

GEOLOGICAL MAPPING APPROACH AND METHOD FOR ASSESSING SUITABILITY OF CRYSTALLINE ROCKS FOR HOSTING CANADA'S DEEP GEOLOGICAL REPOSITORY FOR USED NUCLEAR FUEL

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Abstract

The Nuclear Waste Management Organization (NWMO) is currently conducting initial field studies in a number of communities participating in a site selection process to find an informed and willing community to host Canada's deep geological repository for used nuclear fuel. Initial field studies involve activities such as high resolution airborne geophysical surveys and direct mapping observations. These field activities are designed to further advance understanding of the geology of the areas being studied, building on previously conducted desktop studies. Consistent with NWMO's approach, all field activities are planned and conducted with the involvement and collaboration of the communities and Aboriginal peoples. This paper focusses on the approach, tools and techniques used to plan and conduct geological mapping in crystalline rocks of the Canadian Shield. A description of the site evaluation process and approach used to conduct and analyze high resolution airborne surveys are provided in two companion papers.

The main objective of geological mapping is to further advance understanding of the geological suitability of the various communities being assessed. This involves understanding of the rock type, and the structural character of the bedrock, especially the size, frequency, type and location of fractures. An initial walking of the land using existing roads and trails is conducted to map rock outcrops to observe and understand general geological features. This is followed by detailed geological mapping where the intent is to map as many rock outcrops as possible within the areas of interest. Fieldwork planning involves the analysis of existing relevant datasets including historical bedrock and Quaternary maps, high resolution imagery, road networks and lineament interpretations from remotely sensed geophysical and imagery datasets. Another valuable planning activity is to perform remote predictive modeling using specialized software and satellite imagery to identify potential locations of rock outcrops.

1. Introduction

The Nuclear Waste Management Organization (NWMO) is currently conducting initial field studies, including geological mapping, in a number of communities participating in a site selection process to find an informed and willing community to host Canada's deep geological repository for used nuclear fuel. These field activities are designed to further advance understanding of the geology of the areas being studied, building on previously conducted desktop studies. Consistent with NWMO's approach, all field activities are planned and conducted with the involvement and collaboration of the communities and Aboriginal peoples.

Geological mapping will be conducted in the large general area(s) that were identified in the Phase 1 Geoscientific Desktop Preliminary Assessment desktop studies to have the potential to meet NWMO's geoscientific site evaluation factors [1, 2, 3]. More information regarding site evaluation factors is included in a companion paper [4]. The main objective of geological mapping is to refine understanding of the bedrock units and their distribution and structural character, especially the size, frequency, type and location of fractures in these areas in a non-intrusive manner. Teams of two geoscientists and a local guide with knowledge of the lay of the land will traverse the areas primarily using four-wheel drive and all-terrain vehicles. In order to reach some areas it may be necessary to travel by canoe, boat, aircraft or by foot, depending on the accessibility of the locations of exposed bedrock.

This paper describes the overall approach to the geological mapping (Section 2), including the tools and techniques used to plan and conduct the mapping (Sections 3 and 4) and report and deliver the collected data (Section 5). This is followed by a short summary (Section 6) and a list of references cited (Section 7).

2. Geological Mapping Approach

The geological mapping will be conducted in two stages, including an initial walking of the land followed by detailed outcrop mapping. The initial stage involves the visual observation of general geological features and focuses on general bedrock characterization, including observation of features such as bedrock type(s) and their distribution and the nature and characteristics of geological structures within these areas. The degree of exposed bedrock will be noted while traversing the land, as will be observations relevant to understanding the accessibility of the areas where the observations are made. These initial observations are made over a period of several weeks depending on the size of the area(s) and the number of features of interest. The observations are made primarily along existing roads and trails, and occasionally may involve walking short distances off these trails to explore specific features. The observations are compiled and reviewed in order to help build more knowledge about the rock in the area(s).

The findings from these initial observations, combined with data collected from other field studies such as airborne geophysical surveys and structural lineament interpretations of the resulting geophysical datasets, help determine candidate areas for detailed outcrop mapping. The objective of the detailed outcrop mapping is to undertake additional non-intrusive field observations in a more concentrated manner within these areas in order to further refine the understanding of the geology. Detailed outcrop mapping will be done over a period of several weeks to months with the intent to investigate as many locations of exposed bedrock as possible, including outcrops away from existing roads and trails.

