# 2014 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG)

## - Preliminary Geoscientific Assessments -

December 2014

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# 2014 Report of the NWMO Adaptive Phased Management Geoscientific Review Group

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# Executive summary

This report provides a summary of the work completed by the Adaptive Phased Management Geoscientific Review Group (APM-GRG; abbreviated to GRG) during 2014. The main GRG activities included reviews of: (1) the approach, methods and criteria used by NWMO to conduct Phase 1 desktop geoscientific assessments for twelve communities involved in NWMO's site selection process and to identify critical uncertainties that are relevant for the purpose of selecting a subset of communities suitable for further geoscientific characterization during Phase 2; (2) the approach and methods used by the NWMO to plan and conduct initial Phase 2 field activities, including the acquisition and interpretation of airborne geophysical surveys, lineament interpretation using the newly acquired high resolution geophysical and remote sensing data, and the observation of general geological features in connection with a preliminary geological mapping campaign; and (3) the approach and methods used by the NWMO for assessing whether, based on initial field studies, a Phase 2 community contains smaller potentially suitable areas for further studies, beginning with detailed geological mapping. Other GRG activities have included reviews of generic work plans for the further studies during Phase 2.

The NWMO geoscience team and its consultants have undertaken high quality work that allowed the GRG to carefully assess approaches, preliminary findings and conclusions. Throughout 2014, NMWO has systematically tracked and addressed GRG's recommendations in a satisfactory manner.

The GRG review of the findings of the desktop studies for twelve communities concluded that the resulting geoscientific assessments, despite the obvious remnant uncertainties, are sound and form a reliable basis for the identification of general potentially suitable siting areas in each community. The GRG agrees with NMWO that, except for two communities in sedimentary rock, all Phase1 communities assessed in 2014 contain siting areas that have the potential to meet NWMO's geoscientific site evaluation factors. However, there are varying degrees of geoscientific uncertainty among the communities, the level of which will be reduced during Phase 2 work.

In 2014, as part of Phase 2 of the preliminary geoscientific assessment of the communities, NWMO initiated a series of initial geoscientific field studies including: (i) the acquisition and interpretation of low-elevation, closely-spaced high resolution airborne geophysical surveys to provide higher resolution data; and (ii) initial geological mapping to observe and ground truth general geological features. The objective of these initial field studies is to further assess the geoscientific suitability of the communities and evaluate whether it is possible to identify smaller areas for further field studies, beginning with detailed geological mapping.

The GRG has reviewed the approach and methods to acquire high-resolution, airborne geophysical data (magnetic and gravity) for three communities (Creighton, Ignace and Schreiber) and found it to be appropriate for the purpose of further geoscientific characterization of the communities during Phase 2. Some minor adjustments to line lengths were made to ensure that the data could be adequately interpreted. Due to diligence of the NWMO in planning the work and continuous interaction with the contractor, the newly acquired data is of the highest quality and will greatly improve the ability to further assess the suitability of sites. The GRG reviewed the approach and methods for the Phase 2 lineament interpretation, and recommended that the categorization of Phase 2 lineaments should be consistent with the Phase 1 assessment. The GRG has also reviewed the methods and approach to observe and characterize general geological features in a preliminary geological mapping campaign in four communities (Creighton, Ignace, Hornepayne and Schreiber) and provided several recommendations for the execution of this field programme. Finally, the GRG reviewed and contributed to the development of an approach to identify smaller potentially suitable areas that would constitute primary candidates for detailed geological field mapping in communities selected for additional Phase 2 fieldwork.

The GRG continues to be impressed by the approach adopted by the NWMO and the progress made during 2014. Based on the experience of the GRG members, the adopted approach follows or exceeds best international geoscientific practice.

# 1 Introduction

The Adaptive Phased Management Geoscientific Review Group (APM-GRG; abbreviated to GRG) was established in 2012 by NWMO management to provide advice and review comments on the preliminary geoscientific assessments being conducted as part of NWMO's site evaluation process to identify a suitable host community for a deep geological repository for Canada's used nuclear fuel. Preliminary assessments include both desktop studies and preliminary field investigations. The suitability of communities is assessed using a staged approach including Initial Screenings, Preliminary Assessments and Detailed Site Characterization, considering both technical and community well-being factors (NWMO 2010).

This report covers GRG activities during 2014. A first GRG report was issued in December 2013 and is publically available on NWMO's website (APM-GRG 2013). A brief biography of the five GRG members for the term 2014 is presented as an attachment.

