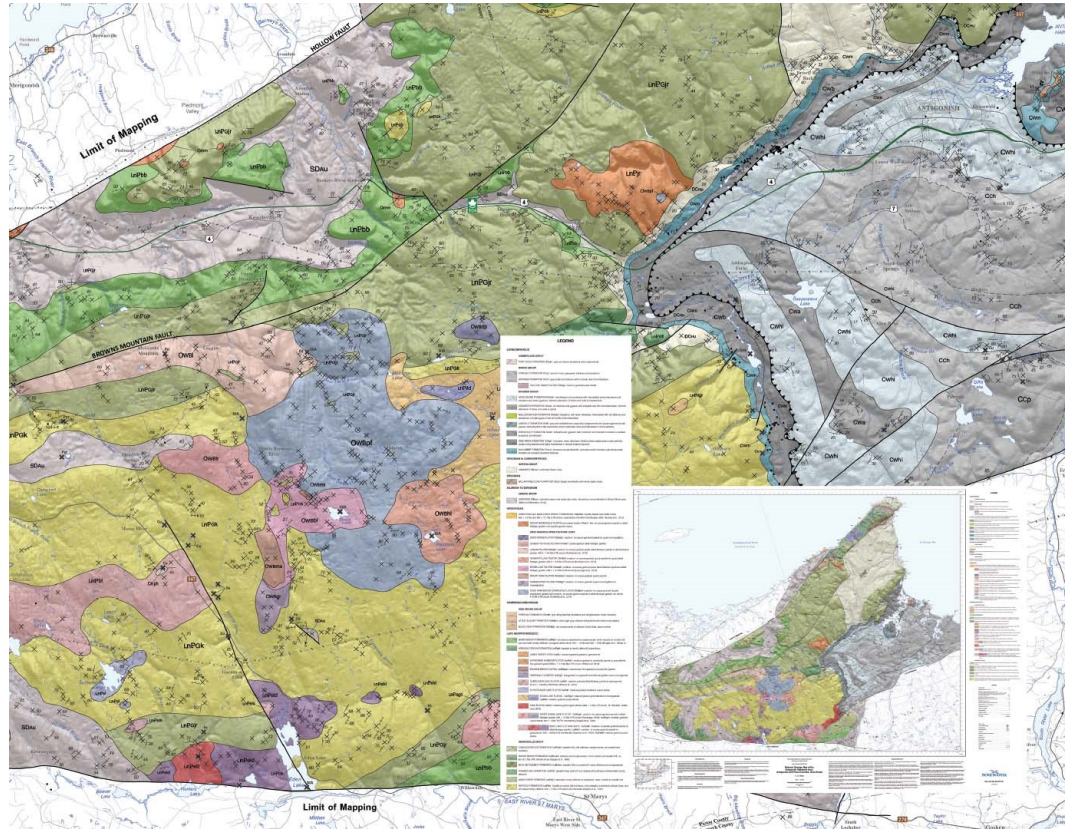


Report of Activities 2018-2019



Report ME 2019-002

Eds. E. W. MacDonald and D. R. MacDonald



Halifax, Nova Scotia

August 2019

Note

This *Report of Activities* summarizes the fiscal year from April 1, 2018, to March 31, 2019. On July 5, 2018, the Geoscience and Mines Branch merged with the Department of Energy to create the Nova Scotia Department of Energy and Mines.

Cover Illustration

Open File Map ME 2018-001 of the Antigonish Highlands was selected and featured in the 2019 Esri Canada calendar. For more information on the map, and other GIS activities, please refer to Poole et al., p. 49-58.

Editing and Layout: E. W. MacDonald and D. R. MacDonald

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Nova Scotia Department of Energy and Mines

Honourable Derek Mombourquette
Minister

Simon d'Entremont
Deputy Minister

Year One of the Mineral Resources Development Fund

J. C. Bonaparte

Introduction

The Nova Scotia Mineral Resources Development Fund (MRDF) was established in 2018 as a replacement for the Nova Scotia Mineral Incentive Program, which operated from 2012 to 2017. The goal of the program is to promote and increase mineral exploration and development in Nova Scotia. The program is administered by the Geoscience and Mines Branch of the Nova Scotia Department of Energy and Mines, and features funding streams for grass-roots mineral exploration, shared funding projects, innovation, education and outreach, marketing, post-secondary research, and major projects.

This report provides an overview of the inaugural year of the MRDF, with an emphasis on the value achieved through the grants provided for mineral exploration.

Program Funding

The MRDF was initially allotted a budget of \$700,000 for the 2018-2019 fiscal year. Due to the amount of interest in the program, however, the department was able to request additional funds, to a total of \$818,750. The program was able to provide funds to 30 projects throughout the province, and across all funding streams.

One of the main objectives of the MRDF is to support prospectors and exploration companies in their efforts to find new discoveries, and advance existing projects closer to production. To this end, nineteen Prospecting and Exploration Grants supporting grass-roots exploration activities totaling \$287,300 were approved in 2018-2019. When combined with the three Shared Funding Grants worth \$158,650, a total of \$445,950 or approximately 54% of the program's total spending was allocated to assisting prospectors and exploration companies (Fig. 1).

Prospectors are also able to apply for Marketing Grants, which assist them to travel to industry

events such as the Prospectors and Developers Association of Canada convention in Toronto or the Mineral Exploration Roundup in Vancouver. A number of prospectors took advantage of this opportunity and scheduled meetings at the events with exploration companies that have the potential to bring investment to Nova Scotia.

One Major Project Grant totaling \$62,000 was awarded in 2018-2019. The Mining Association of Nova Scotia (MANS) used this funding to conduct a province-wide assessment of the need for airborne geophysical data. MANS was also awarded two Education, Outreach, and Engagement Grants. The results of their projects will help support the mining industry in Nova Scotia and build public confidence in the industry.

There were four Research Grants issued in 2018-2019, amounting to \$105,600. The research performed in these studies has the potential to find new mineral deposits and to develop new or more efficient methods of processing minerals.

Finally, one Innovation Grant in the amount of \$142,000 was issued this year. The goal of this project is to develop an effective way of remediating contaminated mine tailing sites in Nova Scotia.

The Year Ahead

The Mineral Resources Development Fund has an approved budget of \$1.5 million in the 2019-2020 fiscal year, which will allow the department to fund even more projects. Expecting the increase in funding to attract more interest in the program, the department hosted an educational workshop on April 3, 2019, in advance of the fund being open to applications. The topics discussed at the workshop provided potential applicants with a greater understanding of how to prepare a high-quality proposal when the program launches on April 9, 2019.

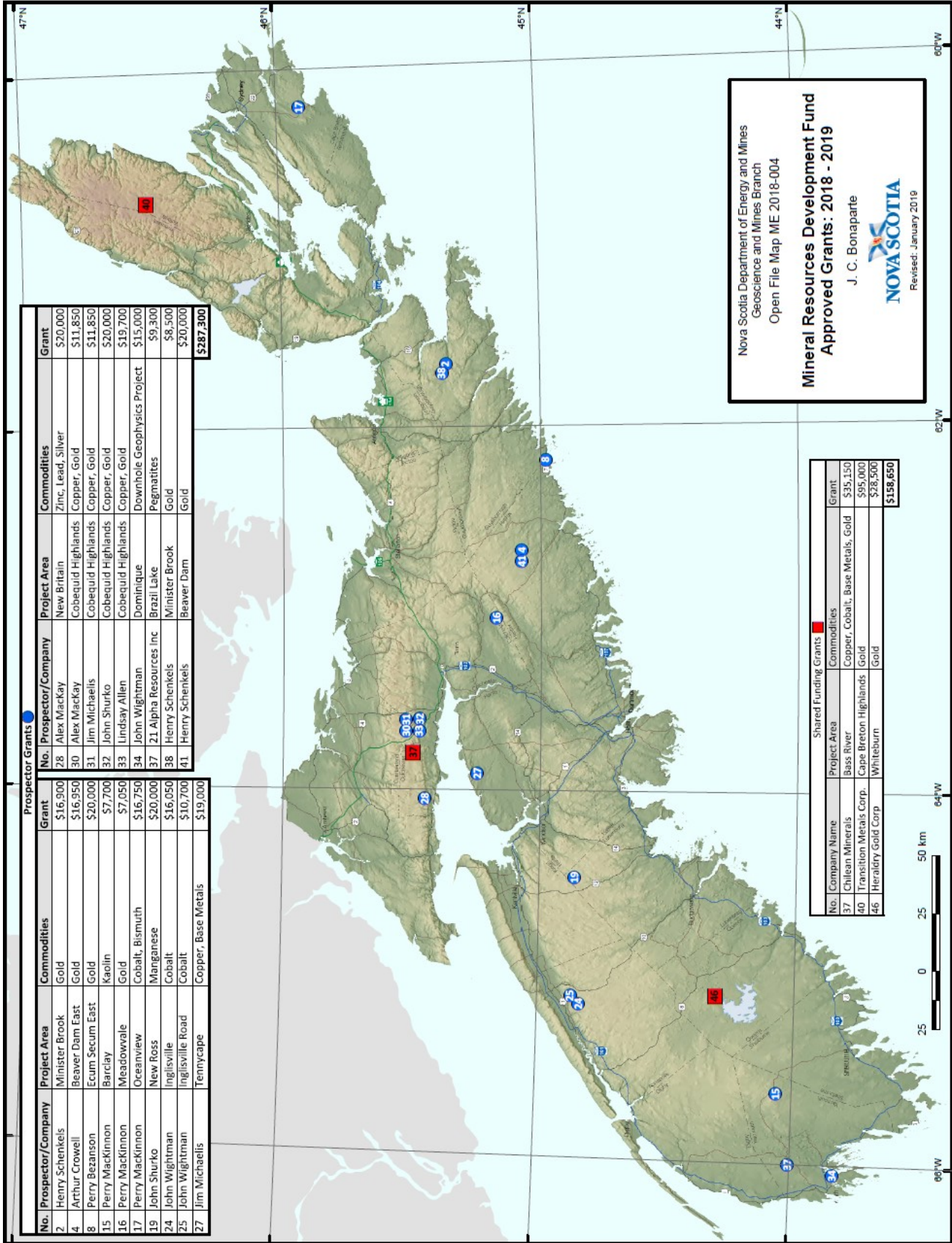


Figure 1. Approved Prospecting and Exploration, and Shared Funding Grants, 2018-2019.

Indicator Mineral and Till Geochemical Signatures of the East Kemptville Sn-Zn-Cu-Ag Deposit, Southwestern Nova Scotia, Canada

D. M. Brushett, C. G. Smith¹, and M. B. McClenaghan²

Introduction

An indicator mineral and till geochemical case study around the East Kemptville Sn-Zn-Cu-Ag deposit was conducted during the summer of 2018 as a continuation of surficial mapping and sampling activities in southwest Nova Scotia. In this region, multiple phases of ice flow during the Wisconsinan glaciation produced thick glacial sediment cover and complex glacial dispersal patterns that have hindered exploration for buried mineralization in southwestern Nova Scotia (Stea and Grant, 1982).

The objectives of this study were (1) to characterize the type and abundance of indicator minerals and elements in till at varying distances from a known tin deposit using modern surficial exploration methods; and (2) to compare the mineralogical and elemental data in till and bedrock heavy-mineral concentrates to previous till and bedrock mineralogy studies in the region and also to recent till geochemical studies of Sn and W mineralization from intrusion-related deposits.

The study was a collaborative effort between the Nova Scotia Department of Energy and Mines and the Geological Survey of Canada and was also part of a B. Sc. Honours thesis project at Acadia University (Smith, 2019). In this report of activities, an overview of the field and analytical methods is provided.

Background

Till geochemistry has been used successfully for Sn exploration in glaciated terrain (e.g. Szabo et al., 1975; Toverud, 1982; Peuraniemi et al. 1984; Finck et al. 1990), and it was an integral part of the discovery of the East Kemptville deposit. Shell

Canada Resources followed up on the discovery of mineralized boulders with a regional till-geochemistry program that identified a large glacial dispersal train of tin extending up to 50 km southeast of the deposit (Wilson and Richardson, 1980; Rogers et al. 1990). Further regional prospecting and till geochemical programs conducted in the 1970s and 1980s identified several areas with anomalous Sn and numerous mineral occurrences associated with the East Kemptville shear zone, a zone of pervasive shearing along the north edge of the South Mountain Batholith near East Kemptville (e.g. O'Reilly and Kontak, 1992; Horne et al., 2006). The most notable mineralization in the area is the greisen-hosted East Kemptville Sn-Zn-Cu-Ag deposit that is associated with Zn, Cu, Ag, and In. Other granite- and metasediment-hosted shear- and replacement-style Sn and base metal mineral prospects include Duck Pond (Sn-Cu-Zn-In), Pearl Lake (Sn-Zn-Cu-In) and Dominique (Sn-Zn-Cu-In) (O'Reilly, 2016) (Figure 1).

Most published reports of till-sampling programs for Sn and W exploration carried out in the 1970s and 1980s (e.g. Lindmark 1977; Brundin & Bergstrom 1977; Toverud 1984; Johansson *et al.* 1986) used heavy mineral methods that were different between each study and not available in commercial labs and geochemical methods that were time consuming and expensive. Recent studies on the use of indicator minerals and geochemistry around Sn and W deposits in New Brunswick used modern methods of till analysis for which the determination of Sn and W content is now routine and inexpensive. Example studies includes those conducted at the Sisson W-Mo deposit (McClenaghan et al., 2014a, 2017) and the Mt. Pleasant Sn-W-Mo-Bi-In deposit (McClenaghan et al., 2014b, 2016). These studies and others are also amongst the first detailed indicator mineral

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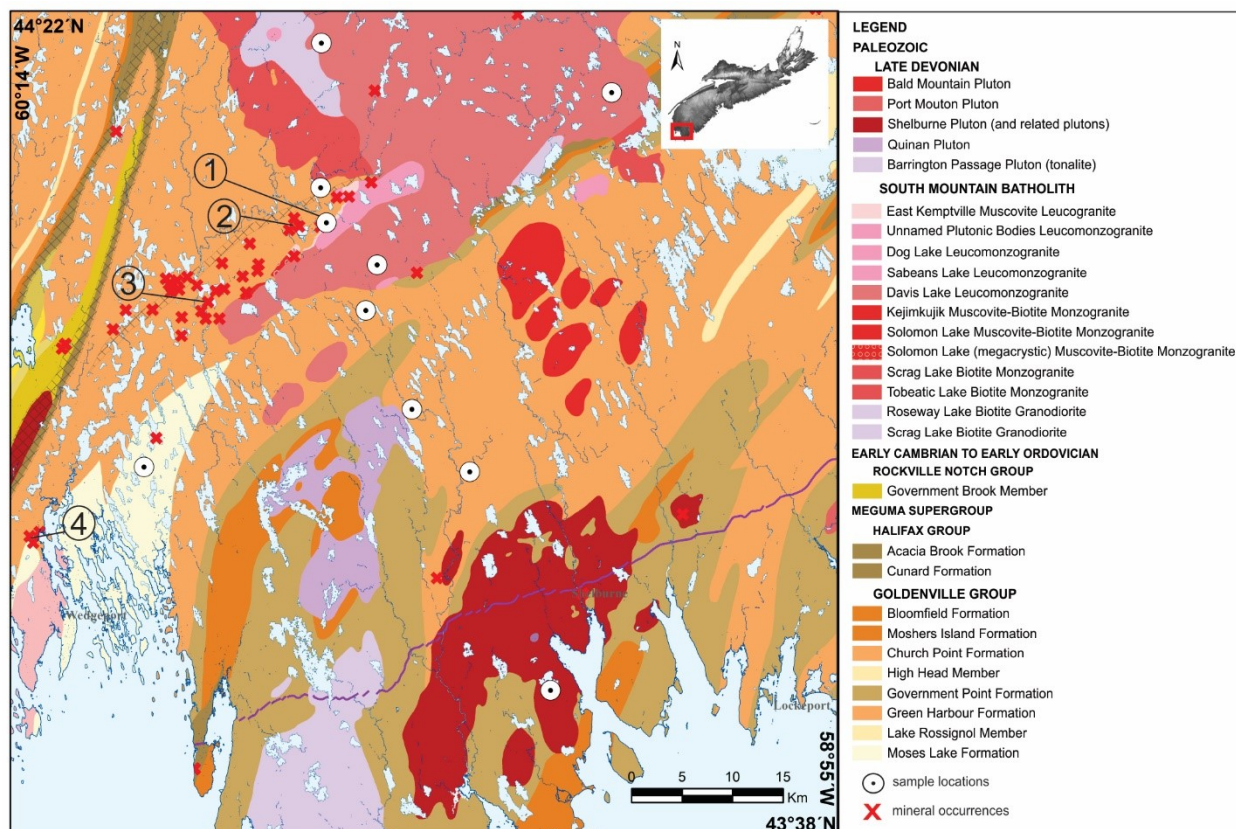


Figure 1. Sample locations underlain by bedrock geology (White, 2012). The study area is indicated by the red box in the inset map. Mineral occurrences are marked by red crosses; those discussed in text include 1. East Kemptville Sn-Zn-Cu-Ag deposit, 2. Duck Pond Sn-Cu-Zn-In prospect, 3. Pearl Lake Sn-Cu-Zn-In prospect, and 4. Dominique Sn-Cu-Zn-In prospect.

studies of till around major Sn and W deposits in glaciated terrain. These new studies produced a more extensive list of indicator minerals and elements than previously identified because of the broader suite of elements that can now be determined using modern analytical techniques.