An important component of the detailed outcrop mapping is the ground-truthing of interpreted bedrock geophysical anomalies and structural lineaments. A remote predictive bedrock mapping exercise is undertaken to show the distribution of potential bedrock outcrop locations within the areas and serves as a practical guide for targeting specific locations to ground-truth. Information collected during the detailed outcrop mapping activities will also aim to advance the understanding of the degree of bedrock exposure within, and potential surface constraints on the accessibility of, the candidate areas.

Planning is an important first step of both the initial observations and detailed outcrop mapping stages of the geological mapping. The pre-mapping planning provides the overall strategy and

guidance for the completion of initial observations and detailed outcrop mapping stages in a manner that ensures the approach is consistent between the different study areas where the geological mapping is to be conducted. The plan includes a standard list of geological and other features to be documented, a standard set of tools and methods used to collect and record the relevant information and a standard approach to reporting and data delivery. The plan also includes guidance on the non-technical daily work flow to be followed during the geological mapping. The tasks employed and methods used in planning and conducting the initial observations and the detailed outcrop mapping are described in detail in the next sections.

3. Planning and Conducting the Initial Observations

3.1 Review of available information

The first steps in planning the initial observations are to review the information compiled during the desktop studies and to undertake a literature review to ensure that any additional new information relevant to the areas being investigated is also identified. These steps help to develop an understanding of the types and locations of bedrock units expected to be encountered, any structural features that have been previously mapped or interpreted and the likely distribution of thick overburden deposits that may mask the underlying bedrock. Spatial datasets including waterbodies, road networks and high resolution imagery provide additional baseline information on the accessibility of the areas. Forest Resource Inventory (FRI) orthoimagery is used whenever this dataset is available. FRI imagery is 4-band (red, green, blue, near infra-red) multi-resolution, 40 cm airborne imagery collected and used for forest resource purposes by the Ministry of Natural Resources. Where FRI imagery is not available, the most suitable alternative is chosen.

3.2 Developing the work plan

The next step in planning the initial observations is the development of a standard list of geological and other general attributes to be documented while conducting the work, as well as outlining the method(s) employed to observe them. This list includes general attributes to be documented such as bedrock outcrop location where the observations were made, overburden thickness estimates and surface constraints on accessibility. The list also includes a comprehensive set of geological attributes including under the headings of bedrock characterization, fracture characterization and dyke characterization. Table 1 below provides a detailed overview of the general and geological attributes to be characterized during the initial observations and the characterization methods that will be employed.

Table 1 General and geological attributes to be characterized during the initial observations.

		Characterization Method(s)
General Attributes	Outcrop Location	- Geo-locate all observation locations using GPS - Take representative digital photograph of outcrop area
	Bedrock exposure and overburden thickness	Visually inspect the distribution and thickness of overburden vs. exposed bedrock during the daily traverse (in comparison to existing understanding)
	Surface Constraints	Visually identify and geo-locate any surface constraints that would create challenges for further geological characterization activities (e.g., bridge