# 2 Objectives of NWMO's geoscientific preliminary assessments

The overall preliminary assessment is a multidisciplinary study integrating both technical and community well-being assessments, including geoscientific suitability, engineering, transportation, environment and safety, as well as social, economic and cultural considerations.

The objective of the geoscientific suitability preliminary assessment is to assess whether the communities contain areas that have the potential to meet NWMO's site evaluation factors. The geoscientific preliminary assessment is conducted in two phases:

- ***Phase 1 –*** *A* ***Desktop Study*** is undertaken for all communities electing to be the focus of a preliminary assessment. This phase involves desktop studies using available geoscientific information and a set of key geoscientific characteristics and factors that can be realistically assessed at the desktop phase of the preliminary assessment.
- ***Phase 2 - Preliminary Field Investigations*** are undertaken for a subset of communities selected by the NWMO, to further assess potential suitability. The field studies can include:
    a) Acquisition and interpretation of high-resolution airborne geophysical surveys and initial geological mapping (referred to as "observing general geological features") to better understand the surface and sub-surface geology. The outcome of these studies is to identify smaller potentially suitable areas for more detailed geological mapping;
    b) Detailed geological mapping to define the location of potentially suitable sites for borehole drilling; and
    c) Drilling of deep boreholes at selected locations within the communities.

The subset of communities considered in Phase 2 of the preliminary assessment will be selected based on the findings of the overall desktop preliminary assessment considering technical and social, economic and cultural considerations. It is important to note that the mandate of the GRG is entirely focussed on the geoscientific suitability assessment component.

# 3 Geoscientific evaluation activities completed by the NWMO during 2014

The status of communities' involvement in NWMO's site selection process is illustrated in Figure 1. NWMO's main geoscientific evaluation activities in 2014 included the following:

1. Completion of Phase 1 Geoscientific Desktop Preliminary Assessments in twelve communities in Ontario (Nipigon, Manitouwadge, White River, Blind River, Elliot Lake, North Shore, Spanish, Arran-Elderslie, Brockton, Huron-Kinloss, Saugeen Shores and South Bruce). The Phase 1 Geoscientific Desktop Preliminary Assessment for the Municipality of Central Huron is still ongoing and will be reviewed by the GRG in 2015;

2. Plan, acquire and interpret high-resolution airborne geophysical surveys (magnetic and gravity) in three communities (Creighton, Ignace and Schreiber), including lineament interpretation of this new data combined with data already acquired;
3. Plan and conduct preliminary geological mapping (observing general geological features) in four communities (Creighton, Ignace, Hornepayne and Schreiber);
4. Further assess geoscientific suitability and identify smaller potentially suitable areas that are candidates for detailed geological mapping in Creighton, Ignace and Schreiber.

# 4 GRG review activities during 2014

In 2014, the GRG has systematically reviewed NWMO's approach, methods, criteria and findings related to the geoscientific activities listed above (Section 3). The main activities during 2014 included the following:

- Review of draft geoscientific desktop preliminary assessment reports, as well as supporting documents (geophysical interpretation, lineament interpretation and terrain analysis) for each of the twelve Phase 1 communities. The review focussed on the approach, methods and criteria used to conduct the assessments and identify residual geoscientific uncertainties relevant to each Phase 1 community (Sections 5.1.1, 5.1.2 and 5.1.3 below).
- Review of work plans for the acquisition of Phase 2 high resolution airborne geophysical surveys in three communities (Creighton, Ignace and Schreiber) and the initial interpretations of the geophysical data and lineaments (Sections 5.2.1 and 5.2.2 below);
- Review of work plans for the conduct of Phase 2 preliminary geological mapping (observing general geological features) in four communities (Creighton, Ignace, Hornepayne and Schreiber) and the initial findings of field studies completed during 2014 (Section 5.2.3 below); and
- Review of the approach for assessing whether, based on initial Phase 2 field studies, the communities of Creighton, Ignace and Schreiber contain smaller potentially suitable areas for further studies, beginning with detailed geological mapping (Section 5.3 below).

Other GRG review components during 2014 included:

- Review of the scope of work for the assessment of hydraulic, geomechanical, structural and thermal characteristics of dykes and sills identified earlier by the GRG as necessary in the identification of suitable areas (Section 5.4.1 below);
- Review of generic work plans for conducting detailed geological mapping during Phase 2 in crystalline rock sites (Section 5.4.2 below);
- Review of preliminary options for Phase 2 preliminary field investigations in sedimentary rock sites (Section 5.4.3 below);
- High-level review of planned use of Discrete Fracture Network (DFN) modelling during Phase 2 assessment (Section 5.4.4 below); and
- Review of the preliminary approach to identify borehole drilling sites in Phase 2 (Section 5.4.5 below).

