sufficient new space in the rock laboratory by 2008 to allow the project partners to continue their cooperative research on the long term under the best possible conditions. The extension will consist of an access gallery – “Gallery 08” – which will be excavated with a road header and will connect the existing Gallery 98 and Gallery 04 (Figure 1). A mine-by test will be carried out during this extension. Seven partners, ANDRA, BGR, CRIEPI, GRS, HSK, NAGRA and SWISSTOPO, will finance the Gallery 08, which will be operable by December 2008.

The particular requirements set by the geological context, the planned excavation techniques and the lining and the safety concept for Gallery 08 will be presented.

EXPERIMENT PROGRAMME
Key experiments and related open questions have been evaluated in a questionnaire completed by the Delegates of the Mont Terri partners. Basically, there are two lines of research and new experiments that could be carried out in Gallery 08. The first line is the continuation of activities in well established research areas with a clear requirement for future research. These are mainly thermo-hydro-mechanical (THM) coupled processes, gas transport, high-pH cement interactions with the clay, all questions related to the excavation disturbed and damaged zones, self-sealing, diffusion and retention of radionuclides and corrosion. The second line proposes demonstration experiments, e.g. improvement of backfill and buffer emplacement techniques (a first experiment, the so-called EB (engineered barrier) experiment, started in 2002 and there is a clear need for improvement of these techniques), large-scale sealing of emplacement and access tunnels, investigation of alternative canister materials aimed at minimising corrosion and associated gas production and intrusive and non-intrusive monitoring. These demonstration experiments are important for showing the feasibility of the techniques in question and also for enhancing public confidence.

The selection process for the experiment proposals to be carried out in Gallery 08 has already started. An overview of the updated experiment programme will be presented.

Reference:
Figure 1: The Mont Terri rock laboratory with its planned extension. Gallery 08.
EUROPEAN BENTONITES
AS ALTERNATIVES TO MX-80

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INTRODUCTION

Because of its unusual characteristics:

- Structure of very small, thin and flexible platelets with big surface.
- Cation exchange capacity because of the negative charge of the elementary cell.
- Capability of reversible adsorption of water at the interlayer cations and particles surfaces (intra-
cristalline swelling).

Bentonite is used as a sealing component for different environmental protection techniques (Koch 2002).

For the management and disposal of radioactive waste, most of the European countries are working on
solutions with bentonite as a key component.

While over many years almost exclusively North American Wyoming Bentonite, a natural sodium
bentonite (MX-80 type), was tested as reference buffer material, since some years also different bentonites
from European sources are examined and commercial available for this application.

Results so far confirm, that there are alternatives to MX-80 for application as buffer but also for
backfilling.

DIFFERENCES IN CHARACTERISTICS OF CA-BENTONITE AND NA-BENTONITE

The properties of bentonite are based on the structure of smectite/montmorillonite. Basic units of smectites
are constructed of a single octahedral sheet sandwiched between two tetrahedral sheets sharing the apical
oxygen of the tetrahedral sheets.

Layer charge arises from substitutions in either the octahedral sheet or the tetrahedral sheet, producing one
negative charge for each substitution. This negative charge is distributed over the surface of the three-layer
platelets, while the edges and corners are bearing positive charges.

The negative layer charges are neutralized by positive charged cations. In natural bentonites these can be
Na⁺ -Ions (Wyoming bentonite, e.g. MX-80) or Ca²⁺, Mg²⁺ – Ions (European bentonites).

The interlayer (the space between the sheets) is hydrated and expansible. Therefore smectites are referred
to as “swelling clay”.

In a water saturated system different kind of bondings of the water dipole molecules exists within the
interlayer space of montmorillonite:

- A thin double-layer of water molecules is fixed rather strong at the particel surface of the montmorillonite
  platelets.
- The interlayer cations are surrounded by hydration shells of water molecules
- Excess water can move as non bonded pore water between the platelets of totally swelled montmo-
rillonite.

Bringing bentonite in contact with a surplus of water, e.g. by preparing an aqueous slurry, the dipole
molecules of water are entering the interspace area, accumulate to the positive charged cations and increase
their hydration-shell.

The effect is, that the distance of the superimposed smectite particles is increasing.
In case of Ca-bentonite, the electrical bonding forces between the Ca\textsuperscript{2+} -Ions und the negative charged particle surface are strong enough to preserve the bundle of 15 – 20 three-layer platelets, building a Ca-montmorillonite crystal. Therefore spacial conditions are limited for taking up additional water molecules. Ca-Bentonite can adsorb between 150 % and 200 % water related to its own weight.

Contrary is the behaviour of Na\textsuperscript{+}-bentonite. As the electrical interaction between the monovalent Na\textsuperscript{+}-ion and the negative charged platelets is much weaker compared to the Ca\textsuperscript{2+}-ions with two positive charges. Excess water molecules can enter completely the interspace area, surrounding the Na\textsuperscript{+}-Ions with a bigger hydration-shell. The distances between the superimposed platelets are increased so much, that the Na-montmorillonite crystal bundle is disbanded in 15 – 20 single platelets.

If the water adsorption can take place without spatial restrictions, Na-bentonite has clearly higher swelling volumes and swelling pressures than Ca-bentonite. The swelling pressure is strongly dependent on the density of the bentonite, the salinity of the pore water and the major type of interlayer cation at low density.

Therefore Na-bentonite like MX-80 for a long time was preferred as a standard buffer material.

Under spatially limited conditions without free swelling, e.g. after compaction bentonite can develop rather high swelling pressures. The difference in swelling pressure between Na-bentonite and Ca-bentonite becomes negligible at higher densities than about 1900 kg/m\textsuperscript{3}, when the stacks of lamellae have been forced together so much that the microstructural patterns are similar (SKB TR 02-12).

**NA-BENTONITE OR CA-BENTONITE AS BUFFER?**

Since many years the Wyoming type bentonite MX-80 had been analyzed by all institutes, that had been concerned with this topic, as reference bentonite for the buffer applications.

Some years ago in discussions with SKB about longterm stability of bentonite in a saline environment, the possibily of ion-exchange of Na-bentonite by Ca\textsuperscript{2+} /Mg\textsuperscript{2+}-ions containing groundwater and as consequence possible structural changes like shrinking or cracking, we proposed the examination of Ca-bentonite as less sensitive alternative for host rock formations with saline rock water.

After several years of analyzing the principle suitability of high grade Ca-bentonite (Montmorillonite content = 75 %) as buffer material was confirmed by SKB.

Meanwhile S&B’s calcium dominated Milos bentonite IBECO Deponit CA-N is listed as SKB reference buffer material, as well as the Wyoming bentonite MX-80 (Sellin et al. 2005).

From our experience as bentonite producer, the question for the most suitable bentonite type as buffer can be answered in such a way that for hard rock formations with saline rock water environment Ca-bentonite should be prefered while for repositories in a clay stone as host rock formation, where no saline water is to be expected, a Na-bentonite can be used.

An additional aspect to be regarded are the different pH-values of Na- and Ca-bentonite.

It may be that the higher alcalinity of Na-bentonite may have a stronger influence on corrosion effects on the canister surface than a neutral pH of a Ca-bentonite.

**References:**