		wash-outs, poorly or unmaintained logging roads, beaver dams, steep and deep (impassable) valleys, etc.) Visually identify access issues in areas without mapped roads or navigable waterways
Geological Attributes: Bedrock Characteristics	Lithology	- Visually inspect weathered and fresh rock surfaces for identification of major and minor lithological units and their constituent colour, primary minerals (e.g., granitic rocks have varying proportions of quartz, K-feldspar and plagioclase plus other minerals including micas, hornblende, etc.), grain size, texture, etc. - Name the lithological unit(s) in terms of relative abundance at the outcrop scale - Collect a representative sample(s) of the dominant lithological unit(s) at each outcrop (will require use of hammer and chisel only; fist-sized piece with both weathered and fresh surface) - Take digital photographs of representative lithological unit(s) across the area of interest [documentation will include (at a minimum), file name, scale, GPS coordinates, direction of view and description of the photo.]
	Primary and Ductile Structure	- Observe and document the bedrock structural features (e.g., bedding, foliations, lineations, folds and shear zones) - Take digital photographs and make field sketches of representative key structural features - Measure and document (by hand with compass-clinometer and subsequent digital and manual entry) - Strike and dip of planar structures - Trend and plunge of linear structures - Orientations of fold hingelines and axial surfaces
	Geophysical and Geomechanical Characteristics	- Record 5 magnetic susceptibility measurements for each identified lithological unit (will require use of magnetic susceptibility meter, e.g., KT10 or KT20) - Undertake gamma ray readings for each identified lithological unit using a gamma ray spectrometer (e.g., RS125) - Undertake field rock strength test on representative lithologies at each station and in spatial relation to identified structural features (i.e. lineaments, fracture zones, dykes)
Geological Attributes: Fracture Characteristics		- Visually inspect the rock surface for identification of systematic fracture sets - Characterize fracture sets by type (joints, faults, veins, altered wallrock around fractures) - Measure and document (by hand with compass-clinometer and subsequent digital and manual entry) - Strike and dip of planar structures - Trend and plunge of linear structures on fracture planes - Document - Fracture mineral filling - Abutting, cross-cutting and intersection (relative age) relationships between fracture sets - Displacement (strike separations and dip separations if visible) - Fracture surface ornamentation - Fracture set spacing - Undertake block size analysis based on outcrop fracture geometry and spacing - Take representative digital photograph(s) and make field sketches of representative key structural features as needed to show key fracture characteristics, for example cross-cutting relationships, damage zone width, alteration, mineral infill

Geological Attributes: Dyke Characteristics		• Visually inspect dyke for characteristic features (e.g., mineralogy, colour) • Collect a representative sample of each dyke type • Document • Internal structure (fractures) • Width • Orientation (strike and dip along bedrock contact) • Nature of bedrock contact (e.g., welded, fractured, sheared, altered, extent of damage, etc.), if exposed • Take representative digital photograph of dyke, and make field sketches of representative key structural features, including contact relationship with bedrock
	Geophysical and Geomechanical Characteristics	• Record 5 magnetic susceptibility measurements for each identified dyke • Undertake gamma ray readings for each identified dyke • Undertake field rock strength test on each dyke

A standard method was developed to digitally collect the observational information appropriate for the types of general geological and other features expected to be encountered (Table 1). The digital data capture method includes an ArcGIS™ compatible data-logging instrument (Trimble or equivalent) along with a modified version of the GanFeld data collection database. The GanFeld system was originally developed at the Geological Survey of Canada [5] and is currently used by the Ontario Geological Survey as their standard system for data collection. Entry of geological information into the database follows a simple data collection protocol, consistent with the attributes listed in Table 1, which directs the observer to the appropriate digital form within the database system to capture the appropriate information. The data logging instrument includes an internal global positioning system (GPS) and an option is also available to pair this unit with an external pocket-sized high resolution global navigation satellite system (GNSS) for added location precision.

In addition to the data logging instrument and locating device(s), each mapping team will carry a typical field geologist's toolkit, including the following items:

- compass;
- digital camera;
- hammer;
- pen knife and magnet;
- sample bags and tags;
- pen and notebook; and
- personal safety equipment (e.g., safety glasses, high-visibility vests and helmets).

The teams will also carry two additional portable instruments including a magnetic susceptibility meter (e.g., KT-10 or KT-20 magnetic susceptibility meter) and a Gamma Ray spectrometer (e.g., RS-125). These instruments are used to investigate the geophysical character of the bedrock units. Magnetic susceptibility measurements are obtained from fresh surfaces of outcrop using a pin adaptor to improve reliability. The instrument operates an oscillator with an inductive coil to measure the frequency difference between a sample and free air measurements. Gamma Ray Spectrometry measurements measure the concentration of naturally occurring elements (Potassium, Uranium and Thorium) to aid in the characterization of the bedrock. Initial calibration of these instruments is undertaken by the supplier prior to usage in the field and also checked on a daily

basis during the mapping in order to ensure consistent and correct operation. The compass and GPS units are also subjected to calibration checks on a daily basis.

Initial geomechanical characterization of the bedrock is undertaken by means of a simple field-based hammer test for intact rock strength and by estimating the average spacing between fractures. Table 2 and Table 3 describe how these geomechanical characteristics are defined.

Table 2 Field estimates of intact rock strength.