In 2014, interactions between the GRG, NWMO and its consultants included one face-to-face meeting in Toronto (June 4-5, 2014) and two teleconference calls (April 24, 2014; October 20, 2014). The review process progressed as follows:

- Prior to meetings, NWMO shared with the GRG draft work plans, reports and findings, as they became available;
- Meetings, teleconferences and email exchanges with NWMO and its consultants were held to discuss GRG review comments;

- GRG comments were documented and tracked in disposition tables, which were sent to the GRG to ensure that the approach to address the review comments was appropriate; and
- Final draft products were reviewed by the GRG to ensure that review comments were addressed by NWMO and its consultants to the satisfaction of the GRG.

# 5 Overall assessment of progress during 2014

The GRG continues to be impressed by the assessment approach adopted by the NWMO and the progress made in geoscientific site assessments. As in previous years, the NWMO team and its consultants have undertaken high quality work that allowed the GRG to carefully assess approaches and conclusions. The GRG has made many suggestions for process improvements and it is pleased to report that NMWO has responded to the identified issues in a timely and transparent manner.

Specific contributions of the GRG in 2014 include:

- Advice on the need to ensure continued consistency in Phase 1 assessment.
- Request for clarification of the terminology for stratigraphy in sedimentary rock sites.
- Advice on types and coverage of airborne geophysical surveys.
- Advice on the need to produce a consistent interpretation of lineaments, for example by using the same contractor.
- Request for the inclusion of mafic sills and felsic dykes during the evaluation of the significance of mafic dykes for the identification of potentially suitable areas in the communities underlain by crystalline rocks.
- Recommendations for geomechanical investigations during geological mapping.
- Comments on potential constraints by old exploration boreholes in sedimentary sites for the definition of potentially suitable areas.
- Request for clarification on exactly which fractures or fracture zones are to be included in the DFN work.

As a consequence, NMWO used appropriate procedures to select communities for Phase 2, has carefully planned activities in this phase and undertaken some of these activities. Based on the experience of the GRG members, the adopted approach to select communities and undertake further studies follows or exceeds best international practice.

## *5.1 Potential suitability of the twelve Phase 1 communities for which a geoscientific desktop study was completed during 2014*

All twelve communities for which a Phase 1 Geoscientific Desktop Preliminary Assessment was completed during 2014 are in Ontario. Seven of these communities are located in the Canadian Shield and are underlain by crystalline rocks of Precambrian age. The five other communities are located in southern Ontario within the Paleozoic sedimentary sequence of the Michigan Basin.

Overall, the GRG was in agreement with the approach, methods and findings of the Phase 1 preliminary assessments for both crystalline and sedimentary sites. These assessments were conducted in a manner that is consistent with the approach followed for the first group of eight communities completed during 2013. The GRG concluded that the resulting geoscientific assessments, despite the obvious remnant uncertainties, are sound and form a reliable basis for the identification of potentially suitable siting areas in each community. The GRG agrees with NMWO that, except for two communities in sedimentary rock, all Phase1 communities assessed in 2014 contain siting areas that have the potential to meet NWMO's geoscientific site evaluation factors.

The GRG agrees with NMWO that the nine communities that remained in the site selection process at the end of 2014 all have the potential to contain suitable siting areas, recognizing that there are varying degrees of geoscientific uncertainties among the communities. As discussed below, the GRG

was also in agreement with the findings of the assessment of uncertainties inherent to each community.

### 5.1.1 Crystalline rock communities

For the seven communities within the crystalline rocks of the Canadian Shield, good quality digital elevation and satellite data, used in the terrain and surficial lineament interpretations, are available for each of the areas. However, there are significant differences between and within the seven communities with respect to the availability and quality of other data; e.g., the scale of geological bedrock and surficial cover mapping, medium to low resolution of airborne geophysical surveys, and coverage of different geophysical data types. This introduces differences in the level of uncertainty between the seven communities.

Furthermore, as for the first eight communities in crystalline rock that were previously assessed (APM-GRG 2013), there is a general lack of information from boreholes penetrating the bedrock to relevant depths, particularly site specific hydrogeological and geotechnical data. However, as in the earlier work, information collected in other parts of the Canadian Shield has been used (e.g., in-situ stress, geotechnical parameters, hydrogeological or hydrochemical scenarios).