Methods

Fieldwork was conducted by truck and helicopter over the summer of 2018. Ten sites were sampled for till at varying distances from the deposit and along a previously identified southeast-trending till dispersal train: five sites were down-ice (southeast) of the deposit, one site overlay the deposit, one site was up-ice (northwest) of the deposit, and three sites were sampled to represent the regional background. Two sites were sampled as field duplicates.

Samples were collected either from hand-dug test pits or from roadcuts following the Geological

Survey of Canada protocols for processing glacial sediments for the recovery of indicator minerals and geochemical analyses of tills (McClenaghan et al., 2013; Plouffe et al., 2013). At each site, two samples were taken from the C-horizon at ~90 cm depth: a small sample (1–3 kg) was taken for geochemical analysis of till matrix and archiving, and a large sample (10–15 kg) was taken to ensure sufficient recovery of indicator minerals. Samples were collected in clean, 6 mm clear plastic bags, secured with cable lock ties, and then stored and shipped in 20 L plastic pails. Field data collected at each site included GPS co-ordinates, general site description, sample description (soil horizon, texture, Munsell colour, lithology of clasts, relative percentages of clasts, matrix description [i.e. percent sand, silt, clay] and sample depth), and the description and measurement of any ice-flow indicators.

The small (1–3 kg) till samples were dried and sieved to the <63 μm fraction (-230 mesh) to recover the silt plus clay fraction. Two separate

aliquots from the <63 µm fraction were submitted to Bureau Veritas (Vancouver, BC). The first was a 30 g aliquot that was analyzed using a modified aqua regia digest (HCl:HNO₃ in a 1:1 ratio) followed by inductively coupled plasma-mass spectrometry (ICP-MS). The second aliquot was 0.2 g and was analyzed using lithium metaborate/tetraborate fusion followed by a nitric acid digestion, inductively coupled plasma emission spectroscopy, and ICP-MS. This borate fusion analysis digested all mineral phases and determined the total element content that is optimal for determining tin concentrations. Two field duplicate samples were taken for quality assurance/quality control (QA/QC) purposes. Six CANMET certified reference standards (TILL-1 and TILL-4) were inserted into the sample suite to evaluate analytical accuracy.

The large (10–15 kg) till samples were shipped to Overburden Drilling Management Limited (ODM), Ottawa, Ontario, for indicator mineral processing. Samples were processed using a combination of tabling, panning and heavy liquid (methylene iodide) separation at a specific gravity of 3.2 to produce 0.25 to 0.5 mm, 0.5 to 1.0 mm, and 1.0 to 2.0 mm non-ferromagnetic heavy mineral fractions for picking of indicator minerals. Fractions were examined for gold, metallic oxide (e.g. cassiterite SnO₂), and silicate indicator minerals. Two blank samples were inserted at beginning and in the middle into the indicator mineral sample batch to monitor cross-contamination.

Four bedrock samples collected from the East Kemptville mine site were also submitted to ODM for heavy mineral recovery to compare with the indicator minerals recovered in till samples. Bedrock heavy-mineral concentrates were produced from these samples by reducing their grain size to <2 mm using electric pulse disaggregation. The <2 mm fraction was then processed using tabling and heavy liquid methods similar to those used for till samples to recover 0.25 to 0.5 mm, 0.5 to 1.0 mm, and 1.0 to 2.0 mm non-ferromagnetic heavy mineral fractions for picking of indicator minerals.

Results to Date

Indicator minerals identified in till down-ice of the deposit include cassiterite, wolframite, scheelite, and topaz. Indicator minerals recovered in the 0.25 to 0.5 mm fraction define glacial dispersal of at

least 50 km southeast of the deposit; cassiterite was identified 30 km southeast and topaz 50 km southeast of the East Kemptville deposit. Elevated concentrations of indicator elements in the <63 µm fraction of till include Sn, Cu, Zn, Ag, and In. Tin was found in elevated concentrations up to 50 km southeast of the deposit, along the previously published Sn dispersal train defined by Shell Canada Resources. Pathfinder elements identified in till include W, Mo, Cs, Bi, As, and Cd.

Future Work

All data, including sample site and location data, till-matrix geochemical data, and indicator mineralogy data for till and bedrock samples will be released along with QA/QC data from duplicate and blank samples in an upcoming open file report from the Nova Scotia Department of Energy and Mines.

Acknowledgments

The authors thank Dave Sinclair, Geological Survey of Canada (retired), for sharing bedrock samples from the East Kemptville area for this study; Randy Cleveland for providing access to the East Kemptville site; and Ian Moore, Reuben Solomon, and Ardell Smith (Air Services, Department of Lands and Forestry) for providing helicopter support. Processing of till and bedrock samples for heavy minerals was funded by the Geological Survey of Canada's Targeted Geoscience Initiative under the Porphyry-style Mineral Systems Project - P 3.3 Mineralogical controls on the fertility of porphyry-style systems.

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Progress Report on the Cliffs of Fundy Aspiring Global Geopark

J. H. Calder

Introduction

The community-based initiative to seek UNESCO Global Geopark designation for the north shore of the Minas Basin in Cumberland and Colchester counties reached further milestones in the 2018-2019 fiscal year. The concept of a global geopark was introduced to the board of the Cumberland Geological Society, the not-for-profit organization that administers the Fundy Geological Museum in Parrsboro. The ‘Parrsboro Shore’ (Fig. 1) was identified as a candidate region for a geopark as an outcome of the Nova Scotia Geoheritage Sites List (Calder and Poole, 2017), which documented a high concentration of geosites along this coast of the Bay of Fundy. The facility and programming of the Fundy Geological Museum was a contributing factor in the identification of a prospective geopark.

Global Geoparks are community-driven initiatives, based on linking a region’s cultural heritage with that of its geological heritage. Sustainable economic development is a key aspiration of Global Geoparks. The program began in Europe in 2000, and joined forces with China’s geoparks in 2014 to become the Global Geoparks Network (GGN). In 2016, Global Geoparks became a program of UNESCO, and today the program comprises 140 geoparks in 38 countries, of which three have been designated in Canada. Unlike conventional parks in North America, Global Geoparks carry no land-use restrictions.

Community ‘town halls’ held across the prospective geopark in 2017 showed near unanimous support for proceeding with the initiative. In 2017, funding for the project was announced by the Atlantic Canada Opportunities Agency (ACOA), with contributions from the two

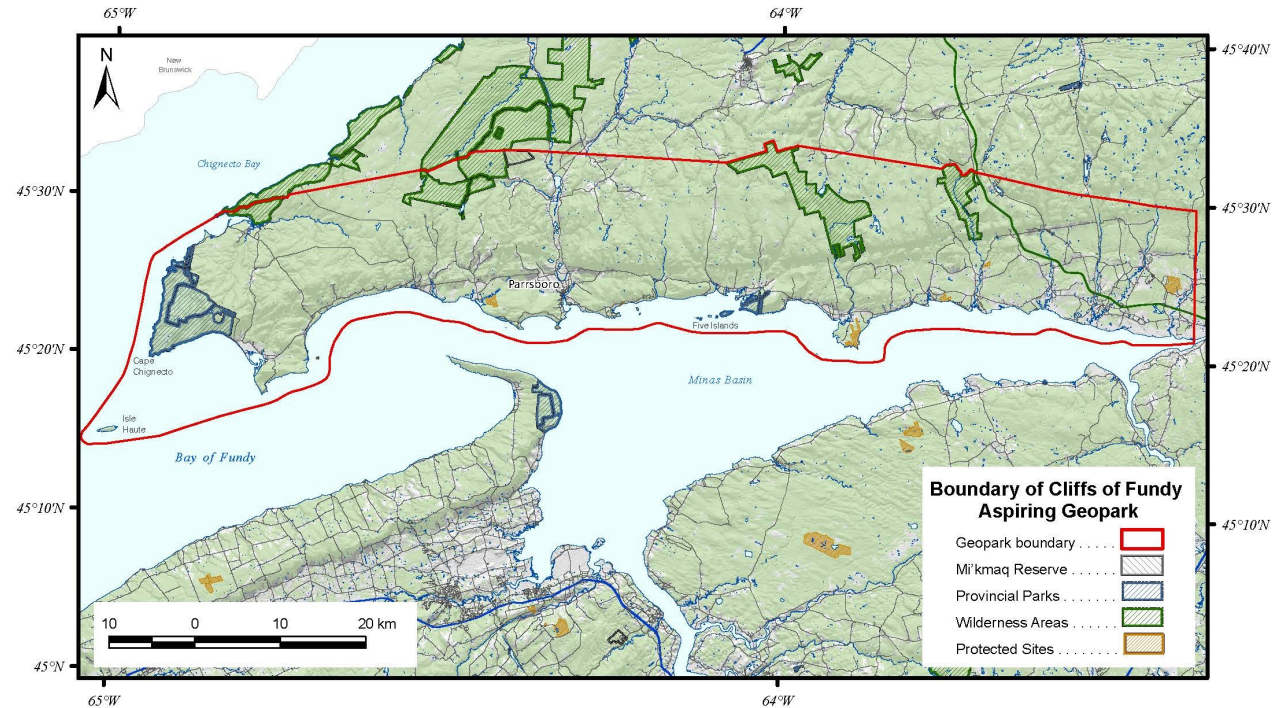


Figure 1. Map of the boundary of the Cliffs of Fundy Aspiring Geopark.

municipalities of Cumberland and Colchester, and the Nova Scotia Department of Communities, Culture and Heritage. Subsequently, a resident of Bass River, Marlee Leslie, was hired as Project Coordinator. The Geological Survey Division of the Nova Scotia Department of Energy and Mines provided expertise in identification of prospective geosites and their significance, as well as developing the over-arching geological storyline for the aspiring geopark.

A central tenet of the aspiring geopark is to represent the traditional storylines of the Mi'kmaq people, for whom the area represented by the geopark holds special meaning. The region occupies the traditional territory of Kluscap, whose exploits shaped the coastal landscape of Five Islands, Three Sisters, Isle Haute, and many other geosites. The geopark will endeavor to treat this as an example of “two-eyed seeing,” wherein indigenous and western scientific explanations are treated equally. In response to feedback from the Mi'kmaq community (Elders Advisory Council and Confederation of Mainland Mi'kmaq), the eastern boundary of the geopark was extended to include Mi'kmawey Debert, the earliest indigenous site in northeastern North America.

Progress Achieved in 2018

In 2018, a draft application for the Cliffs of Fundy was completed and submitted to the Canadian National Committee for Geoparks (CNCG), and to the Canadian Commission for UNESCO. Together, these groups evaluate the readiness of aspiring geoparks in Canada to submit their application to UNESCO for formal evaluation and first arrange for the aspiring geopark to host a pre-evaluation mission by the CNCG. The application was lauded by the CNCG as setting a new benchmark for applications of aspiring geoparks in Canada.

In June 2018, the Cliffs of Fundy hosted two members of the CNCG (Sarah Gamble, Tumbler Ridge UNESCO Global Geopark, British Columbia, and Pierre Verpaelst, CNCG member, retired from the Québec Geological Survey), who assessed the readiness of the aspiring geopark to proceed with its application to UNESCO (Fig. 2). Their assessment described the aspiring geopark as “impressive” and that it was now a *de facto* geopark.

The CNCG evaluators advised that a long-standing but controversial position of the Global Geoparks



Figure 2. Evaluators from the Canadian National Committee for Geoparks visiting the geosite of East Bay.

network has been to disallow organizations involved in the direct sale of mineral products from partaking in the governance of the geopark. This position is seen as problematic as it suggests that the long-standing tradition of collection and trade of sustainably sourced minerals, such as the provincial gemstone agate in the Bay of Fundy region, is improper, even though it has been a sustainable tradition spanning millennia. It is important to note that this issue involves governance only and does not mean that mineral collecting or sales will be discontinued; UNESCO has no jurisdiction over laws in any country. Provincial laws and guidelines for mineral collecting remain unchanged. For guidance pertaining to mineral collecting in Nova Scotia, please refer to Nova Scotia Department of Natural Resources (2007).

This challenging issue consumed considerable resources during the Fall of 2018, but led to a resolution with the Cumberland Geological Society that allowed submission of the revised application to UNESCO before the end November deadline (Fig. 3). This resolution ensures that the Fundy Geological Museum will remain a key partner in the Geopark, and that the Nova Scotia Gem and Mineral Show continues as a vibrant event.

The Road Ahead: 2019-2020

A permanent governing board for the Cliffs of Fundy was established early in 2019, led by the Municipalities of Cumberland and Colchester with broad community and indigenous representation. Early in 2019, UNESCO announced that the Cliffs of Fundy Aspiring Geopark would be one of 14 aspiring geoparks worldwide to be evaluated this year. During the summer of 2019, a UNESCO evaluation mission will formally evaluate the aspiring geopark and thereafter will submit their recommendations to the Executive Committee of the Global Geoparks Network for their consideration in September 2019. Subsequently, the recommendation of the GGN will be forwarded to the general assembly of UNESCO for their consideration and decision in March-April 2020, at which time the outcome will be made known.

Regardless of that outcome, the exercise of seeking global geopark status has highlighted the rich geological heritage for the residents and government representatives of this exceptional region of Nova Scotia.

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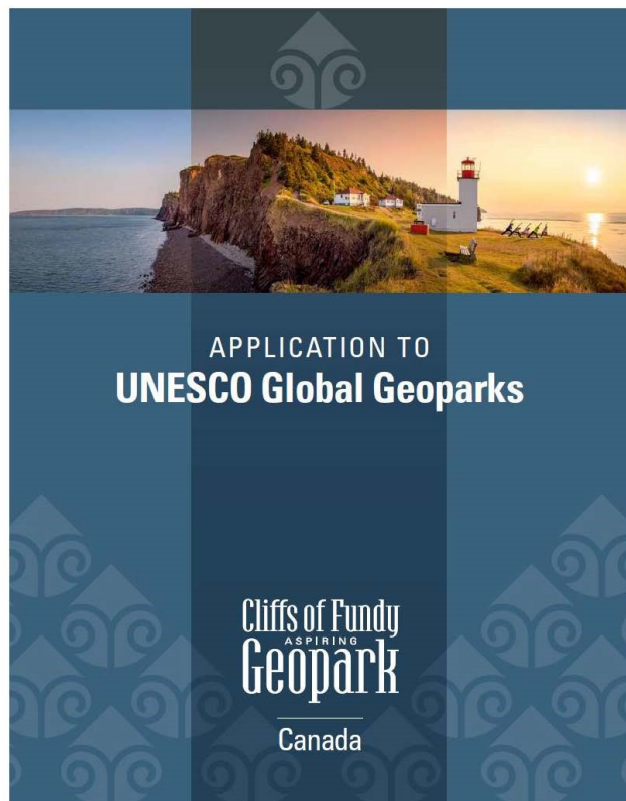


Figure 3. Cover of the Cliffs of Fundy application to UNESCO.