Grade	Description	Field identification
R6	Extremely strong	Specimen can only be chipped with a geological hammer
R5	Very strong	Specimen requires many blows of a geological hammer to fracture it
R4	Strong	Specimen requires more than one blow of a geological hammer to fracture it
R3	Medium strong	Cannot be scraped or peeled with a pocket knife, specimen can be fractured with a single blow from a geological hammer
R2	Weak	Can be peeled with a pocket knife with difficulty, shallow indentation made by firm blow with point of a geological hammer
R1	Very weak	Crumbles under firm blows with a geological hammer, can be peeled by a pocket knife
R0	Extremely weak	Indented by thumbnail

Note: From [6]

Table 3 Rock characterization based on observed fracture spacing.

Joint Spacing (cm)	Block Size	Description
>1000	Intact	Very large undisturbed rock mass blocks formed by two or less discontinuity sets which are not pervasive throughout the rock volume (very wide joint spacing with no intersection)
500 – 1000	Massive	Large undisturbed rock mass blocks formed by three or less discontinuity sets with very wide joint spacing
100 – 500	Sparsely Fractured	Very well interlocked, undisturbed rock mass blocks formed by three or less discontinuity sets with very wide joint spacing (fracture sets may divide the rock mass into blocks or slabs depending on the spacing of the sets and the manner of their termination)
30 – 100	Blocky	Very well interlocked, undisturbed rock mass consisting of cubical blocks formed by three orthogonal discontinuity sets
10 – 30	Very blocky	Interlocked, partially disturbed rock mass with multifaceted angular blocks formed by four or more discontinuity sets
3 – 10	Blocky/disturbed	Folded and/or faulted with angular blocks formed by many intersecting discontinuity sets
1 – 3	Disturbed	Poorly interlocked, heavily broken rock mass with a mixture of angular and rounded rock pieces
<1	Foliated/laminated/sheared	Thinly laminated or foliated, tectonically sheared rock, closely spaced schistosity prevails over any other discontinuity set, resulting in complete lack of blockiness

Note: From [7]

The culmination of the planning stage is the development of the final plan for the initial observations. The work plan includes all of the information described above and was developed in order to ensure consistency in how the initial observations are conducted in different areas. The work plan also identifies proposed daily traverses along which the general and geological attributes listed in Table 1 will be observed. For the initial observations, the traverses primarily follow existing roads and trails, however other means (e.g., boat, helicopter, etc.) may be utilized in order

to reach less accessible areas. The motivation for locating the traverses in an area is based on the distribution of the existing road and trail network and the distribution of the bedrock units of interest in the areas.

An important additional aspect of planning to conduct the initial observations is the development of a daily non-technical workflow. This set of tasks provides a framework within which the technical work can be done to meet the required objectives in a safe and consistent manner. This daily non-technical workflow includes:

- daily safety briefing to all individuals who will be in the field;
- daily instrument calibration checks;
- transport to, during and from daily mapping location(s) and while traversing during the day;
- daily data QA check and backup of collected data; and
- daily log write-up and transmittal (including shapefile indicating daily progress).

This simple workflow is adhered to while conducting the initial observations. Meetings are held nightly in order to discuss the traverse plan for the following day. On-going analysis of the initial observations, as well as access and weather conditions, may also prompt modifications to the work plan.

3.3 Engagement and knowledge sharing

First steps in each community may include ceremonies and introductions with community and Aboriginal groups, and cultural awareness training sessions. There is also an initial Health, Safety and Environment training session for all individuals, including local guides.

As part of NWMO's promise to develop partnerships with First Nation and Métis people and the local community, there is a commitment to interweaving local and Aboriginal Traditional Knowledge in all phases of NWMO's work, including the planning and conducting of the initial observations. Traditional Knowledge involves all aspects of Aboriginal peoples' unique understanding, relationship and how they connect the land to their way of life. This unique understanding influences the way in which Aboriginal people use the land.

Prior to the commencement of the geological mapping, information sharing meetings are held with local Aboriginal and non-Aboriginal people. The meetings provide an opportunity to work collaboratively on planning the mapping activities to ensure these activities will be carried out in a manner that is respectful of the land and its local users.