The GRG has emphasized and noted that NWMO is fully aware of the subjective character of the interpretation of lineaments. The GRG is satisfied that NWMO has responded to the GRG´s comments on lineament interpretation work at an early stage in the feasibility study. As a consequence, the NWMO has worked to develop, as much as possible, a consistent approach to limit inconsistencies between different interpreters and different data sources (digital elevation, satellite and airborne magnetic data).

In June 2014, the Township of Nipigon requested from the NWMO interim reports on the social and geological assessments. After receiving the reports, the Township passed a resolution to discontinue its involvement in the site selection process. The interim geoscientific report highlighted significant uncertainties on the geoscientific suitability of the Nipigon area. The GRG agreed that the geology of the Nipigon community is complex and there are a number of features that increase the uncertainties, particularly the presence of Proterozoic mafic sills. This feature makes it more difficult for the NWMO to identify areas that will ultimately meet NWMO's geoscientific site evaluation factors.

### 5.1.2 Sedimentary rock communities

A desktop preliminary assessment was undertaken for the five communities in southern Ontario, within the Paleozoic sedimentary sequence of the Michigan Basin. Some geoscientific information is available for the communities, including a limited number of deep boreholes. The assessment relied heavily on geotechnical information from the site characterization activities conducted at the Bruce nuclear site for OPG's proposed Low and Intermediate Level Waste Deep Geological Repository.

The GRG reviewed the desktop geoscientific preliminary assessment reports for the five sedimentary sites, which are comprehensive and well written. The GRG agreed with the findings for each community, in particular that the Arran-Elderslie and Saugeen Shores communities do not show the potential to contain potentially suitable siting areas. The GRG's main comments were about resolving inconsistencies in the stratigraphic terminology used to describe the various geological units in the sedimentary sequence. The terminological inconsistencies were documented and have now been resolved in a satisfactory and consistent manner.

### 5.1.3 Approach for assessment of residual uncertainties

The GRG feels satisfied that NWMO has used the same approach for the assessment of residual uncertainties and their impact on identifying a subset of communities for Phase 2 in the seven crystalline sites as that adopted for the first group of eight communities (APM-GRG 2013). While

most of the seven communities contain areas that have the potential to meet NWMO's site geoscientific site evaluation factors, there are a number of geoscientific uncertainties that would need to be addressed through field investigations and more detailed studies. These uncertainties are inherent to the early stage of the assessment.

Uncertainties associated with the crystalline rock sites are essentially the same nature as those identified for the first group of crystalline communities (APM-GRG 2013). They include uncertainties in estimating the density of lineaments, when the magnetic data have different resolution in different areas; the occurrence of mafic dyke swarms or mafic sills in all the communities that leads to conspicuous bedrock heterogeneity; and the limited size of some potential siting areas due to the limited exposure of potentially suitable bedrock. The GRG is satisfied that NWMO agrees to highlight these uncertainties in the executive summary and conclusions of each community geoscientific report.

Uncertainties associated with the sedimentary rock sites are mainly related to the assumption of transferability of geoscientific characteristics and understanding based on regional data and data from the Bruce nuclear site to the communities assessed. The potential for hydrocarbon resources and the presence or absence of faults within the sedimentary sequence beneath the remaining communities will also need to be further assessed through more detailed community-specific studies and field investigations, including the more detailed interpretation of existing data or the acquisition and interpretation of 2-D seismic ground surveys, geological mapping, and the drilling of deep boreholes.

## *5.2 Planning and interpretation of Phase 2 geoscientific field investigations in Phase 2 communities (Creighton, Ignace, Schreiber and Hornepayne)*

The goal of Phase 2 work is to reduce or diminish residual uncertainties remaining after completion of Phase 1 desktop studies. NWMO shared with GRG work plans for the initial Phase 2 field work for the current Phase 2 communities (Creighton, Ignace, Schreiber and Hornepayne), including acquisition and interpretation of high-resolution airborne geophysical surveys, lineament interpretation, and preliminary geological mapping (observing general geological features).

### 5.2.1 High-resolution airborne geophysical surveys

The NWMO generated a Request For Proposal (RFP) using a number of different governmental guidance documents that included procedures for the collection of magnetic, radiometric and electromagnetic data. The RFP was reviewed by the GRG to ensure that equipment and procedures used are consistent and up-to-date. GRG also recommended extending acquisition of gravity data to the entire survey areas rather than focussing on discrete lines. The gravity data was acquired to estimate the depth of intrusions and to ensure that they are adequate for the planned depth of the repository.