Geohazards in Nova Scotia – Overview of Program Activities, April 2018 to March 2019

J. Drage and G. W. Kennedy

Introduction

Geohazards are natural geological hazards that are caused by the earth and have potential to cause harm to humans, infrastructure, and the environment. There are several important geohazards in Nova Scotia. Examples include radon gas in indoor air, sinkholes in karst terrain, and historical mine tailings. The Nova Scotia Department of Energy and Mines' (NSDEM) geohazard work focuses on identifying and mapping the most significant geohazards in the province to ensure they are understood and mitigated. Selected activities undertaken within the Geohazard Program for the period from April 1, 2018 to March 31, 2019 are highlighted below.

Radon in Indoor Air

Radon gas occurs naturally in soil, rock, and groundwater and can migrate through cracks and openings in foundations and accumulate inside buildings. Radon in indoor air is the second leading cause of lung cancer after smoking. Health Canada estimates that radon causes more than 3,000 deaths each year in Canada (Health Canada, 2015). In Nova Scotia, it is estimated that 11% of homes exceed the indoor air radon guideline and that more than 100 people die each year due to radon exposure (CAREX Canada, 2016).

In 2018–19, the department's radon work focused on developing and maintaining the provincial radon database, participating on the Nova Scotia Radon Working Group, and conducting research on seasonal variations of indoor radon levels. We also supported the Nova Scotia Public Libraries radon detector loan program.

The program to loan radon detectors through libraries was launched in November 2017. The goals of the program are to help raise awareness about radon, promote radon testing, and highlight the easy and inexpensive ways it can be done. The

program is the first of its kind in Canada and was led by the Lung Association of Nova Scotia with support from the Province, Nova Scotia Public Libraries, and Health Canada. The program initially involved the placement of 50 user-friendly digital radon detectors in public libraries for homeowners to borrow. Additional detectors were added in 2018 bringing the total to 146. The program has been very popular (CBC, 2018), and as of March 2019 there were over 1,100 people on the wait list to borrow a detector. In March 2019, NSDEM purchased an additional 21 radon detectors to help meet the demand. This will bring the total number of detectors available at public libraries to 167.

As part of the library loan program, homeowners can send their radon results on a volunteer basis to the Department of Energy and Mines via a dedicated email address (radon@novascotia.ca). The results are compiled into a database and used to map radon risk throughout the province. As of March 2019, there have been 83 results received (Table 1). Approximately 18% of these exceed the Canadian radon guideline of 200 Bq/m³ (Health Canada, 2014). Homeowners with radon results that exceed the guideline were provided information on how to reduce radon levels in their homes.

Radon levels in buildings are known to vary seasonally due to seasonal weather changes (e.g. temperature, wind patterns) and the seasonal habits of building occupants (e.g. doors and windows may be left open more often in the summer than winter, affecting air-exchange rates). Indoor radon levels are typically higher in winter than summer. When testing radon levels in a building, it is helpful to know how seasonal variations can affect the estimate of the annual average radon level. This is important because the radon guideline is based on the average annual radon level. However, most homeowners run their radon tests for three months or less, rather than one year. Several jurisdictions have published seasonal radon correction factors so that short-term tests can be adjusted to reflect the

Table 1. Voluntary radon test results received from homeowners (Nov 2017 to Mar 2019)

Description	Value
Number of samples, n	83
Number exceeding Canadian guideline of 200 Bq/m ³	15 (18%)
Maximum (Bq/m ³)	5,012
Minimum (Bq/m ³)	3
Average (Bq/m ³)	221
Median (Bq/m ³)	70
Average length of test (weeks)	5
Number of tests that were at least 4 weeks long	74 (89%)

average annual radon level in a building. These are not currently available for Nova Scotia and, therefore, a project was initiated in 2019 to monitor seasonal changes to indoor radon levels. The project will use continuous radon detectors in 10 volunteer homes for one year. The radon detectors will be installed in 10 different homes each year until enough data are available to calculate seasonal

radon correction factors. Figure 1 shows preliminary results from an eight-week test in a basement of a residential home in Halifax between January 2019 and March 2019. During this test, the radon level varied from approximately 100 Bq/m³ to 480 Bq/m³ and averaged 258 Bq/m³. Additional results from this study will be reported in subsequent years as the study progresses.

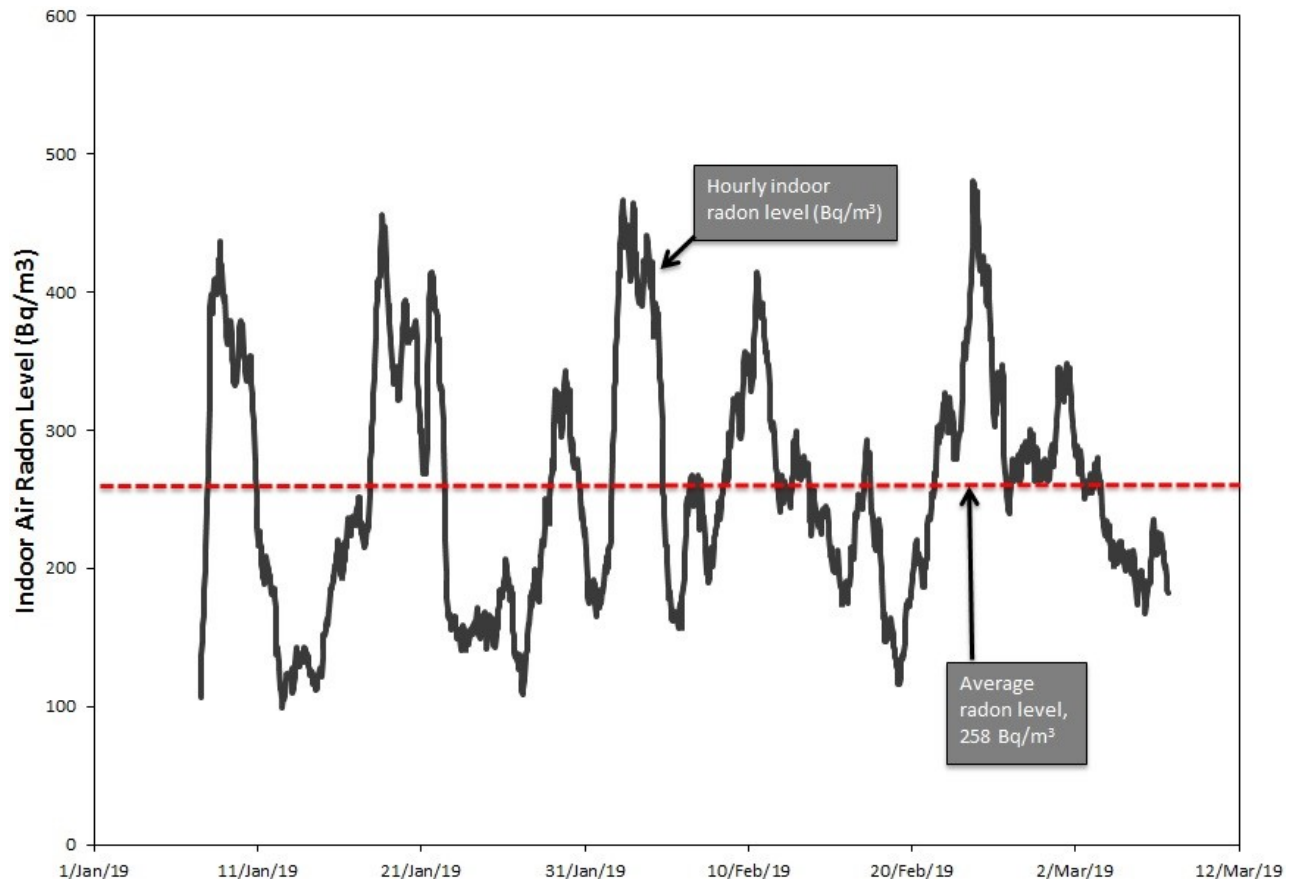


Figure 1. Hourly indoor radon levels from a residential basement in Halifax (Jan-Mar 2019).

For further information about radon, please visit the Nova Scotia radon risk map, which includes links to information on how to purchase radon test kits and how to find certified radon contractors for mitigation work (Nova Scotia Department of Energy and Mines, 2009).

Karst Risk Map

Sinkhole development in karst terrain can cause extensive damage to buildings, roads, and other infrastructure. In Nova Scotia, most natural sinkholes associated with karst are formed in areas where gypsum occurs, although other rock types in the province are also known to have sinkholes. In 2015, a project was initiated to develop a new provincial karst risk map. The work involved the compilation of existing geology maps and karst occurrence data, review of lidar data, and field verification of sinkhole occurrences. The resulting database contains over 1,000 records of known locations with karst topography, sinkholes, and

karst springs. The new interactive karst risk map and associated open file report were released in February 2019. The new karst risk map is shown in Figure 2. The map (Nova Scotia Department of Energy and Mines, 2019) and open file report (Drage, 2019) can be accessed from the Geoscience and Mine Branch's sinkhole webpage (Nova Scotia Department of Energy and Mines, 2013). In addition to completing the new karst risk map, the department assisted with the evaluation of a significant sinkhole that developed in the Town of Oxford in July 2018. A separate report on the Oxford sinkhole can be found in this issue of Report of Activities (please see page 63).

Other Activities

Gold mining that occurred in Nova Scotia between the 1860s and the 1940s produced over three million tonnes of tailings at 64 historical gold-mining districts. During this period, no environmental regulations were in place and tailings were

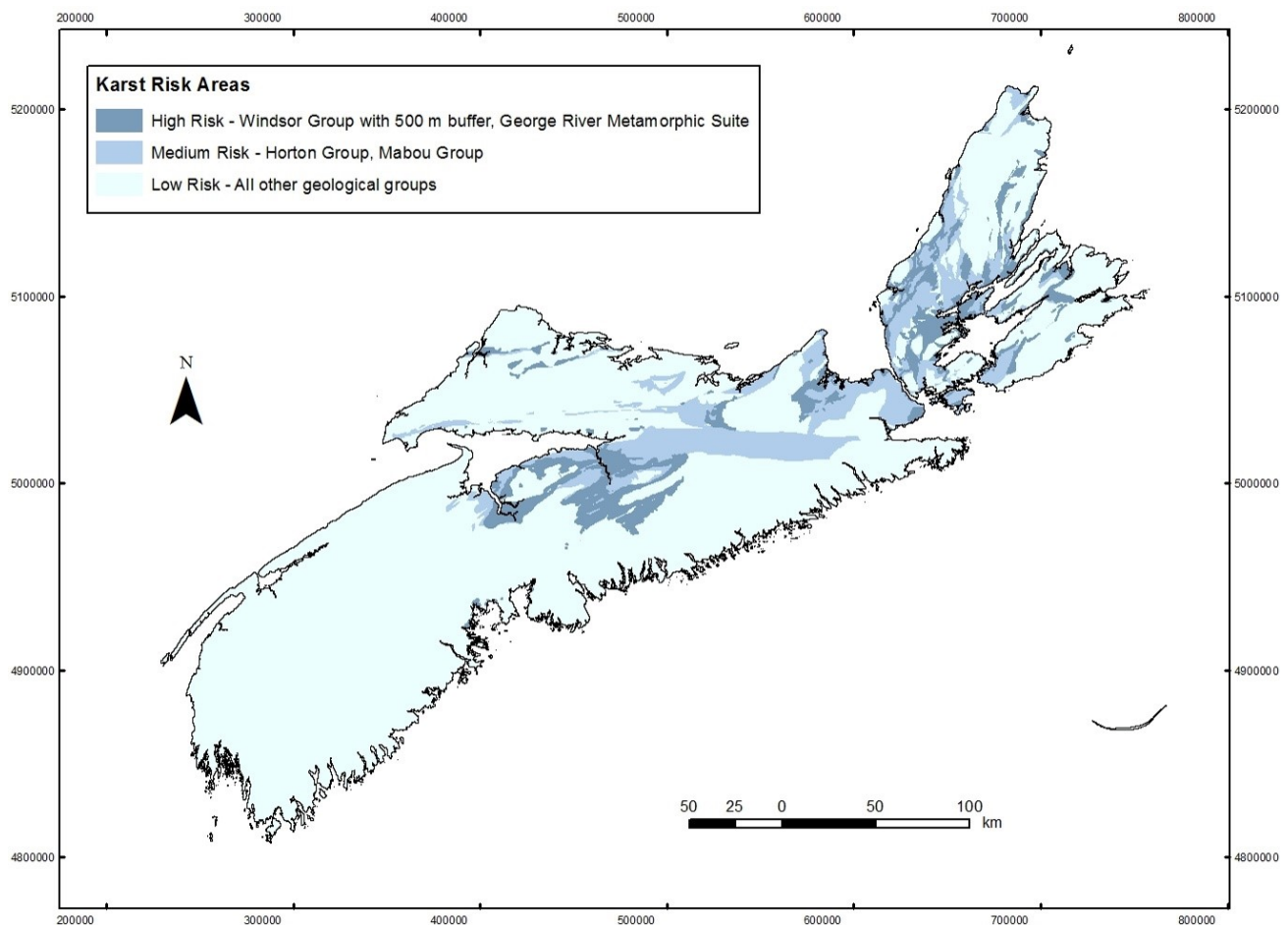


Figure 2. A karst risk map of Nova Scotia.

commonly discharged into streams, ponds, rivers, wetlands, and surface depressions. This resulted in the formation of tailing deposits with high concentrations of arsenic, mercury, and other metals. In 2018-19, NSDEM continued to support research by St. Mary's University to advance the understanding of the impacts of historical gold-mine tailings on aquatic wetland ecosystems. In particular, the department supported an M.Sc. project that aims to identify invertebrate species that can serve as biomonitors of contaminants in impacted wetlands, and to assess the risk of biotransport of arsenic and mercury from key aquatic insect species to terrestrial organisms that consume the insects. Further information about the tailings is available in government reports and webpages (Drage, 2015; Nova Scotia Environment, 2017).

The department continued efforts to develop quantitative information on background concentrations of chemicals in soils in both rural and urban areas. This information is needed to develop appropriate soil quality standards and to enhance science- and evidence-based decision making in relation to contaminated sites. In 2015, the department participated in a project with Dalhousie University and Nova Scotia Environment to conduct soil sampling in urban areas of the Halifax Regional Municipality. Samples were analyzed for metals and polycyclic aromatic hydrocarbons. In 2018, the soil sample results were released in digital format (Kennedy et al., 2018).

Acknowledgments

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An Overview of Hydrogeology Program Activities for April 2018 to March 2019

G. W. Kennedy and J. Drage

Introduction

The Hydrogeology Program is one of nine program areas within the Geological Survey Division of the Nova Scotia Department of Energy and Mines. Over the past year the Hydrogeology Program continued to focus on broadening the province's understanding of the distribution of various naturally occurring contaminants in private well water, such as arsenic, uranium, and manganese. The Hydrogeology Program also investigated the distribution of corrosive groundwater in Nova Scotia, which is associated with leaching of metals, such as lead, from plumbing materials. About 40% of Nova Scotians use private wells for their water supply (Kennedy and Polegato, 2017), and these supplies are not regulated or monitored by the province for water quality. Therefore, exposure to well water contaminants poses a significant challenge for public health protection. Another key activity of the program in 2018-2019 was the development and field testing of a low-cost meter for monitoring water levels in shallow wells.