4. Planning and Conducting the Detailed Outcrop Mapping

The objective of the detailed outcrop mapping is to undertake additional non-intrusive field observations in a more concentrated manner in order to further refine the understanding of key geological features of the bedrock, especially the size, frequency, type and location of fractures. Most of the planning steps for the detailed outcrop mapping, including the guidance developed to ensure consistency during data collection (e.g., Tables 1, 2 and 3) and the development of a work plan, are the same as those described above in Section 3 for the initial observations and will not be

repeated below. This section focuses on describing the key additional tasks done in planning and conducting the detailed outcrop mapping, including:

- undertake a desktop remote predictive modelling exercise to identify potential locations of exposed bedrock; and
- review of new information, including findings from the initial observations and the geophysical bedrock and structural lineament interpretations of airborne gravity and magnetic survey datasets.

The results from these two tasks are combined and incorporated into a work plan for conducting the detailed outcrop mapping, as described below.

4.1 Remote predictive bedrock outcrop modelling

A predictive exercise is performed to interpret potential location of bedrock outcrop using remote sensing data. This work involves two main tasks: 1) automated object-based image analysis (OBIA) and 2) manual filtering of OBIA results to produce an output of potential outcrop locations. Predicted outcrop locations are verified, in general, through reconnaissance fly-overs prior to conducting the detailed outcrop mapping and ultimately validated during the mapping.

Automated OBIA is conducted using Trimble's eCognition 9.1 software for the candidate areas identified for detailed outcrop mapping. Forest Resource Inventory (FRI) orthoimagery is the primary dataset used in the analysis. A ruleset was developed in eCognition which initially employed multi-resolution segmentation to develop small image objects of almost pixel size. Through a series of iterative steps, the ruleset was refined and the small image objects were merged into larger more identifiable objects of distinct classes. Areas of water were classified first, followed by those areas that are spatially and spectrally similar to exposed bedrock, such as unpaved road surfaces, sand covered areas and brightly reflecting bogs. The remaining image objects were considered to most likely represent exposed outcrop and output as a distinct data set. This raw eCognition output provided a framework for manual filtering of the results to develop a reasoned interpretation of the location of probable bedrock outcrop (Figure 1).

It is understood that similarities in spectral response of areas of ground cover versus areas of exposed bedrock can result in instances of false positive and false negative exposed bedrock classification when classifying by means of OBIA. In order to use the remotely predicted outcrop data set in a meaningful way for detailed outcrop mapping, an additional step of manually comparing the raw output against the FRI imagery was conducted.

The process to undertake this filtering is straightforward and involved examining the FRI imagery in areas where the eCognition output showed clusters of pixels locating possible exposed bedrock. The cluster area is visually evaluated in the FRI imagery and a determination by consensus of two or more individual interpreters was made as to whether the location in question did or did not likely represent actual exposed bedrock. If it is determined likely, then the location is outlined and defined as a unique polygon. Often the resultant interpreted polygons were larger than those of the raw eCognition output due to the advantage of human interpretation of shaded outcrop present in forest canopy openings. This analysis produces a set of shapefiles of polygons representing interpreted bedrock outcrop locations, for all potentially suitable areas.