A member of the GRG also participated in a planning meeting between NWMO and the selected contractor (Sander Geophysics Ltd) to discuss plans for the acquisition of the geophysical data in a manner that was consistent with the objectives of the goals of the NWMO. This included a detailed discussion of the areas to be covered, the required logistics and communities' involvement, the flight line direction, filling in between two proximal areas, and extending the lines to ensure adequate data to allow interpretation to take place. At this meeting (and afterwards) there was good dialogue between the contractor and the NWMO to ensure that the contractor understood the goals of the survey so that the appropriate data could be acquired and that the appropriate interpretation methods could be applied to the data. Such detailed discussions at a survey planning stage are not common in the industry and highlight the diligence process followed by the NWMO.

Standard practice for quality assurance/quality control (QA/QC) is to include a brief visit to the survey crew while acquisition is taking place. However, the NWMO exceeded this industry practise

by conducting numerous audits both in the field and at the contractor's offices. Three field audits focused on verifying compliance with approved plans and procedures for Health and Safety, calibration of instruments and acquisition of data. One audit at the contractor's offices focussed on QA procedures for the processing and interpretation of survey data. In addition, NWMO requested daily reports from Sander Geophysics Ltd to ensure compliance with surveys goals, plans and procedures. Due to the planning and diligence of the NWMO and the continuous interaction with the contractor, the newly acquired data is of the highest quality and will serve the needs of the NWMO in assisting with the site selection process.

The GRG agreed that the newly acquired high-resolution magnetic and gravity data constituted a major improvement and will provide much more information than the available data used in Phase 1. The new data will also provide uniform resolution in all Phase 2 crystalline sites, so that reliable comparisons can be made between the sites (lineament density, etc). The GRG recommended that the additional data acquired between the planned survey blocks in both Ignace and Schreiber should be processed and interpreted since it will provide additional information on the local geology. The GRG also recommended that geophysical anomalies (i.e. potential different intrusive phases) be visited during future field mapping campaigns.

### 5.2.2 Lineament interpretation

The GRG recommended that the NWMO ensure that geophysics and lineament contractors exchange information as the interpretations progress, so that i) there is good integration of information concerning structure, lithology etc., from different perspectives; and ii) terminology being used by the contractors and the NWMO in the reporting is clear and consistent.

The categorization of Phase 2 lineaments should be consistent with the Phase 1 assessment. Lineaments associated with brittle structures should be distinguished from lineaments associated with dykes and from those associated with ductile fabrics and structures in the bedrock. At this stage of the assessment it is not possible to further categorize lineaments associated with brittle structures into, for example, joints or faults.

With respect to the data collection and interpretation process, the GRG noted that attention should be paid to flight line direction to ensure that features parallel to flight lines are not missed. The Phase 2 lineaments interpreted using the geophysical and surficial data sets should be compared to mapped faults, and some representative lineaments should be revisited when planning field visits to ensure that significant features are investigated. Inspection of initial interpretations shows that the style of lineament interpretation is consistent across the communities, supporting the decision to use one contractor for the interpretation of lineaments.

### 5.2.3 Preliminary geological mapping (observing general geological features)

The objective of observing general geological features during the preliminary geological mapping campaign was to confirm and evaluate the understanding of geological and surficial features within areas identified as potentially suitable in Phase I. For each of the current Phase 2 communities (Ignace, Schreiber, Creighton, Hornepayne), observations focussed on the general potentially suitable areas identified in Phase 1.

Given there will be different field mappers involved, with different levels of expertise, the GRG recommended that an independent mapping expert and NWMO staff should participate in field activities to ensure consistency between assessments at different locations.

The GRG also noted that given the tight window that is available for preliminary geological mapping (August-October, 2014), it will be important to prioritize features and characteristics that should be mapped and documented in the field. The GRG also noted that activities and observations to be carried out during initial geological mapping versus detailed mapping campaigns need to be clearly defined.

The GRG noted that a tiered methodology should be developed for dealing with fracture evaluations. Such a tiered approach could build towards assessment of site-specific cross-cutting and abutting relationships, and fracture set, fracture spacing and aperture characterization. Special attention should be paid to the effects of post-emplacement structural overprinting of dykes, which can significantly alter their hydrological and geotechnical properties. At most outcrops, a full assessment of fracture characteristics will likely not be possible during initial geological mapping. However, it is important that NWMO is prepared to collect information when exceptionally high-quality and informative outcrops are encountered. The GRG also recommended that field mapping activities should include careful checking for sheet-joints, which could be indicative of high rock stress.