Staff of the Geological Survey Division and Nova Scotia Environment worked collaboratively on many of the projects described herein. Collaborative work with external organizations included providing data and technical support to various B.Sc. and M.Sc. student projects. Geological Survey Division activities related to geohazard research are reported in the Geohazard Program report (Drage and Kennedy, this volume, p. 13-16).

Program Highlights

Groundwater Data Management and Access

Updates to Groundwater Databases

Activities related to the management of provincial groundwater information in 2018-2019 included routine updating of groundwater databases, such as the Well Logs Database (Nova Scotia Department

of Energy and Mines, 2018a) and the Pumping Test Database (Nova Scotia Department of Energy and Mines, 2018b).

Web Services and Client Applications

A new client application for the relative risk of corrosive groundwater in drilled water wells was launched in 2019 and can be accessed at https://fletcher.novascotia.ca/DNRViewer/index.html?viewer=Drilled_Corrosive_Groundwater_NS.Relative_Corrosivity_of_Groundwater_in_Drilled_Water_Wells. Owners of drilled wells can enter their civic address and find out if their well is located in a relative low-, medium-, or high-risk zone for corrosive groundwater. The development of the risk zones is discussed in the following section. Where there is a higher potential for corrosive groundwater, there is a higher likelihood of concentrations of lead in well water exceeding acceptable levels. Because well water testing is the only way to find out whether lead is present, it is recommended that private well owners regularly test their water no matter where they live.

Another new client application was produced by Nova Scotia Environment and the Geological Survey Division in collaboration with students from Nova Scotia Community College. A groundwater level timeline map was created using groundwater level data from the Nova Scotia Groundwater Observation Well Network (Nova Scotia Environment, 2019). The map provides a visual representation of historical groundwater level data in Nova Scotia by comparing monthly groundwater levels to the historical averages at each observation well for the period between 2012 and 2017 (Leahy and Lloyd, 2018). The application can be accessed at <http://www.arcgis.com/apps/webappviewer/index.html?id=0074d282ec244efb889fab65b8d4bc22>.

The Nova Scotia Groundwater Atlas, which can be accessed at <https://fletcher.novascotia.ca/DNRViewer/?viewer=Groundwater>, was updated in July of 2018. The Potential Impact of Drought to Private Wells application was updated monthly

during the summer of 2018, and can be accessed at <https://fletcher.novascotia.ca/DNRViewer/?viewer=DroughtIndex>.

Groundwater Research and Mapping

Uranium in Well Water

Uranium is a naturally occurring contaminant in Nova Scotia groundwater and is associated with kidney damage at levels above the Health Canada (2017) maximum acceptable concentration (MAC) of 20 µg/L. A project was initiated in 2017 to review available research related to uranium in Nova Scotia well water, to develop our understanding of the hydrogeological controls of uranium in well water, and to produce a revised risk map to communicate risk to private well users. The overall objective of the project is to protect the health of Nova Scotians from exposure to uranium in well water by promoting the importance of water testing and appropriate treatment.

Activities of Geological Survey Division staff in 2018-19 included the publication of an Open File Report (Kennedy and Drage, 2018b) that reviews available research related to uranium occurrence in well water in Nova Scotia. A second report, investigating the association of uranium with various hydrogeologic criteria, and a new risk map and web mapping application, are planned for 2019-2020.

Potential Corrosivity of Groundwater

Lead in private well drinking water in Nova Scotia has been associated with corrosive groundwater that leaches lead and other metals from plumbing materials (e.g. Maessen et al., 1985; Sweeney et al., 2017). Waterborne lead is associated with various adverse human health effects, including neurological impacts, increased blood pressure and kidney damage, and is a probable human carcinogen (Health Canada, 2019). Health Canada recently lowered the maximum acceptable concentration of lead in drinking water from 10 µg/L to 5 µg/L (Health Canada, 2019). Although public drinking water systems in Nova Scotia are risk-managed for lead exposure, private well water supplies are not regulated; therefore, additional efforts to communicate risks are needed.

A project was initiated in 2018 to investigate spatial patterns of the potential corrosivity of

groundwater and lead in well water compared to Nova Scotia's major aquifer types. The project's goal was to produce a map to communicate to private well users the relative risk of having potentially corrosive well water, and hence the relative risk of having elevated levels of lead and other metals (e.g., copper) in their drinking water. In 2018-2019 the Hydrogeology Program published an Open File Report on the corrosivity of groundwater in Nova Scotia and its association with lead in private well water (Kennedy, 2019), and produced a risk map application indicating the relative risk of corrosive groundwater in private drilled wells.

Manganese in Well Water

Manganese is a naturally occurring chemical that is commonly found in Nova Scotia well water. The existing Health Canada guideline for manganese in drinking water is an aesthetic objective of 50 µg/L. However, a health-based maximum acceptable concentration of 120 µg/L (Health Canada, personal communication) has been proposed based on emerging epidemiological evidence (Health Canada, 2016). Manganese commonly occurs in Nova Scotia well water and it is estimated that approximately 30% of the province's private water wells will have manganese levels above the proposed Health Canada health-based guideline. A revised aesthetic objective of 20 µg/L has also been proposed by Health Canada (Health Canada, 2016). It is estimated that over 50% of the province's private water wells may exceed the proposed aesthetic objective.

A project was initiated in 2018 under the Hydrogeology Program to develop our understanding of the hydrogeological controls of manganese in well water, which will be used to develop a risk map for private well users. The aim of the project is to protect the health of Nova Scotians from exposure to manganese in well water by promoting water testing and appropriate treatment.

In 2018-2019, program activities focused on the preparation of a manganese in well water chemistry dataset. Future work will focus on the spatial correlation between manganese in well water and hydrogeologic criteria, and the potential development of a risk map and web application.

Profiling Contaminants in Nova Scotia Drinking Water

A joint project with researchers from the Nova Scotia Health Authority was initiated in 2019 to develop comprehensive exposure maps for various contaminants by combining well water sample data from the Geological Survey Division and Atlantic Path, a long-term cohort study of chronic disease in Atlantic Canada. Contaminant-specific maps will be produced at two levels of geography (community areas and a 5 km square grid) considered to be relevant to address public health concerns (e.g., see Saint-Jacques et al., 2016; Saint-Jacques et al., 2017). These exposure maps will thereafter be used to support knowledge transfer projects and environmental health research.

One of the most important predictors of private well owners testing and treating their water is risk knowledge. This project aims to improve the understanding of the spatial distribution of naturally occurring groundwater contaminants, which will be used to develop appropriate communication materials that aim to raise awareness and promote private well water testing and treatment. An improved understanding of the spatial distribution of the contaminants will also enable the province to focus its risk mitigation efforts on areas where there is the greatest potential exposure to groundwater contaminants. Further, it will provide more comprehensive environmental exposure data to examine the association between the spatial distribution of environmental risk factors and health risk, particularly cancer.

Shallow Aquifer Water Level Monitoring

The need for a real-time monitoring network for shallow aquifers was highlighted during a drought in Nova Scotia in 2016. The drought was particularly severe in southwestern Nova Scotia where the driest summer in 137 years was recorded. This area of the province relies more heavily on shallow dug wells for private water supplies, and over 1,000 wells went dry in the summer of 2016 (Kennedy et al., 2017). During the drought, there was a need to track aquifer levels so that emergency management staff could plan appropriate management responses and the public and media could be kept informed about the drought impacts. Although Nova Scotia has a provincial groundwater observation well network, it monitors deeper drilled wells and is not equipped for real-time reporting. Therefore, a low-cost real-

time water level meter for dug wells was developed and pilot tested in 2017.

The newly developed water level meters are permanently installed in dug wells and use an ultrasonic sensor to measure water levels. The meters are custom-built and cost approximately \$200 each to build. The water level data are transmitted daily via WiFi and are immediately available for viewing and download. The water level data collected during the 2017 pilot test compared well with data from pressure transducers and manual measurements (Drage and Kennedy, 2018). In 2018, the network was expanded to 10 monitoring sites across Nova Scotia. The network relies on private well owners to volunteer their dug wells for meter installation, and to provide access to their WiFi network to transmit the daily water levels. The monitoring site locations are shown on the *Potential Impact of Drought to Private Wells* map (<https://fletcher.novascotia.ca/DNRViewer/?viewer=DroughtIndex>), which also provides access to the real-time water level results.

Example results from one of the dug wells in the network are shown in Figure 1. These results show a typical seasonal water level pattern that appears in many of the dug wells in the network. As shown in Figure 1, spring water levels are relatively high until July, when they begin to decline, which continues throughout the summer until fall precipitation causes a rapid rise in October. Water levels then remain high for the fall and early winter, until cold winter conditions reduce recharge to the aquifer, causing water levels to decline again in January. The maximum water level range from summer to fall in this well was 3.7 m.

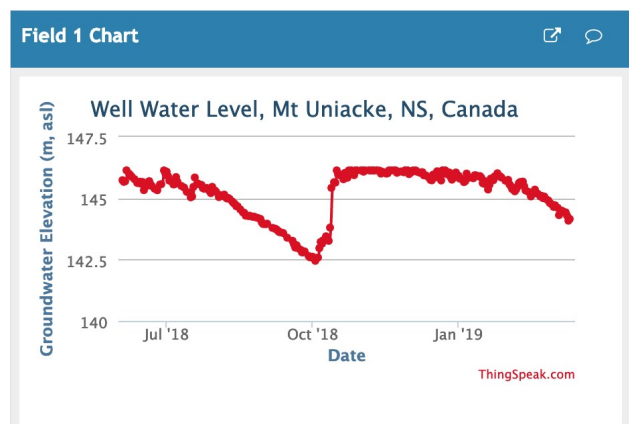


Figure 1. Groundwater level results from a dug well in Mount Uniacke, Nova Scotia.

Groundwater Management

Changes to Health Canada Drinking Water Quality Guidelines

Health Canada has recently reviewed aesthetic and/or health-based limits for several chemical parameters for drinking water quality, such as aluminum, antimony, arsenic, copper, lead, manganese, strontium, and uranium. To assist Nova Scotia Environment (NSE) with evaluation of the potential impact of any proposed changes to the Health Canada drinking water guidelines on private and public water supplies in Nova Scotia, staff of the Geological Survey Division performed analyses of available well water chemistry data compared to the distribution of private well users (Nova Scotia Department of Energy and Mines, 2018c). In addition, Nova Scotia Geological Survey Division staff provided technical support in 2018-2019 to NSE in preparation for changes to the lead in drinking water guideline.

Private Water Supplies Committee

Geological Survey Division staff participated on a Private Water Supplies Committee initiated in October of 2018 and consisting of members from Nova Scotia Environment and the Nova Scotia Department of Health. The committee aims to reduce barriers to testing and treatment of private water supplies and will continue to be active in 2019-2020.

Outreach and Support Activities

Support Activities

Geological Survey Division staff assisted various clients with requests for data and technical advice in 2018-2019. Clients included other government departments, universities, homeowners, municipalities, and groundwater consultants. Support to universities included the provision of data to a Dalhousie M.Sc. project on well water quality issues in Harrietsfield, and to a Dalhousie B.Eng. project on well water quantity issues in southwest Nova Scotia.

Presentations

The Hydrogeology Program delivered the following presentations during 2018-19:

- A lecture on the hydrogeology of Nova Scotia to a first-year hydrogeology class in the Faculty of Engineering at Dalhousie University;
- A conference poster presentation at Resources for Future Generations in Vancouver on a low-cost meter for aquifer drought monitoring in Nova Scotia (Drage and Kennedy, 2018); and
- A presentation to the Nova Scotia Groundwater Association titled *Well Logs Data: From Rig to Regional Assessment*.

Publications

The following publications by the Hydrogeology Program were released in 2018-2019.

Open File Report: Potential Corrosivity of Groundwater in Nova Scotia and its Association with Lead in Private Well Water (Kennedy, 2019), available online at https://novascotia.ca/natr/meb/data/pubs/19ofr02/ofr_me_2019-002.pdf.

Report: An Overview of Hydrogeology Program Activities for April 2017 to March 2018 (Kennedy and Drage, 2018a), available online at https://novascotia.ca/natr/meb/data/pubs/18re01/8_ROA2018Kennedy_hydrology.pdf.

Open File Report: A Review and Summary of Activities Related to Uranium in Nova Scotia Well Water (Kennedy and Drage, 2018b), available online at https://novascotia.ca/natr/meb/data/pubs/18ofr06/ofr_me_2018-006.pdf.

Conference Poster: A Low-Cost Internet of Things Aquifer Drought Monitoring Network in Nova Scotia, Canada: Pilot Program Results (Drage and Kennedy, 2018).

Open File Report: Mapping Historical Groundwater Levels of Nova Scotia: A Conceptual Model (Leahy and Lloyd, 2018), available online at https://novascotia.ca/natr/meb/data/pubs/18ofr07/ofr_me_2018-007.pdf

Journal publication: Development of a leaching procedure to assess the risk of uranium leaching due to construction and demolition waste disposal (Letman et al., 2018), abstract available online at <https://doi.org/10.1016/j.wasman.2018.05.038>

Journal publication: Low-impact development effects on aquifer recharge using coupled surface and groundwater models (Mooers et al., 2018), abstract available online at [https://doi.org/10.1061/\(ASCE\)HE.1943-5584.0001682](https://doi.org/10.1061/(ASCE)HE.1943-5584.0001682)

Research Directions

Private well water quality concerns due to naturally occurring contaminants will remain a significant area of focus for the Hydrogeology Program. The program will therefore continue to advance the province's understanding of the hydrogeological controls on naturally occurring contaminants in private well water and to develop risk communication tools and other interventions to promote appropriate well water testing and treatment. While much of the pilot phase work is complete on the development of a shallow aquifer monitoring network, the Hydrogeology Program will continue to monitor, test and refine the network.

Other high priority activities include the compilation of legacy groundwater data, the improvement of data capture processes, the maintenance of spatial data, and the development of online applications to publish and provide access to these data.

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Metallogeny of the Avalonian Mira Terrane, Southeastern Cape Breton Island, Nova Scotia: a Preliminary Study

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Introduction

The Mira terrane of Cape Breton Island is composed of northeast-trending belts of Neoproterozoic volcanic, sedimentary and plutonic rocks separated by regional-scale faults and/or Cambrian and Carboniferous sedimentary sequences (Fig. 1). Also present in the terrane are scattered Devonian (ca. 370–360 Ma) granitoid plutons and associated skarns.