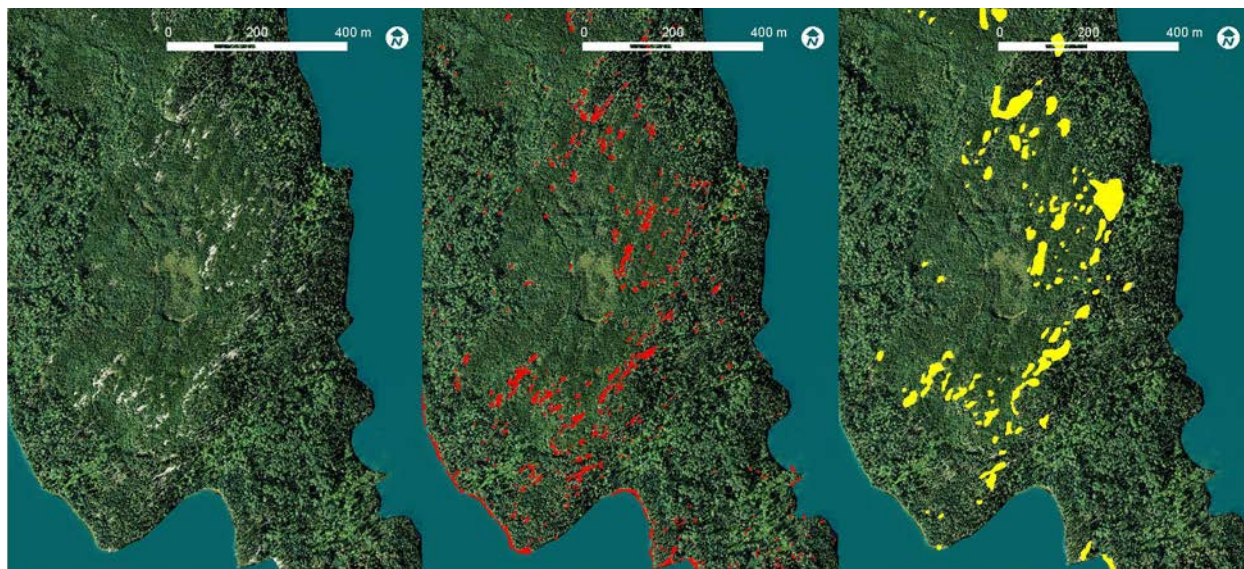


Figure 1 Example of results from the remote predictive bedrock outcrop modelling exercise. Left: FRI satellite imagery. Centre: Raw OBIA output highlighting potential bedrock outcrop locations in red. Right: Manually filtered OBIA results showing final interpretation of potential bedrock outcrop locations in yellow.

4.2 Review of available information

The detailed outcrop mapping stage benefits from the increased understanding gained by the initial observations and the results from the geophysical bedrock and structural lineament interpretations of airborne gravity and magnetic survey datasets. The information gained from these activities helps determine the candidate areas where the detailed outcrop mapping will be conducted. This new information also helps to refine the understanding of the key geoscientific features of interest in the areas, and provides insight regarding accessibility.

The increased emphasis on fracture characterization highlights the importance, in particular, of the structural lineament interpretation for identifying the major structures and features to be targeted during mapping, including geological contacts, fractures and dykes. The lineaments chosen as specific targets include primarily high certainty and long magnetic lineaments, and high certainty and long surface lineaments which subdivide the candidate areas into structural blocks of varying sizes.

The predicted bedrock outcrop locations within the candidate areas are then overlain with the identified major structures to show the spatial relationship between these two sets of features (Figure 2). This arrangement then serves as a practical guide for identifying proposed traverses along which interpreted major structures are most likely to be exposed for observation. A simple hypothesis that can be tested while conducting the detailed outcrop mapping is that bedrock locations in close proximity to interpreted major structures likely exhibit a higher density of fractures than those locations more distal to these structures. Based on this analysis, a traverse plan is then developed for the detailed outcrop mapping work plan that both tests this hypothesis and allows for the detailed characterization of fractures across the candidate areas.

The last planning step prior to conducting the detailed mapping are undertaken in the community. As is done prior to beginning the initial observations, information sharing meetings are held with local Aboriginal and non-Aboriginal people prior to the commencement of the detailed outcrop mapping. The meetings again provide an opportunity to work collaboratively on planning the mapping activities to ensure these activities will be carried out in a manner that is respectful of the land and its local users.

In addition, a reconnaissance aerial fly-over of the areas using fixed-wing aircraft is undertaken to verify the results of the remote bedrock interpretation. The detailed outcrop mapping work plan may be modified based on the outcome of these meetings, and the reconnaissance fly-over.