GRG noted that field reconnaissance activities should identify locations where detailed field mapping is warranted in 2015. Some initial geotechnical data should also be collected during initial geological mapping and then increased during detailed mapping. Rock samples should be routinely collected during both the initial and detailed mapping stages, so that an archive of samples can be acquired for subsequent petrographic, geochemical and petrophysical analysis.

## *5.3 Approach for identifying smaller candidate areas for detailed geological mapping in Phase 2 communities*

NWMO presented an approach for identifying preliminary smaller candidate areas for detailed mapping once the preliminary geological mapping (observing general geological features) is completed in 2014. The approach for identifying such areas is similar to that used to identify general potentially suitable areas in each Phase 1 community, but will be augmented with the findings of the initial Phase 2 field work, including newly acquired geophysical surveys, lineament interpretation and preliminary geological mapping. The GRG noted that the overall proposed approach is consistent, of high quality and compatible with international best practice

The approach for selecting areas for additional detailed mapping is based on an integrated understanding of the geoscientific characteristics of the communities and the application of key geoscientific evaluation factors and constraints that can be realistically evaluated at this early stage of the assessment. In addition to the available geoscientific information from Phase 1, the location and size of potentially suitable areas for each community is identified and refined through a detailed analysis of the newly acquired, high-resolution geophysical data in terms of the interpreted homogeneity of the lithology; characteristics and distribution of lineaments in terms of length, orientation, density and intersections; and the findings from the preliminary geological mapping. Geophysical lineaments interpreted from the new high-resolution magnetic and gravity surveys are of particular interest because they are not affected by the presence of overburden deposits, and most likely represent structures that exist at depth.

## *5.4 Other 2014 GRG review components*

In addition to the main reviews described above (Sections 5.1, 5.2 and 5.3), the NWMO discussed with the GRG during 2014 the high-level and generic approaches for: i) the scope of work to assess the significance of dykes and sills in the identification of potentially suitable areas; ii) conducting detailed mapping in Phase 2 communities once initial geological mapping is completed; iii) conducting Phase 2 field investigations in sedimentary sites; iv) the scope of work for Discrete Fracture Network (DFN) modelling during Phase 2 assessment; and v) identifying repository-scale sites for borehole drilling.

### 5.4.1 Dykes and sills in crystalline rock sites

GRG advised the NWMO to include felsic dykes and mafic sills together with mafic dykes in the planned special study to evaluate the hydraulic, geomechanical, structural and thermal characteristics of such minor intrusions in the context of the identification of potentially suitable

areas. The GRG also provided several other refinements to the work plan for this special study. The GRG have emphasized the importance of this issue bearing in mind the common occurrence of these geological features in the communities of Manitouwadge, Hornepayne, White River, Blind River, Elliot Lake, North Shore and Spanish.

### 5.4.2 Detailed geological mapping in Phase 2 crystalline rock sites

NWMO discussed with the GRG the preliminary plans for detailed geological mapping, which will follow preliminary geological mapping in Phase 2 communities. The objective of the detailed geological mapping activity is to further understand the lithological and structural framework of the bedrock in each community, in order to identify potentially suitable repository-scale areas and ultimately define the location of borehole drilling sites.

The GRG recommended that geotechnical data be collected during the course of the detailed geological mapping exercise. For petrographic, petrophysical and geotechnical analysis, it is also recommended that small rock samples be collected for: i) hand sample and thin section petrography; ii) density and magnetic susceptibility measurements; and iii) geotechnical analyses Rock sampling should be restricted to reasonably fresh outcrops whereas structural mapping should be carried out on both fresh and weathered outcrops. A guidance document was provided by the GRG for use during the field mapping exercise. In addition to the recording of field observations, structural measurements and details of samples, the GRG recommended that photographs of outcrop geological features should be taken at various scales and combined with field notebook sketches, in order to document and understand the local geology.

### 5.4.3 Preliminary options for Phase 2 field investigations in sedimentary rock sites

Given the differences in the geological setting and the amount of available information between the sedimentary and crystalline rock sites, the approach adopted for the four crystalline communities currently in Phase 2 is not fully transferrable to the communities underlain by sedimentary rock that may potentially advance to Phase 2. NWMO shared with the GRG the type of field investigations identified as being useful to further assess the suitability of sedimentary sites, including preliminary mapping; 2D seismic ground surveys; and borehole drilling. The GRG agreed with the type of planned field activities for sedimentary sites, and made recommendations on how these activities can be designed and sequenced.