The Neoproterozoic rocks include three magmatic associations (Barr et al., 1996; Willner et al., 2015) with ages of ca. 680 Ma (Stirling Group), ca. 620 Ma (Coxheath, East Bay Hills, and Pringle Mountain groups and related plutons), and ca. 575–560 Ma (Fourchu and Main-à-Dieu groups and related plutons). Known mineral occurrences in these rocks were described by Macdonald (1989). However, the metallogenetic potential of the Mira terrane has not been subsequently assessed in

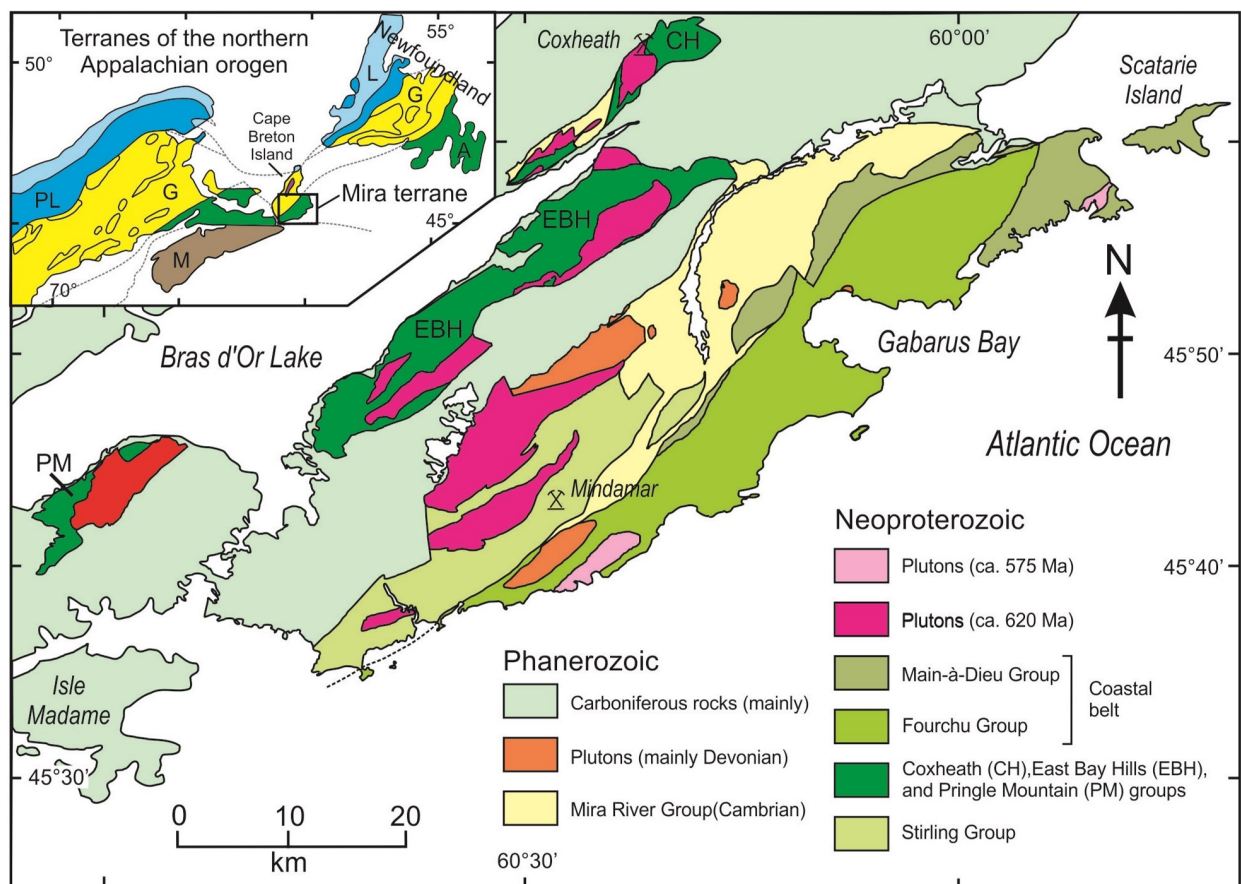


Figure 1. Simplified geological map of southeastern Cape Breton Island redrawn from Barr et al. (1996). Inset map of the northern Appalachian orogen (redrawn from Hibbard et al., 2006) shows the location of the study area (black box) in Avalonia (Mira terrane) of southeastern Cape Breton Island, Nova Scotia. Abbreviations: A, Avalonia; G, Gandaria; L, Laurentia; M, Meguma; PL, peri-Laurentian.

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detail, despite the greatly improved understanding of its petro-tectonic evolution that has since emerged (e.g. Barr et al. 1996).

This preliminary study is focused on metallogeny related to the multiple episodes of granitoid plutonism recognized in the Mira terrane during the late Neoproterozoic. In particular, the ca. 620 and ca. 575 to 560 episodes are recognized as prospective by comparison to recent studies of the closely analogous, age-contemporaneous Avalon zone of Newfoundland (Sparkes et al., 2005, 2016; Ferguson et al., 2014; Layne et al., 2016; Ferguson, 2017).

Geological Setting

The ca. 680 Ma Stirling Group consists primarily of andesitic to basaltic lapilli tuff interbedded with tuffaceous arenite and laminated siltstone. Barr et al. (1996) interpreted it to have formed in an extensional basin within a volcanic arc. The Stirling Group contains the historically mined Mindamar Zn-Pb-Cu-Ag-Au deposit (interpreted as an exhalative, VMS-type deposit by Miller, 1978; Barr et al., 1996; and others), as well as other stratiform zones of pyrite-rich, laminated litharenite-siltstone-chert-dolomite.

The ca. 620 Ma associations are composed mostly of granitic to granodioritic rocks and andesitic to rhyolitic tuffs and flows. Barr et al. (1996) interpreted these high-K, calc-alkaline rocks to have formed in a subduction-related convergent-margin setting. The historically mined Coxheath porphyry-style Cu(-Mo-Au) deposit is hosted by the Coxheath Group and comagmatic Coxheath Hills pluton (Barr et al., 1996). The host rock and molybdenite mineralization have been dated at 620 Ma ($^{40}\text{Ar}/^{39}\text{Ar}$) and 626 Ma \pm 3 Ma (Re-Os), respectively (Kontak et al., 2008). A nearby zone of pyrophyllite alteration (Kontak et al., 2004), although not auriferous, may be a consequence of shallow high-sulphidation activity related to the Coxheath porphyry-Cu system. The geology and ore mineralization of the Coxheath deposit have been extensively documented in previous studies (Lynch and Ortega, 1997; Kontak et al., 2003; O'Sullivan and Hannon, 2007). Other less well documented occurrences of porphyry-style Cu mineralization are associated with the Sporting Mountain Pluton (Sexton, 1988).

The ca. 575 Ma Fourchu Group consists mainly of dacitic tuffs and flows, together with minor basaltic to rhyolitic tuffs and flows and tuffaceous

sedimentary rocks. It was interpreted by Barr et al. (1996) to represent a volcanic-arc setting. The overlying Main-à-Dieu Group consists mainly of tuffaceous sedimentary and epiclastic rocks and minor basaltic and rhyolitic flows, interpreted by Barr et al. (1996) to have formed in an intra-arc extensional setting. The Main-à-Dieu Group is overlain with little or no time gap by Cambrian rocks of the Mira River Group.

The late Neoproterozoic parts of the Mira terrane and their magmatic associations provide favourable environments for “intrusion-related” hydrothermal ore deposits associated with granitoid plutonism and related volcanism. Epithermal Au-Ag deposits are characteristic of arc volcanism and are typically penecontemporaneous with their host rocks. Porphyry-style deposits are related to epithermal deposits in that they are closely associated with subvolcanic granitoid intrusions that may give rise to epithermal systems. Unlike epithermal deposits, however, porphyry deposits are fostered by fluids originating within and proximal to the intrusion. Skarn deposits are a subset of porphyry-style deposits where dominantly magmatic fluids have metasomatized calcareous country rock. If these same magmatic fluids separate and migrate to near surface, they may foster the primary stages of high-sulphidation-type epithermal Au deposits. Thermally driven shallow circulation of predominantly meteoric waters in intracaldera fracture zones above the intrusions may foster low-sulphidation-type precious metal deposits in this same near-surface regime.

Based on the rock types and ages, the Neoproterozoic rocks of the Mira terrane have significant potential for hydrothermal mineral deposits, especially epithermal Au(-Ag) and porphyry Cu(-Mo-Au) deposits.

Results

Host Rocks and Lithogeochemical Analyses

Representative rock samples were collected and submitted for research-grade lithogeochemical analysis, and results are summarized in Tables 1 to 3 (including UTM locations). Incompatible element diagrams are plotted in Figures 2a-d.

A sample of pyroclastic metabasalt (MTP18-22) was collected from a beachfront outcrop near Point

Table 1. Lithochemical analyses of samples from the Mira terrane — locations, descriptions and major element data

Sample	Unit	Rock type	Age (Ma) ¹	Eastings ²	Northing ²	SiO ₂ %	Al ₂ O ₃ %	Fe ₂ O ₃ ⁽¹⁾ %	MnO %	MgO %	CaO %	Na ₂ O %	K ₂ O %	TiO ₂ %	P ₂ O ₅ %	LOI %	Total %
Detection limit	--	--	--	--	--	0.01	0.01	0.01	0.001	0.01	0.01	0.01	0.01	0.001	0.01	0.01	0.01
MTP18-1	Coxheath-Blue Dyke	Basalt porphyry (amygdaloidal)	--	704237	5107320	51.09	16.87	8.81	0.22	6.79	6.20	3.53	0.77	0.83	0.13	5.15	100.40
MTP18-4	Coxheath-fine-grained wallrock	Silicified wallrock	--	704134	5107335	78.04	7.72	2.91	0.08	0.94	2.82	0.09	2.01	0.35	0.05	4.29	99.29
MTP18-8	Coxheath-medium-grained diorite	Diorite - epidotized	620	704169	5107263	58.01	17.74	6.62	0.14	3.47	5.47	3.68	2.11	0.79	0.18	1.95	100.20
MTP18-11B	East Bay Hills Coxheath Rhyolite Quarry	Rhyolite porphyry (plagioclase, phytic)	623	711788	5096630	70.73	14.05	2.19	0.09	0.22	1.28	4.87	3.79	0.38	0.09	1.79	99.48
MTP18-11C	East Bay Hills Coxheath Rhyolite Quarry	Rhyolite porphyry (glassy)	623	711788	5096630	74.09	12.80	1.31	0.05	0.14	0.81	4.32	3.81	0.16	0.03	1.04	98.56
MTP18-12	Mam-à-Dieu Wind Turbine	Rhyolite porphyry (spherulitic)	575-560	(274782) ²	(5097534) ²	74.61	13.00	2.45	0.09	0.35	0.88	6.10	1.43	0.35	0.09	0.59	99.94
MTP18-13	Big Hill Road Quarry	Epiclastic - pyritiferous	575-560	724389	5096063	61.90	15.57	7.10	0.10	1.62	3.24	5.91	0.36	0.87	0.16	3.75	100.60
MTP18-14	Big Hill Road Quarry	Epiclastic - hematitic	575-560	724389	5096063	70.09	14.55	3.37	0.09	0.61	2.10	2.96	2.96	0.45	0.12	3.13	100.40
MTP18-15A	Belfry Beach	Rhyolite	575-560	717233	5071619	76.17	12.34	1.98	0.08	0.25	1.02	5.17	1.73	0.28	0.04	0.47	99.53
MTP18-18	Sporting Mountain Pluton	Granitoid - sericitized/carbonatized	620	663979	5069248	75.20	10.91	2.20	0.08	0.66	2.64	2.09	2.18	0.23	0.06	3.27	99.52
MTP18-19	Highway Roadcut	Rhyolite porphyry - deformed/hematitized	--	676077	5073994	72.39	13.91	2.43	0.06	0.62	0.96	4.91	2.70	0.27	0.07	1.00	99.32
MTP18-21	Irish Cove Quarry	Granitoid - epidotized	619	681343	5075678	66.82	15.36	4.20	0.08	1.78	2.30	4.10	3.70	0.58	0.13	1.53	100.60
MTP18-22	Beachfront Stirling Metabasalt	Mafic pyroclastic (amygdaloidal)	680	681036	5051352	60.51	13.10	7.50	0.16	4.11	5.31	3.57	0.19	0.43	0.05	5.28	100.20
MTP18-23	Brook/Road (Grand River)	Granitoid	575-560	683217	5055139	77.04	11.72	1.53	0.04	0.60	0.79	6.08	0.16	0.28	0.07	0.67	98.98
MTP18-25	Highway Roadcut (Chisholm Brook)	Granitoid (granophyric)	620	689437	5070389	70.63	14.84	2.85	0.09	1.00	0.90	4.62	3.03	0.39	0.11	1.43	99.87

All lithochemical data in Table 1 was generated using Actlabs package Litho4Res (www.actlabs.com).

1. Age (Ma) is estimated age from literature as cited in text.
2. All UTM co-ordinates are in zone 20T, except for MTP18-12, which is in zone 21T.

Table 2. Lithogeochemical analyses of samples from the Mira terrane — trace element data.

Sample	Unit	Sc	Be	V	Cr	Co	Ni	Cu	Zn	Ga	Ge	As	Rb	Sr	Y	Zr	Nb	Mo	Ag	In	Sn	Sb	Cs	Ba
Detection	--	1	1	5	20	1	20	10	30	1	0.5	5	1	2	0.5	1	0.2	2	0.5	0.1	1	0.2	0.1	2
limit		ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
MTP18-1	Coxheath-Blue Dyke	34	<1	248	190	27	300	50	220	17	2.1	8	23	400	15.5	64	1.3	<2	<0.5	0.1	1	0.8	3.9	422
MTP18-4	Coxheath- fine-grained wallrock	8	<1	52	40	7	<20	<10	<30	9	0.9	5	85	40	20.3	78	3.9	2	<0.5	<0.1	1	1.1	4.9	278
MTP18-8	Coxheath- medium-grained diorite	15	1	138	20	19	20	60	90	19	1.0	13	67	643	14.3	118	5.2	<2	<0.5	0.1	1	0.7	4.4	716
MTP18-11B	East Bay Hills Coxheath Rhyolite Quarry	6	2	17	20	1	<20	<10	70	14	0.8	24	114	106	40.9	223	5.8	<2	0.8	0.1	2	2.5	4.1	1183
MTP18-11C	East Bay Hills Coxheath Rhyolite Quarry	3	2	5	20	1	<20	<10	40	14	1.1	10	124	48	29.6	98	5.5	<2	<0.5	<0.1	1	0.5	4.0	855
MTP18-12	Main-à-Dieu Wind Turbine	9	<1	9	30	2	<20	<10	70	13	1.5	<5	16	90	38.0	144	2.5	<2	<0.5	0.1	1	0.2	0.4	521
MTP18-13	Big Hill Road Quarry	25	<1	136	30	15	<20	70	100	14	0.7	<5	9	420	24.9	89	2.0	<2	<0.5	0.1	1	0.3	1.0	201
MTP18-14	Big Hill Road Quarry	16	1	16	<20	2	<20	<10	40	16	1.0	<5	93	324	37.0	138	3.4	<2	<0.5	0.1	1	0.3	7.0	631
MTP18-15A	Belfry Beach	12	1	<5	<20	1	<20	<10	40	14	1.0	<5	29	132	47.6	160	2.9	2	<0.5	0.1	2	<0.2	0.4	572
MTP18-18	Sporting Mountain Pluton	3	<1	28	30	2	<20	10	80	12	0.7	<5	79	163	4.9	74	1.9	3	<0.5	<0.1	<1	0.4	3.7	635
MTP18-19	Highway Roadcut	3	1	19	<20	2	<20	<10	40	12	1.0	<5	72	192	12.2	136	4.4	<2	<0.5	<0.1	1	0.8	3.3	718
MTP18-21	Irish Cove Quarry	10	1	69	30	9	<20	<10	40	15	0.8	<5	129	228	23.3	202	6.0	<2	<0.5	<0.1	1	0.4	1.6	784
MTP18-22	Beachfront Stirling Metabasalt	31	<1	224	30	24	<20	100	90	12	1.2	6	3	141	7.4	21	0.3	<2	<0.5	<0.1	<1	<0.2	0.4	103
MTP18-23	Brook/Road (Grand River)	12	<1	10	30	2	<20	<10	<30	14	1.0	<5	3	57	26.0	98	2.1	2	<0.5	0.1	4	<0.2	0.1	66
MTP18-25	Highway Roadcut (Chisholm Bk)	6	2	22	<20	3	<20	<10	160	15	0.9	<5	82	189	23.8	167	5.4	2	0.5	<0.1	1	0.4	3.4	850

Table 3. Lithochemical analyses of samples from the Mira terrane — REEs and additional trace element data.