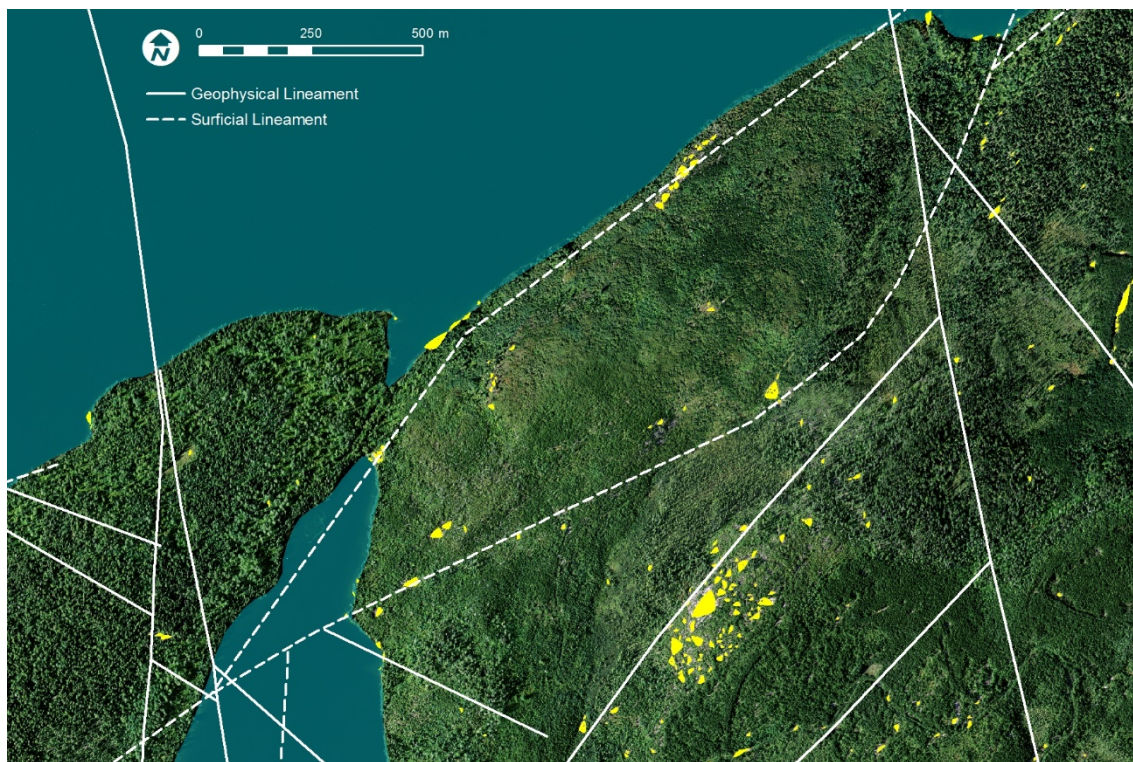


Figure 2 Interpreted geophysical and surficial lineaments (major structures), and predicted bedrock outcrop locations shown in yellow, overlain on FRI imagery.

5. Reporting and Data Delivery

The task of reporting and data delivery is generally the same for both the initial observations and detailed outcrop mapping stages. The primary variations between the two are in the amount of information reported on, with a much larger amount of information collected during detailed outcrop mapping. As discussed above, the work plans are designed to ensure that a standard approach to data collection is used in both the initial observations and the detailed outcrop mapping, across different communities participating in the site selection process. The same approach applies to the reporting and data delivery stage whereby measures are put in place in order that the collected information is compiled in a consistent manner.

A standard report structure with a common table of contents is developed for presenting the results from the geological mapping activities[8, 9, 10]. The report structure is aligned with the general and geological attributes that were the focus of the geological mapping (Table 1). Although the geological setting may vary considerably between different crystalline bedrock environments, using a common structure allows for the efficient assessment of key findings.

Digital data collection provides for relatively seamless data delivery at the end of the mapping stages. The deliverables of the initial observations and detailed outcrop mapping include ArcGIS-compatible shapefiles that contain station location, lithology, structure, photographs, and sample information that was collected and stored in a manner consistent with the general and geological attributes defined for observation (Table 1). All digital photographs and scanned field notebooks are included in the data delivery. Metadata accompanying each shapefile and other deliverables is prepared according to standard metadata guidelines that stipulate a standard file naming convention and that provide traceability of genesis of the data products.

6. Summary

The Nuclear Waste Management Organization (NWMO) is currently conducting initial field studies, including geological mapping, in a number of communities participating in a site selection process to find an informed and willing community to host Canada's deep geological repository for used nuclear fuel. These field activities are designed to further advance understanding of the geology of the areas being studied, building on previously conducted desktop studies. Consistent with NWMO's approach, all field activities are planned and conducted with the involvement and collaboration of the communities and Aboriginal peoples.

Geological mapping will be conducted in the large general areas that were identified in the Phase 1 Geoscientific Desktop Preliminary Assessment desktop studies to have the potential to meet NWMO's geoscientific site evaluation factors. The main objective of geological mapping is to further assess the geological suitability of the communities being assessed. This involves understanding of the bedrock units and their distribution and structural character, especially the size, frequency, type and location of fractures in these areas using non-intrusive measurement techniques.