There was agreement by the GRG that 2D seismic ground surveys and borehole drilling should be carried out in parallel as an integrated process. In an ideal situation, 2D seismic lines should be collected first and then used to guide the selection of borehole drilling sites. The GRG noted that NWMO may want to first identify “no-go” surface areas based on surficial/social constraints, and then use this information to guide planning the seismic line locations.

The GRG recommended the collection of at least two long seismic lines, one parallel and one perpendicular to strike. Suggested locations for 2D seismic lines were also provided by the GRG. The GRG noted that it is worth investing in high-resolution seismic lines with closely spaced source and receiver points for improved confidence in identified structural features, which has been the experience in France and Switzerland.

It was noted by the GRG that current top basement structure contour maps indicate the Precambrian basement-Paleozoic cover unconformity to be a uniformly dipping surface, whereas it may instead be stepped by fault offsets. Previous field work in south-central Ontario has also indicated that fracturing in the Paleozoic cover is partly controlled by compaction above an irregular paleo-erosion surface on top of the Precambrian basement. The GRG recommended that these features be kept in mind when conducting and interpreting the initial field studies described above. Existing airborne gravity and magnetic data could be used to help choose the location of ground-

based seismic lines. Evaluation of initial field study results will determine the need for additional airborne or ground geophysical surveys.

The GRG also recommended that an inventory of boreholes should be made and that the integrity of old (abandoned and orphaned) boreholes in areas under consideration should be assessed at later stages of the evaluation.

### 5.4.4 Discrete Fracture Network (DFN) modelling

DFN/conceptual models are valuable tools for site characterization. It is a good practice to initiate model development early in the site characterisation process. Such models are developed iteratively throughout the site characterisation program as new surface and sub-surface information become available. This iterative process allows for the continual revision and testing of the conceptual model/DFN that ultimately improves the understanding of the sub-surface at crystalline and sedimentary sites.

Initial geological mapping provides information that will be used to inform the initial versions of DFN/conceptual models. Results from detailed geological mapping will be used to prioritize and collect information required to improve the model.

The GRG noted that the future development of site-specific rules that will be used to constrain the DFN/conceptual models remain a key issue. Such rules will need to be updated from generic Canadian Shield rules to site-specific rules as the models evolve through the various stages of site characterisation. The NWMO will need to develop a plan to iteratively refine and justify site-specific rules that dictate DFN geometrical and cross-cutting relationships.

### 5.4.5 Selection of borehole drilling sites

NWMO discussed with GRG a preliminary approach to identify potentially suitable repository-scale sites for borehole drilling, once the detailed geological mapping is completed. The approach follows the same general approach used in Phase 1, augmented by the gradual and iterative use of numerical conceptual geosphere models and Discrete Fracture Network (DFN) modelling as more and more field data is collected.

# 6 References

NWMO, 2010. Moving Forward Together: Process for Selecting a Site for Canada's Deep Geological Repository for Used Nuclear Fuel, Nuclear Waste Management Organization. Available at www.nwmo.ca

GRG 2013. 2013 Report of the NWMO Adaptive Phased Management Geoscientific Review Group (GRG). Available at www.nwmo.ca