Sample	Unit	La	Ce	Pr	Nd	Sm	Eu	Gd	Tb	Dy	Ho	Er	Tm	Yb	Lu	Hf	Ta	W	Tl	Pb	Bi	Th	U
Detection limit		0.05	0.05	0.01	0.05	0.01	0.005	0.01	0.01	0.01	0.01	0.01	0.005	0.01	0.002	0.1	0.01	0.5	0.05	5	0.1	0.05	0.01
MTP18-1	Coxheath-Blue Dyke	10.6	23.1	3.07	12.9	3.06	0.952	3.22	0.48	2.76	0.57	1.66	0.241	1.62	0.258	1.8	0.14	0.9	0.17	8	<0.1	2.29	0.61
MTP18-4	Coxheath-fine-grained wallrock	16.7	35	4.2	16.3	3.76	0.96	3.26	0.56	3.51	0.69	2.06	0.311	2.06	0.344	2	0.47	1.1	0.39	6	<0.1	4.9	1.14
MTP18-8	Coxheath-medium-grained diorite	21.9	43.7	5.14	20.1	4.01	1.13	3.41	0.46	2.62	0.52	1.53	0.217	1.3	0.206	3.4	0.29	1.1	0.34	9	<0.1	7.01	1.63
MTP18-11B	East Bay Hills Coxheath Rhyolite Quarry	44.4	89.2	10.6	42.5	7.91	1.91	6.83	1.22	7.2	1.45	4.26	0.682	4.29	0.603	4.9	0.56	1.7	0.91	9	0.1	13.9	3.32
MTP18-11C	East Bay Hills Coxheath Rhyolite Quarry	26.9	58.5	6.05	21.2	4.19	0.599	3.92	0.71	4.64	1	3.18	0.482	3.52	0.577	3.3	0.6	0.5	0.63	11	0.1	15.1	3.03
MTP18-12	Main-à-Dieu Wind Turbine	15.9	37.6	4.99	22.6	5.58	1.12	5.7	0.96	6.14	1.37	4.17	0.638	4.62	0.711	3.7	0.28	<0.5	0.17	6	<0.1	3.32	0.84
MTP18-13	Big Hill Road Quarry	11.4	25.8	3.57	15.9	4.11	1.33	4.38	0.74	4.39	0.91	2.59	0.399	2.63	0.42	2.6	0.16	<0.5	0.06	20	<0.1	1.83	0.48
MTP18-14	Big Hill Road Quarry	15.8	34.4	4.42	20.3	5.1	1.09	4.7	0.89	5.94	1.38	4.18	0.645	4.54	0.724	3.5	0.36	0.9	0.4	6	0.1	3.86	0.69
MTP18-15A	Belfry Beach	20.6	47	6.45	29.7	7.42	1.6	7.66	1.29	7.97	1.71	5.02	0.75	5.13	0.842	4.6	0.32	<0.5	0.25	8	0.1	3.21	1.01
MTP18-18	Sporting Mountain Pluton	10.6	18.3	2.13	8.12	1.34	0.249	1.09	0.17	0.9	0.17	0.5	0.077	0.51	0.077	2.2	0.26	1.3	0.4	8	0.2	4.74	0.75
MTP18-19	Highway Roadcut	30.1	54.7	5.47	16.9	3.12	0.681	2.11	0.33	2.1	0.43	1.38	0.227	1.59	0.25	3.4	0.56	0.9	0.45	11	<0.1	14.1	3.23
MTP18-21	Irish Cove Quarry	32.9	62.9	7.23	26.5	5.13	1.14	4.47	0.66	3.84	0.77	2.4	0.358	2.31	0.376	5	0.49	0.7	0.67	8	<0.1	15.1	3.02
MTP18-22	Beachfront Stirling Metabasalt	2.07	4.58	0.6	2.77	0.73	0.305	0.94	0.19	1.23	0.25	0.76	0.122	0.7	0.084	0.6	0.08	0.5	<0.05	<5	<0.1	0.54	0.19
MTP18-23	Brook/Road (Grand River)	7.83	17	2.2	9.69	2.47	0.784	2.77	0.56	3.91	0.89	3.01	0.503	3.14	0.457	2.3	0.22	0.5	<0.05	<5	<0.1	2.02	0.54
MTP18-25	Highway Roadcut (Chisholm Bk)	34.7	58.7	8.01	30.8	5.81	1.26	4.73	0.72	4.23	0.87	2.46	0.395	2.73	0.436	3.6	0.48	0.8	0.4	6	0.1	11.4	1.83

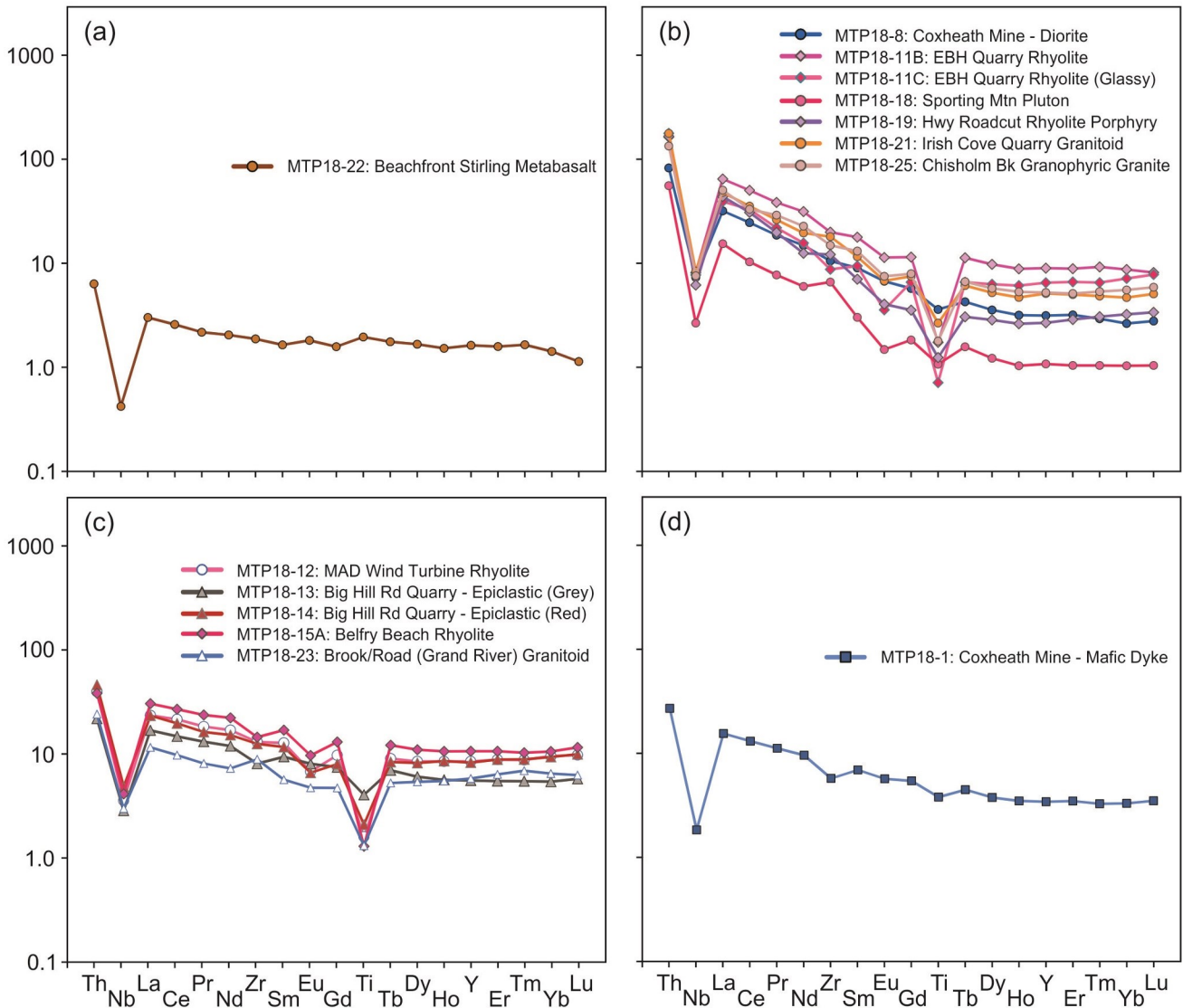


Figure 2. Incompatible element plots. (a) a ca.680 Ma sample; (b) ca.620 Ma samples; (c) ca.575 Ma samples; and (d) a post-575 Ma sample.

Michaud in an area mapped as Stirling Group (ca. 680 Ma). The incompatible element pattern (Fig. 2a) is flat and approaching 1x chondrite abundance and exhibits a negative Nb anomaly. These features are consistent with the interpretation of Barr et al. (1996) that the Stirling Group formed in an extensional basin within a volcanic arc. The Stirling Group is not considered highly prospective for porphyry- and epithermal-style precious metal deposits, but this sample provides a useful reference for discriminating the Stirling Group from younger rocks in the Mira terrane.

Seven samples were collected from rock units currently considered to have ages of ca. 620 Ma. A diorite sample (MTP18-8) from the Coxheath Hills

pluton was collected immediately adjacent to the former Coxheath Mine site. Samples MTP18-11B and -11C were collected from two rhyolite phases in a quarry in the East Bay Hills Group, and rhyolite porphyry sample MTP18-19 was collected from a roadcut on Highway 4 between Johnstown and Irish Cove. Samples of granitoid plutonic rocks were taken from quarries and roadcuts at Sporting Mountain (MTP18-18), Irish Cove (MTP18-21), and Chisholm Brook (MTP-18-25). All seven samples show negative Nb and Ti anomalies and combined steep LREE/flat HREE patterns, compatible with an origin from magmatism in a continental arc (Fig. 2b). The relatively lower absolute abundance of incompatible elements in Sporting Mountain

sample MTP18-18 reflects, at least in part, dilution by pervasive carbonate (sericite) alteration.

Four samples were collected of rocks currently considered to be ca. 575 to 560 Ma. They include spherulitic rhyolite from the wind turbine installation at Main-à-Dieu (MAD; MTP18-12) and sparsely phyric rhyolite from a beachfront exposure at Belfry Beach (MTP18-15A). Also analyzed in this sample set were two examples of coarse epiclastic sedimentary rock collected from the Big Hill Road Quarry near Albert Bridge: one a grey silicified/pyritized facies (MTP18-13) and the other a red hematitic facies (MTP18-14). All four samples show similar incompatible element patterns (Fig. 2c), that is, negative Nb and Ti anomalies and shallow LREE/flat HREE geometry. These patterns are also compatible with origin during volcano-plutonism in a continental arc. However, the negative slope of the LREEs is definitively shallower than that for the ca. 620 samples, and Figures 2b and 2c thus provide a basis for discriminating these two age groups in subsequent studies. Further, the similarity of the Big Hill Road epiclastic rocks strongly supports the interpretation that they were penecontemporaneously derived from ca. 575 to 560 Ma volcanic rocks.

Sample MTP18-1 was collected from an amygdaloidal mafic dyke (51.06 weight percent SiO₂) that crosscuts the Coxheath Hills diorite adjacent to the former Coxheath mine site. It is tentatively interpreted to represent a post-575 Ma episode of intrusive activity, based on the broad resemblance of its incompatible trace-element pattern (Fig. 2d) to ca. 566 Ma intermediate dykes in the vicinity of the Big Easy prospect in Newfoundland (Ferguson, 2017).

In summary, these four episodes of volcano-plutonism appear to have distinctive features on incompatible element plots (Fig. 2a-d) and these features are thus potentially useful in distinguishing age belts within the Mira terrane.

Occurrences of Mineralization

Epithermal vein systems eluded recognition in the Newfoundland Avalon zone until quite recently (by and large the 1990s) as they can be cryptic during grassroots exploration and prospection. For example, some styles of low-sulphidation veins (e.g. low-vein density peripheral occurrences) can go unrecognized as such during prospection. High-sulphidation systems can have substantial volumes

of relatively Au-barren alteration surrounding a smaller auriferous core.

During the 2018 field work, several zones of altered and/or mineralized rock were encountered and assessed. Samples from these zones were submitted for high-quality exploration geochemical analysis. Four of these localities returned values for Au, Ag, and/or related pathfinder metals that are considered informative in terms of a regional metallogenic study. The results for these localities are summarized in Table 4 (including UTM locations) and are described below.

Andesite Quarry

This quarry, located off Coxheath Road approximately 7 km southwest of the former Coxheath Mine, is predominantly in andesite porphyry. Many parts of the bedrock exposed in the quarry show intense epidote-rich propylitic alteration, accompanied by greenish copper gossans consequent to weathering of small anastomosing veins of copper sulphide minerals. A grab sample of chalcopyrite-(bornite)-rich angular float (MTP18-9-2) from the quarry returned 501 ppb Au and 3.1 ppm Ag, as well as anomalous concentrations of Pb, Zn, Bi, Sb and Se, and >1 weight percent Cu. Taking into account the intermediate volcanic host/protolith and the style and ore assemblage of the veining, this showing has the characteristics of porphyry-style Cu-Au mineralization.

Sporting Mountain — Main Quarry

This quarry, off West Bay Road near Urquharts Pond, exposes volcanic rocks of the Pringle Mountain Group. The dominant rock type appear to be felsic volcanic rocks (rhyolite). Several zones of alteration, each several metres in width, cross the quarry walls. A sample of highly siliceous, pyritiferous rock (MTP18-17A1) from one of these altered zones returned 11 ppb Au and 1.1 ppm Ag, as well as anomalous concentrations of Cu, Bi, and Se. The sample is mainly composed of fine- and coarse-grained quartz, sericite, and pyrite, as well as very minor rutile. It bears textural resemblance to remineralized “vuggy silica” from some high-sulphidation epithermal deposits.

Big Hill Road Quarry

The peripheral area of an operating commercial quarry off Big Hill Road near Albert Bridge was

Table 4. Analyses of mineralized samples from the Mira terrane.

Sample	Unit	Rock type	Easting	Northing	Au		Ag		As		Cd		Cu		Mn		Mo		Ni		Pb		Zn	
					ppb	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm	ppm
Detection Limit	--	--	--	--	5	0.2	2	0.5	1	2	0.5	1	2	2	2	2	2	2	1	1	2	2	1	1
MTP18-9-1	Andesite Quarry	Propylitic altm; py-rich	702138	5101480	<5	<0.2	6	<0.5	59	1110	<2	18	<2	263	<2	106								
MTP18-9-2	Andesite Quarry	Propylitic altm; cpy(brown)-rich			501	3.1	12	<0.5	>10000	406	4	45	4	42	55									
MTP18-17A1	Sporting Mountain-Main Quarry	Qz-Ser-Rut-(Chalced); minor py	661618	5069570	11	1.1	7	<0.5	35	25	8	2	23	3										
MTP18-17A2	Sporting Mountain-Main Quarry	Qz-Ser; 15% py			<5	0.4	3	<0.5	25	23	<2	<1	3	3										
MTP18-17B	Sporting Mountain-Main Quarry	Hm-chlor altm (rhy protolith?); 10% hm(py)			<5	<0.2	4	<0.5	8	39	<2	<1	3	4										
MTP18-17C	Sporting Mountain-Main Quarry	Qz-ser-rut-(chalced); 10% py			<5	<0.2	4	<0.5	6	31	<2	<1	<2	5										
MTP18-17D	Sporting Mountain-Main Quarry	Qz-ser; 0% py			<5	<0.2	3	<0.5	7	48	<2	4	<2	8										
MTP18-26A1	Park Brook Au Prospect	Sericitized rhy; 25% py	696675	5092101	33	1.2	12	<0.5	9	25	2	1	24	<1										
MTP18-26A3	Park Brook Au Prospect	Sericitized rhy; 15% py			45	1.2	25	<0.5	11	43	34	1	15	<1										
MTP18-26B1	Park Brook Au Prospect	Sericitized rhy; 20% py	696675	5092101	24	0.3	19	<0.5	7	52	<2	1	5	8										
MTP18-26B2	Park Brook Au Prospect	Chlor-ser intermediate; qz vein with trace py (maritized)			88	<0.2	3	<0.5	26	989	<2	11	<2	183										
MTP18-26B3	Park Brook Au Prospect	Sericitized rhy; 10% py			37	<0.2	11	<0.5	39	32	5	2	6	2										
MTP18-26C	Park Brook Au Prospect	Sericitized rhy; 15% py	696676	5092146	45	0.2	13	<0.5	50	31	8	2	7	1										

(Table 4 concludes next page.)