The geological mapping is conducted in two stages, including an initial walking of the land followed by detailed outcrop mapping. The initial stage involves the visual observation of general geological features and focuses on general bedrock characterization, including observation of features such as bedrock type(s) and their distribution and the nature and characteristics of geological structures within these areas. The findings from these initial observations, combined with data collected from other field studies such as airborne geophysical surveys and structural lineament interpretations of the resulting geophysical datasets, help determine candidate areas for detailed outcrop mapping.

Planning is an important first step of both the initial observations and detailed outcrop mapping stages of the geological mapping. The pre-mapping planning provides the overall strategy and guidance for the completion of initial observations and detailed outcrop mapping stages in a manner that ensures the approach is consistent between the different study areas where the geological mapping is to be conducted. Planning includes the development of a standard list of geological and other features to be documented, a standard set of tools and methods used to collect and record the relevant information and a standard approach to reporting and data delivery. The plan also includes guidance on the non-technical daily work flow to be followed during the geological mapping.

7. References

- [1] AECOM Canada Ltd., “Phase 1 Geoscientific Desktop Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada’s Used Nuclear Fuel, Township of Schreiber, Ontario”, Prepared for Nuclear Waste Management Organization (NWMO), NWMO Report APM-REP-06144-0035, 2013, Toronto, Canada.
- [2] Golder (Golder Associates Ltd.), “Phase 1 Geoscientific Desktop Preliminary Assessment of Potential Suitability for Siting A Deep Geological Repository for Canada's Used Nuclear Fuel, Town of Creighton, Saskatchewan”, Prepared for Nuclear Waste Management Organization (NWMO), NWMO Report APM-REP-06144-0051, 2013, Mississauga, Canada.
- [3] Golder (Golder Associates Ltd.), “Phase 1 Desktop Geoscientific Preliminary Assessment of Potential Suitability for Siting a Deep Geological Repository for Canada’s Used Nuclear Fuel, Township of Ignace, Ontario”, Prepared for Nuclear Waste Management Organization (NWMO), NWMO Report APM-REP-06144-0011, 2013, Mississauga, Canada.
- [4] M. Ben Belfadhel, “Siting Canada’s deep geological repository for used nuclear fuel- an update on the technical site evaluation process”, 3rd Canadian Conference on Nuclear Waste Management, Decommissioning and Environmental Restoration Ottawa Marriott Hotel, Ottawa, ON, Canada, September 11-14, 2016.
- [5] Barton, N.R., “Suggested methods for the quantitative description of discontinuities in rock masses”, International Journal of Rock Mechanics and Mining Sciences, Vol. 15, 1978, pp. 319–368.
- [6] Hoek, E. “Practical Rock Engineering”, e-book, 2007, 47 p.
https://www.rockscience.com/hoek/corner/Practical_Rock_Engineering.pdf
(Accessed February 2014)
- [7] Shimamura, K., Williams, S. P. and Buller, G. “Ganfild user guide: a map-based field data capture system for geoscientists”, Geological Survey of Canada, Open File 5912, 2008, 90 p.
- [8] Fladgate (Fladgate Exploration Consulting Corporation) and Geofirma (Geofirma Engineering Ltd.), “Phase 2 Geoscientific Preliminary Assessment, Observation of General Geological Features, Township of Schreiber, Ontario”, Prepared for Nuclear Waste Management Organization (NWMO), NWMO Report APM-REP-06145-0008, 2015, Toronto, Canada.
- [9] SRK (SRK Consulting Inc.) and Golder (Golder Associates Ltd.), “Phase 2 Geoscientific Preliminary Assessment, Observation of General Geological Features, Town of Creighton, Saskatchewan”, Prepared for Nuclear Waste Management Organization (NWMO), NWMO Report APM-REP-06145-0012, 2015, Toronto, Canada.
- [10] SRK (SRK Consulting Inc.) and Golder (Golder Associates Ltd.), “Phase 2 Geoscientific Preliminary Assessment, Observation of General Geological Features, Township of Ignace,

Ontario”, Prepared for Nuclear Waste Management Organization (NWMO), NWMO Report
APM-REP-06145-0004, 2015, Toronto, Canada.