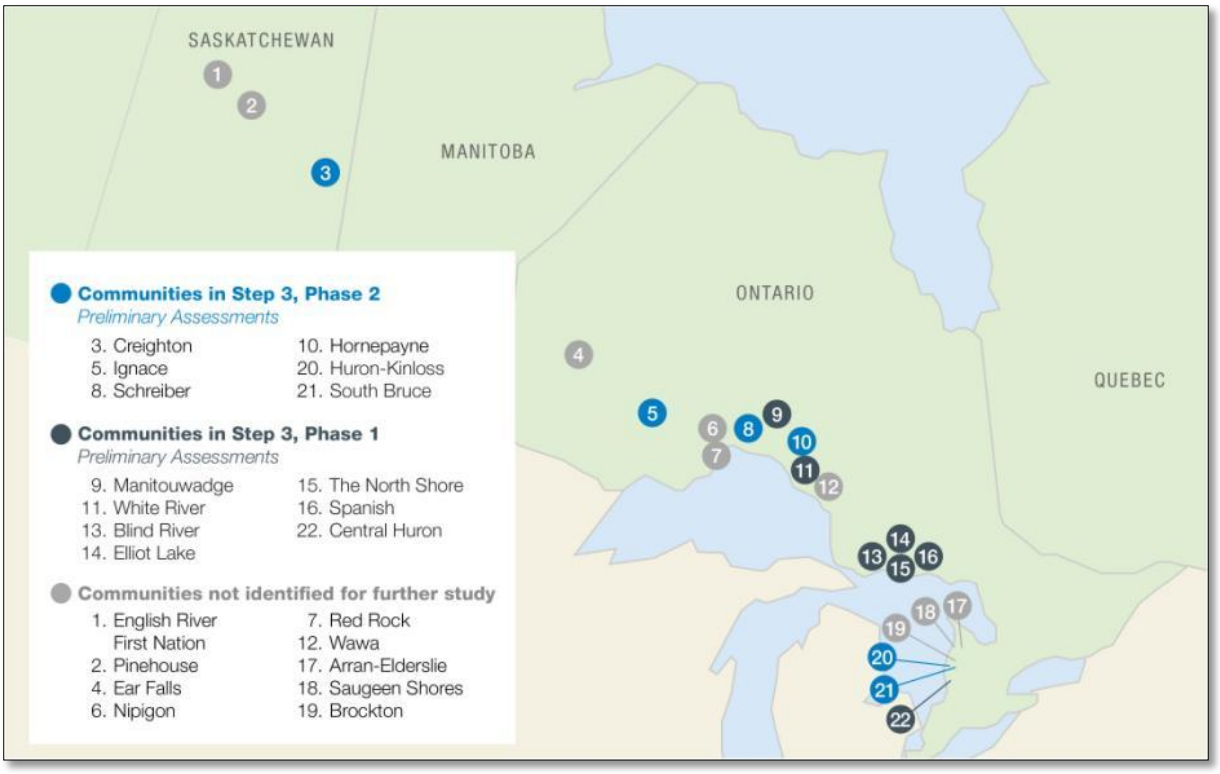


Figure 1 – Status of community interests (as of November 2014)

# 7 Attachment - Brief biographies of the APM-GRG members

**Dr. Alexander (Sandy) Cruden,** Professor and Head, School of Earth, Atmosphere & Environment, Monash University (Australia). Sandy has more than 25 years of geoscience experience related to structural geology, analysis and characterization in both crystalline and sedimentary rock settings. Sandy completed a fault reactivation analysis and structural characterization of Southwestern Ontario as part of site characterization activities for OPG's proposed Low and Intermediate Level Waste DGR at the Bruce site.

**Dr. Andreas Gautschi**, Division Head Geology, Safety at Nagra (the Swiss National Cooperative for the Disposal of Radioactive Waste). Andreas has more than 25 years of geoscience experience related to the planning, coordination and implementation of site evaluation programs for deep geological repositories in both crystalline and sedimentary rocks. He coordinated successful geoscience activities that contributed to the selection of the Opalinus Clay formation as the preferred geologic setting for long-term management of high-level waste in Switzerland.

**Dr. Peter Kaiser (APM-GRG Chairman),** Professor of Mining Engineering at Laurentian University and Chair for Rock Engineering and Ground Control; former Director of the Rio Tinto Centre for Underground Mine Construction and former Founding Director of the Center for Excellence in Mining Innovation (CEMI). His interests lie in geomechanics, underground excavation stability, mine design, mechanized excavation and the applications of other emerging technologies that increase mining safety and productivity. Dr. Kaiser is the author of more than 300 technical and scientific publications. He is a Fellow of the Engineering Institute of Canada and the Canadian Academy of Engineers.

**Dr. Richard Smith,** Professor in the Department of Earth Sciences at Laurentian University, Industrial Research Chair of Exploration Geophysics; he has expertise in the application of geophysical methods generally and airborne methods specifically to investigate the geosphere at depth. Richard brings over 20 years of experience working in the exploration business.

**Dr. Michael (Mike) Stephens**, Senior State Geologist with the Geological Survey of Sweden in Uppsala. Mike has been actively involved in the Swedish site evaluation process including country-wide reconnaissance studies conducted in Sweden to identify potentially suitable regions for hosting a deep geological repository, geoscientific feasibility studies, and the detailed characterization of the Forsmark site which was selected by SKB as the site for the deep geological repository for used nuclear fuel in Sweden.