Table 4. (concluded).

Sample	Ba	Bi	Ca	Cs	Fe	Ga	Ge	Hg	K	Na	Sb	S	Se	Te	Tl	W	Mass
	ppm	ppm	%	ppm	%	ppm	ppm	ppm	%	%	ppm	%	ppm	ppm	ppm	ppm	g
Limit	100	0.1	0.01	0.05	0.02	1	0.1	1	0.01	0.01	0.2	0.001	0.1	0.1	0.1	4	
MTP18-9-1	100	0.1	3.99	1.37	5.85	12	<0.1	<1	0.12	1.38	0.4	0.968	1.1	0.2	<0.1	<4	36
MTP18-9-2	<100	9.7	5.71	0.06	8.95	21	0.4	<1	<0.01	0.05	2.9	1.537	8.9	2.0	<0.1	<4	40
MTP18-17A1	100	2.6	0.02	1.03	1.33	2	<0.1	1	0.27	0.05	1.4	0.639	5.9	1.9	0.1	<4	27
MTP18-17A2	1100	0.4	0.03	1.62	1.29	8	<0.1	<1	0.32	0.05	1.2	0.058	0.8	0.7	0.1	<4	28
MTP18-17B	300	0.3	<0.01	1.24	3.48	7	<0.1	<1	0.23	0.04	1.4	0.02	0.9	<0.1	<0.1	<4	31
MTP18-17C	1900	<0.10	0.03	2.27	1.52	14	<0.1	<1	0.53	0.06	1.0	0.06	0.5	<0.1	0.2	<4	25
MTP18-17D	200	<0.10	0.09	3.43	1.56	4	<0.1	<1	0.36	0.78	0.9	0.00	0.5	<0.1	0.2	<4	27
MTP18-26A1	<100	5.4	0.21	0.61	4.48	2	<0.1	<1	0.18	0.13	4.3	3.75	7.4	4.0	0.1	<4	29
MTP18-26A3	<100	3.6	0.62	0.45	2.98	1	<0.1	<1	0.06	0.09	23.8	2.60	3.1	8.9	0.1	6	31
MTP18-26B1	<100	1.3	0.51	0.42	5.62	3	<0.1	<1	0.04	0.09	6.2	4.40	3.0	2.8	<0.1	25	27
MTP18-26B2	<100	<0.10	0.24	1.68	4.57	8	<0.1	<1	0.24	0.08	2.3	0.01	0.5	0.4	0.2	<4	29
MTP18-26B3	<100	4.0	0.34	0.65	3.99	3	<0.1	<1	0.21	0.13	5.8	3.88	2.1	4.0	0.1	<4	31
MTP18-26C	<100	7.3	0.40	0.56	5.46	2	<0.1	<1	0.11	0.14	6.0	5.12	3.3	8.5	<0.1	10	34

Abbreviations: altn = alteration, chalced = chalcedony, chlor = chlorite, cpy = chalcopyrite, hm = hematite, py = pyrite, qz = quartzite, rhy = rhyolite, rut = rutile, ser = sericite.

1. All compositional data tabled was generated using Actlabs package 1EPI-MS (www.actlabs.com).
2. Values set in bold are considered anomalous.

accessible during field work. The dominant rock types observed in that area were epiclastic sandstone and conglomerate. Constituent clasts have variable degrees of rounding and are mainly volcanic. Most of these epiclastic rocks are red (hematitic) (e.g. MTP18-14). A hard, grey facies of the epiclastic rocks is highly silicified and contains abundant fine-grained pyrite. The lithogeochemical analysis of this highly silicified facies (sample MTP18-13) returned 70 ppm Cu, 100 ppm Zn, and 20 ppm Pb (Tables 2, 3). Scanning electron microscope imaging of sample MTP18-13 confirmed that fine-grained pyrite is confined to the silicified matrix between volcanic clasts and revealed delicate (epithermal-style) overgrowths of galena on fine-grained pyrite.

With reference to the incompatible element plot of Figure 2c, the slightly more depleted (but parallel) composition of silicified sample MTP 18-13 versus hematitic sample MTP18-14 is interpreted as a simple consequence of silicification (dilution) of the former sample during induration relative to the predominant red (hematitic) facies.

The grey silicified facies at Big Hill Road quarry bears a strong resemblance to the silicified and pyritized epiclastic conglomerates that host the mineralized veins of the Big Easy low-sulphidation Au-Ag prospect in the Avalon zone of Newfoundland (Ferguson, 2017). At Big Easy this facies is interpreted as having formed at surface in sulphidic geothermal ponds, and then was subsequently crosscut (post-induration) by the precious-metal veins. Mineralization at Big Easy has been dated at ca. 575 Ma (Ferguson, 2017) making it potentially age correlative with the Big Hill Road host rocks, pending more explicit dating of these and other ca. 575 to 560 Ma rocks in the Mira terrane.

Park Brook Prospect

This prospect is listed in the Nova Scotia Mineral Occurrence Database (Nova Scotia Department of Natural Resources, 2016) as *Park Brook Au Occurrence*. It is described therein as auriferous sericite-hematite mineralization hosted in shear zones within volcanic rocks of the East Bay Hills Group (ca. 620 Ma). This prospect was explored for gold in 1986 by INCO Ltd./Scominex as part of their East Bay Hills Project (Booth, 1986).

We visited the surface showings along Park Brook that were documented in the above report and

collected samples of altered/mineralized rock along the banks. The main host rock at these sites is altered, foliated rhyolite with substantial pyrite mineralization (10-25%), largely as coarse (>1 mm) spots or grain clusters. Samples of this rock (Table 4; MTP18-26A, B, C) returned values of between 33 and 45 ppb Au and up to 1.2 ppm Ag. These values are consistent with those reported by Booth (1986) from these locations. These samples also returned anomalous concentrations of Cu, Mo, Zn, Bi, Sb, Te, and W. A single sample (MTP18-26B2) that was hosted by an enclave of intermediate (pyroclastic) volcanic rock and that contained a small pyritiferous quartz vein returned 88 ppb Au. The hematite in all these samples is a consequence of later martitization (weathering) of the original pyrite. The predominant alteration phase is a sericite.

The style of mineralization/alteration in these rocks is equivocal (at least at the showings visited) in terms of characterizing this occurrence as epithermal (versus orogenic).

Summary and Conclusions

The lithogeochemical sampling and analysis accomplished during this study has provided a starting point for further assessing and subdividing rock types in the Mira terrane, especially those in the ca. 620 and ca. 575 to 560 Ma belts. Three locations discovered during the relatively brief initial field campaign are anomalous for Au and pathfinder metals, as well as displaying alteration typically associated with epithermal- or porphyry-style mineralization. Further work is planned to follow up on the positive implications of these findings for mineral exploration within the Mira terrane.

Acknowledgments

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Geoscience Editing and Publishing, April 2018 to March 2019

D. R. MacDonald, E. W. MacDonald, and J. S. Saunders

Staff of the geoscience editing and publishing group work toward the goal of high-quality, timely and cost-effective reporting on activities carried out by the Geoscience and Mines Branch. The group's work involves editing manuscript maps and reports to conform to the branch standards for peer review, content, and style. When a map or report has been completed and approved for publication, the group works to prepare the publication for release in hard copy and online. The Geoscience and Mines Branch web site provides an average of more than 25,000 downloads of its documents per month to clients, all free of charge.

All geoscientists in the branch are required to publish accounts of their work. These accounts may be published as scientific reports, memoirs, or maps, or they may be more effectively summarized in less technical publications such as information circulars or newsletters. All forms of publication play an important role in delivering geoscience information to enhance public awareness of earth science, geoheritage, groundwater resources, and geohazards, and to promote the mineral resources of Nova Scotia. A consistent record of publication is also an excellent measure of accountability for staff of the Geoscience and Mines Branch.

In July 2018, the Geoscience and Mines Branch merged with the Nova Scotia Department of Energy to form the Nova Scotia Department of Energy and Mines. Branch webmaster Susan Saunders retired in August 2018, after more than a decade of building the online presence of the Geoscience and Mines Branch.

The following publications were released in the 2018-2019 fiscal year.

Contribution Series

CS ME 2018-001¹. U-Pb (zircon) ages and provenance of the White Rock Formation of the Rockville Notch Group, Meguma terrane, Nova Scotia, Canada: evidence for the "Sardinian gap"

and West African origin, by C. E. White, S. M. Barr, and U. Linnemann; *Canadian Journal of Earth Sciences*, April 2018, 15 p.

Digital Products

A full list of digital products released is given in Poole et al. (this volume, p. 57-58).

Newsletter

The *Geological Record*, v. 5, nos. 2 and 3; v. 6, no. 1 (winter 2019).

Open File Maps

OFM ME 2018-004. Mineral Resources Development Fund approved grants 2018-2019, revised January 2019, by J. C. Bonaparte, scale 1:1 000 000.

OFM ME 2019-001. Geology of the Parrsboro shore, Black Rock to Moose River, Cumberland County, Nova Scotia, by J. H. Calder, J. W. F. Waldron, R. D. Naylor, K. Adams, T. Fedak, E. George and T. G. MacHattie, scale 1:25 000.

Open File Reports

OFR ME 2018-006. A review and summary of activities related to uranium in Nova Scotia well water, by G. W. Kennedy and J. Drage, 34 p.

OFR ME 2018-007. Mapping historical groundwater levels of Nova Scotia; a conceptual model, by J. Leahy and S. Lloyd, 21 p.

OFR ME 2019-001. A karst risk map of Nova Scotia, by J. Drage, 9 p.

¹ Awarded Best Paper of 2018 by *Canadian Journal of Earth Sciences* in May 2019.

OFR ME 2019-002. Potential corrosivity of groundwater in Nova Scotia and its association with lead in private well water, by G. W. Kennedy, 22 p.

Report ME 2019-001. Mineral production report, by Nova Scotia Department of Energy and Mines, 20 p.

Reports

Report ME 2018-001. Geoscience and Mines Branch, Report of Activities 2017-2018, eds. D.R. MacDonald and E.W. MacDonald, 102 p.

Sulphide Mineralization at the Core Shack and Galena Mine Occurrences, Chéticamp Area, Cape Breton Island, Nova Scotia

K. Neyedley¹, C. E. White, G. J. Baldwin, and G. R. Hooey²

Introduction

The Chéticamp area of Cape Breton Island, Nova Scotia, is located in the western part of the Ganderian Aspy terrane (Fig. 1) and has been an exploration target for economic mineral since the 1890s (e.g. Sangster et al., 1990; DeMont 1992). The units that host these Cu-Pb-Zn mineral occurrences are part of the Jumping Brook Metamorphic Suite (Jamieson et al., 1989; Barr et al., 1992). In recent work (e.g. White et al., 2017), the stratigraphic units in the Jumping Brook Metamorphic Suite have been simplified to consist of the dominantly metavolcanic Faribault Brook Formation and the overlying, dominantly metasedimentary Dauphinee Brook Formation (Fig. 1).

Based on U-Pb zircon ages (White et al., 2016) and geochemical studies (Tucker 2011; Shute 2017; Vibert 2018; Hooey 2019), the ca. 530 to 490 Ma Jumping Brook Metamorphic Suite has MORB-like characteristics that suggest correlation with Newfoundland's Exploits subzone and related volcanic massive sulphide and gold deposits (Rogers et al., 2006; Galley et al., 2007; van Staal, 2007; McNicoll et al., 2010).

This report summarizes a detailed petrographic and litho-geochemical study on mineralized samples collected from the Core Shack and Galena Mine occurrences in the Dauphinee Brook Formation.

Field Relations

The Faribault Brook Formation forms the lower part of the Jumping Brook Metamorphic Suite and is dominantly a mafic metavolcanic package, but includes less abundant intermediate and felsic metavolcanic rocks and minor metasedimentary rocks (Jamieson et al., 1989; White et al., 2015).

The Dauphinee Brook Formation forms the upper part of the Jumping Brook Metamorphic Suite and is dominantly metasedimentary. The contact between the two is interpreted to be gradational (White et al., 2015, 2017). A more detailed description of the various rock types in these formations is in White et al. (2015).

Detailed mapping confirmed that most of the documented mineralization occurs near the contact between the Faribault Brook and overlying Dauphinee Brook formations (White et al., 2015, 2016, 2017). The Core Shack and Galena Mine occurrences are near the lower part of the Dauphinee Brook Formation and are associated with a distinctive, pale muscovite-garnet schist with quartz eyes (Connors 1986; Tucker 2011; White et al., 2015). This muscovite-garnet schist is interlayered with phyllite, metawacke, and quartzite.

At both locations, mineralization occurs as lenses and pods, typically 3 to 10 cm thick and 5 to 30 cm long. They are concordant with the main schistosity and are typically boudinaged and elongated parallel to the well developed regional mineral lineation, which plunges shallowly to the north-northwest. This concordancy confirms an origin that predates metamorphism and deformation (Lynch and Mengel, 1995; White et al., 2015, 2016). The presence of a younger set of sulphide-bearing, deformed quartz veins suggests a later remobilization of quartz and sulphide minerals (e.g. Hooey 2019).

Sulphide Petrography

Introduction

Three samples (CW18-060A, B, C) were collected from the Core Shack occurrence (UTM in NAD83:

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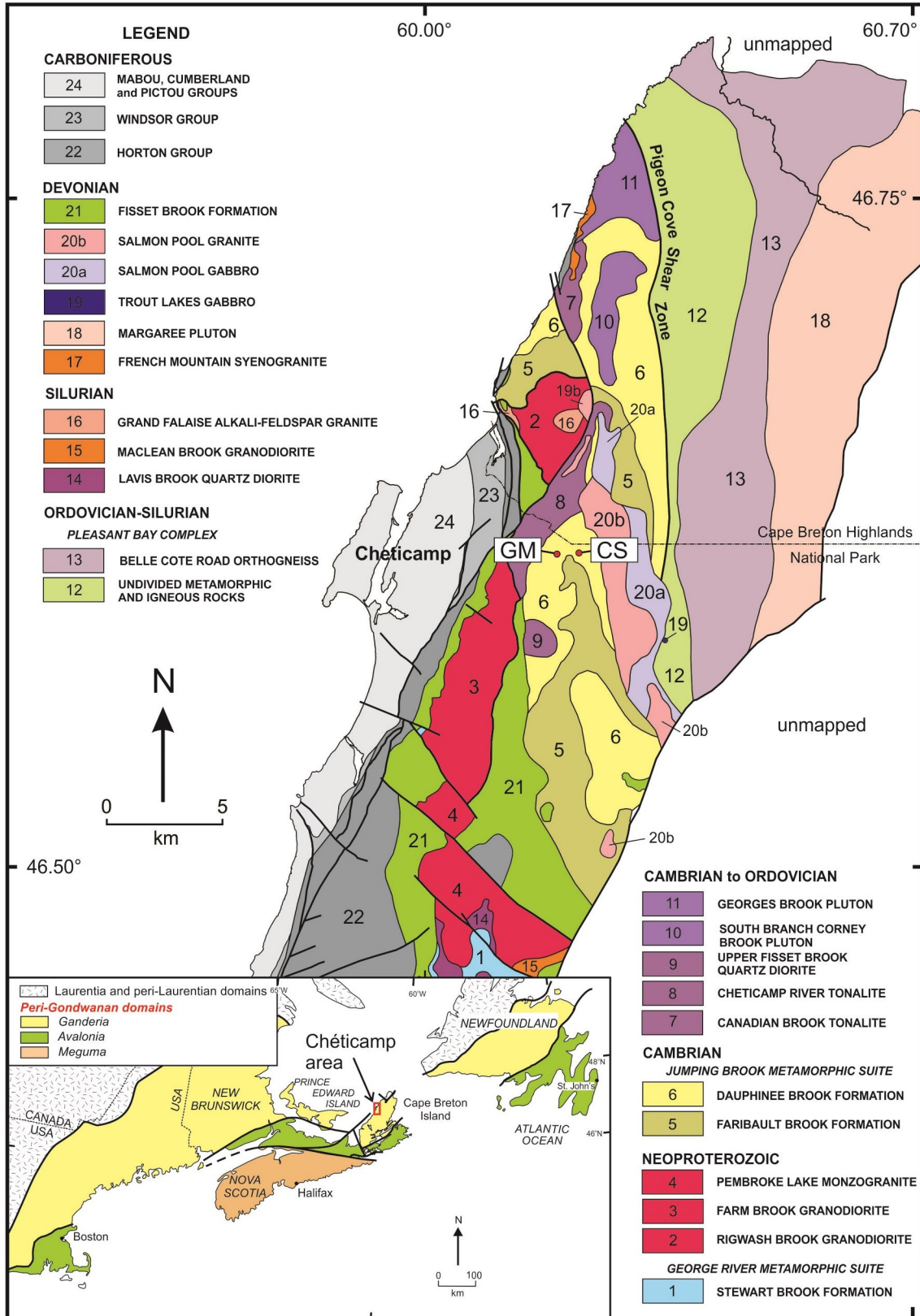


Figure 1. Geological map of the Chéticamp area (after White et al., 2017) showing the locations of the Core Shack (CS) and Galena Mine (GM) occurrences. Inset map of the northern Appalachian orogeny (redrawn from Hibbard et al., 2006) shows the location of the study area (red box) in Ganderia (Aspy terrane) of western Cape Breton Island, Nova Scotia.

E=659768, N=5165207): one from each of three different 5 cm thick mineralized layers within a 5 to 6 m wide muscovite-garnet schist unit. Eight samples were collected from the Galena Mine occurrence: one sample (15GB0380; UTM in NAD83: E = 658922, N = 5165460) from near audit #2 as defined by DeMont (1992); two samples (15GB0381; UTM in NAD83: E = 658948, N = 5165431 and 15GB0382; UTM in NAD83: E = 658924, N = 5165441) from the Highlands Mercury showing approximately 20 m up stream from the previous sample; and five samples (15GB0383A, B, C, D, and E; UTM in NAD83: E = 658905, N = 5165456) from a mineralized boulders in the stream bed between the above samples.

Although the host rocks are deformed and metamorphosed, most of the sulphide mineralization, at least on a thin-section scale, appears to have retained its primary mineralogy and texture.

Core Shack Occurrence

All three samples collected from the Core Shack occurrence have similar features. They display banded, disseminated to semi-massive sulphide mineralization consisting of 15 to 35 volume % sulphide minerals (Figs. 2a-d). Arsenopyrite is the dominant sulphide mineral in all three samples, forming 0 to 30% of each. Sulphides found in lesser amounts are pyrite (1–5%), sphalerite (1–3%), chalcopyrite (trace–1%), and galena (trace–1%).

Two textural varieties of arsenopyrite are present (Fig. 2d). Type 1a (Apy1a) occurs as fine-grained (20–400 μm), weakly sieved (few inclusions), euhedral to subhedral grains that occur parallel to white mica-rich foliation (Fig. 3a). Type 1b (Apy1b) occurs as fine- to coarse-grained (10–2000 μm), subhedral, weakly to moderately sieved, fractured grains that occur in a weakly foliated granoblastic matrix of quartz and minor white mica (Fig. 3b). The percentage of Apy1a versus Apy1b in thin section varies depending on where the section was cut from the sample.

Two generations of pyrite are present. Type 1 (Py1) is interpreted as an early phase pyrite. It is fine- to coarse-grained (10–2000 μm), subhedral, moderately sieved and fractured, and is associated with Apy1b in the granoblastic quartz-rich areas (Fig. 3b). Type 2 (Py2) is a later phase pyrite that is

typically fine-grained (< 100 μm) and subhedral. It occurs on the rims of all sulphide minerals, either as individual grains or as clusters, or in fractures of Apy1b (Fig. 3c).

Sphalerite is generally restricted to granoblastic quartz-rich bands, and the percentage of sphalerite is highly variable amongst individual bands (trace–5%). In bands where sphalerite is more abundant, it forms anhedral masses, which contain inclusions of Apy1b and Py1, and it also occurs along the rims and within fractures of Apy1b and Py1 (Fig. 3d). In sphalerite-poor bands, however, it occurs only along the rims and within fractures of Apy1b and Py1 (Figs. 3c, e). Chalcopyrite is generally present only in granoblastic quartz-rich bands and occurs along the rims and within fractures of Apy1b and Py1 (Figs. 3c, e). Rarely, chalcopyrite occurs on the rim of Apy1a, but only on grains at the contact between mica- and quartz-rich bands (Fig. 3c) or along grain boundaries between quartz grains. Galena is observed only along the rims and within fractures of Apy1b as 100 to 2000 μm , subhedral grains in granoblastic quartz-rich bands (Fig. 3f). Chalcopyrite is typically present in close association with galena.

Galena Mine

Samples collected from the Galena Mine occurrence have a banded appearance similar to the Core Shack occurrence but have lower abundances of sulphide minerals (5–10 volume per cent). Two varieties of mineralization are present in the samples and are referred to as MZ-1 and MZ-2.

MZ-1

MZ-1 consists of 0.5 to 1 cm thick layers of massive arsenopyrite-sphalerite-galena (Fig. 2e). The mineralization comprises sphalerite (5–8 volume per cent) and lesser proportions of arsenopyrite (2–5%), pyrite (1–3%), galena (trace–2%), and chalcopyrite (trace). Sphalerite predominately occurs as anhedral, inclusion-rich masses with indistinguishable grain boundaries (Figs. 4a, b, c) and subhedral, fairly inclusion-poor grains (Fig. 4d). Inclusions of pyrite and arsenopyrite are present in sphalerite; both are moderately to heavily fractured, and fractures are infilled in places with sphalerite (Figs. 4a, b). Arsenopyrite grains are subhedral, weakly to moderately sieved, up to 200 μm in diameter, and occur as inclusions in the sphalerite (Figs. 4a, b, c).

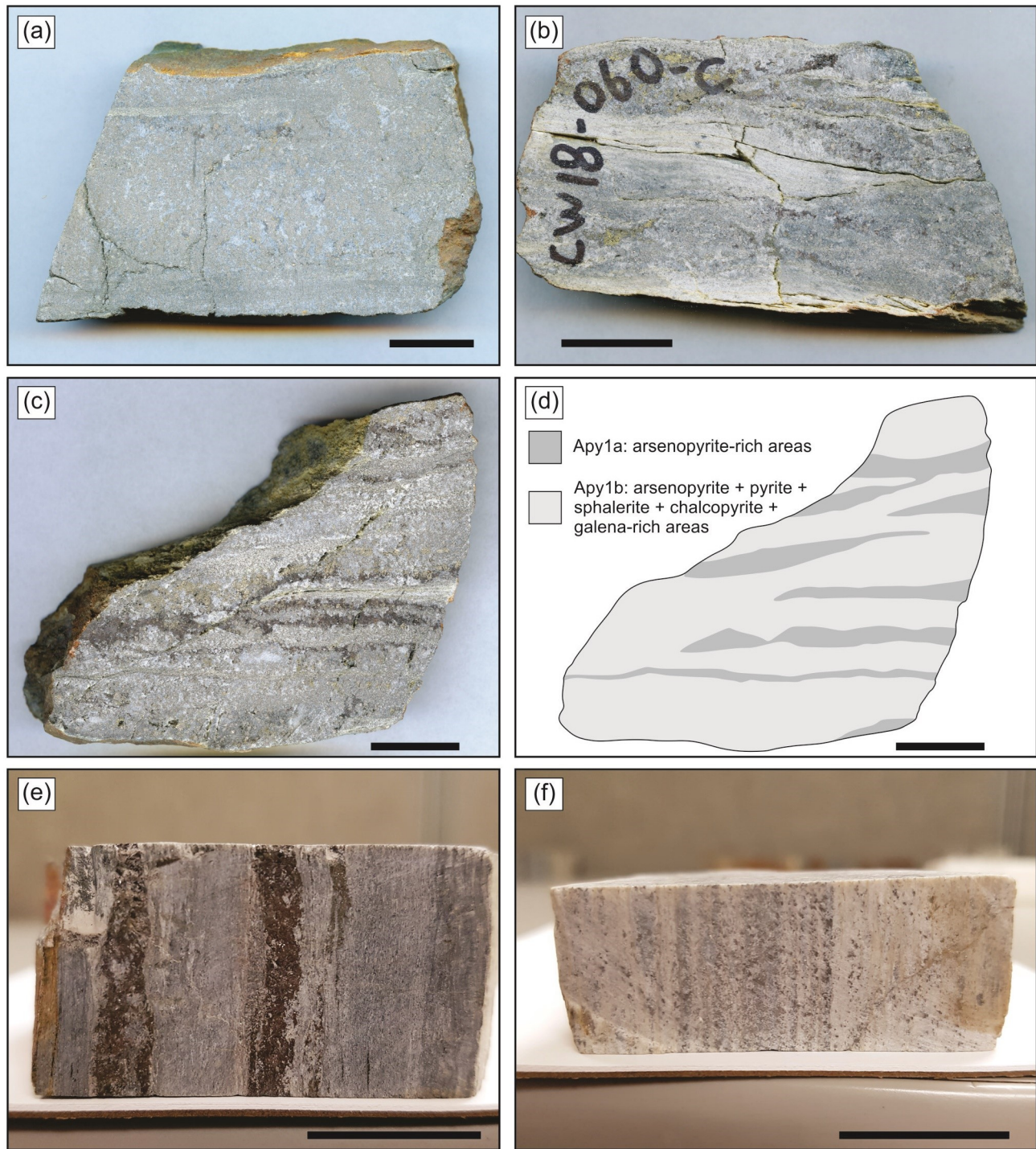


Figure 2. Slabs of sulphide mineralization from the Core Shack (a-d) and Galena Mine (e, f) occurrences. All scale bars are 2 cm. (a) Banded arsenopyrite layers up to 30-35 volume % (sample CW18-060A). (b) Weakly banded disseminated arsenopyrite-sphalerite-chalcopyrite (sample CW18-060C). (c) Semi-massive banded sulphide mineralization consisting of arsenopyrite-pyrite-sphalerite-chalcopyrite-galena (sample CW18-060B). (d) Sketch of slab in Figure 2c showing the banded nature of sulphide mineralization and the locations of the different textural variations of arsenopyrite (see petrography section for explanation). (e) Banded sphalerite-arsenopyrite representative of mineralization style MZ-1. (f) Banded arsenopyrite representative of mineralization style MZ-2.

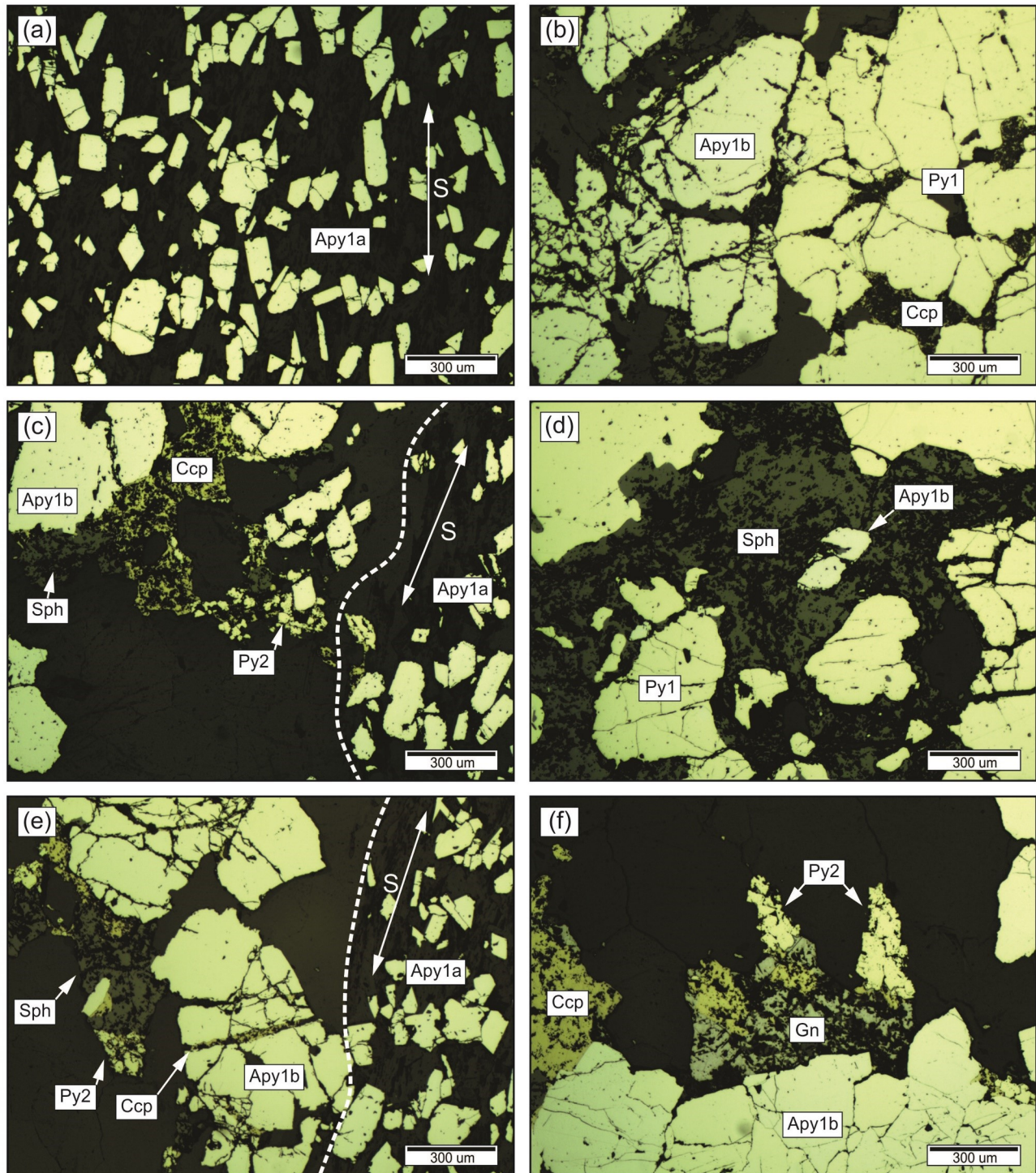


Figure 3. Representative photomicrographs of sulphide mineralization from the Core Shack occurrence. All photos were taken in reflected light. (a) Arsenopyrite style 1a (Apy1a) grains subparallel to foliation (S) in mica-rich bands. (b) Arsenopyrite style 1b (Apy1b) in contact with the early generation of pyrite (Py1). Chalcopyrite (Ccp) is fracture filling. (c) Boundary (dashed white line) between mica-rich and granoblastic quartz-rich bands. Note the difference in grain size and form between Apy1a and Apy1b. Chalcopyrite and sphalerite (Sph) occur along the edges of Apy1b. The late generation of pyrite (Py2) occurs along the edges of Apy1b and chalcopyrite. Note the difference in grain size between Py1 (in frame b) and Py2. (d) Anhedronal mass of sphalerite containing inclusions of Apy1b and Py1. (e) Boundary (dashed white line) between mica-rich and granoblastic quartz-rich bands. The fracture in Apy1b is infilled with chalcopyrite. Chalcopyrite and sphalerite also occur along the grain margins of Apy1b. (f) Galena (Gn) and chalcopyrite occurring along the margins of Apy1b and Py2 occurring along the margins of galena.

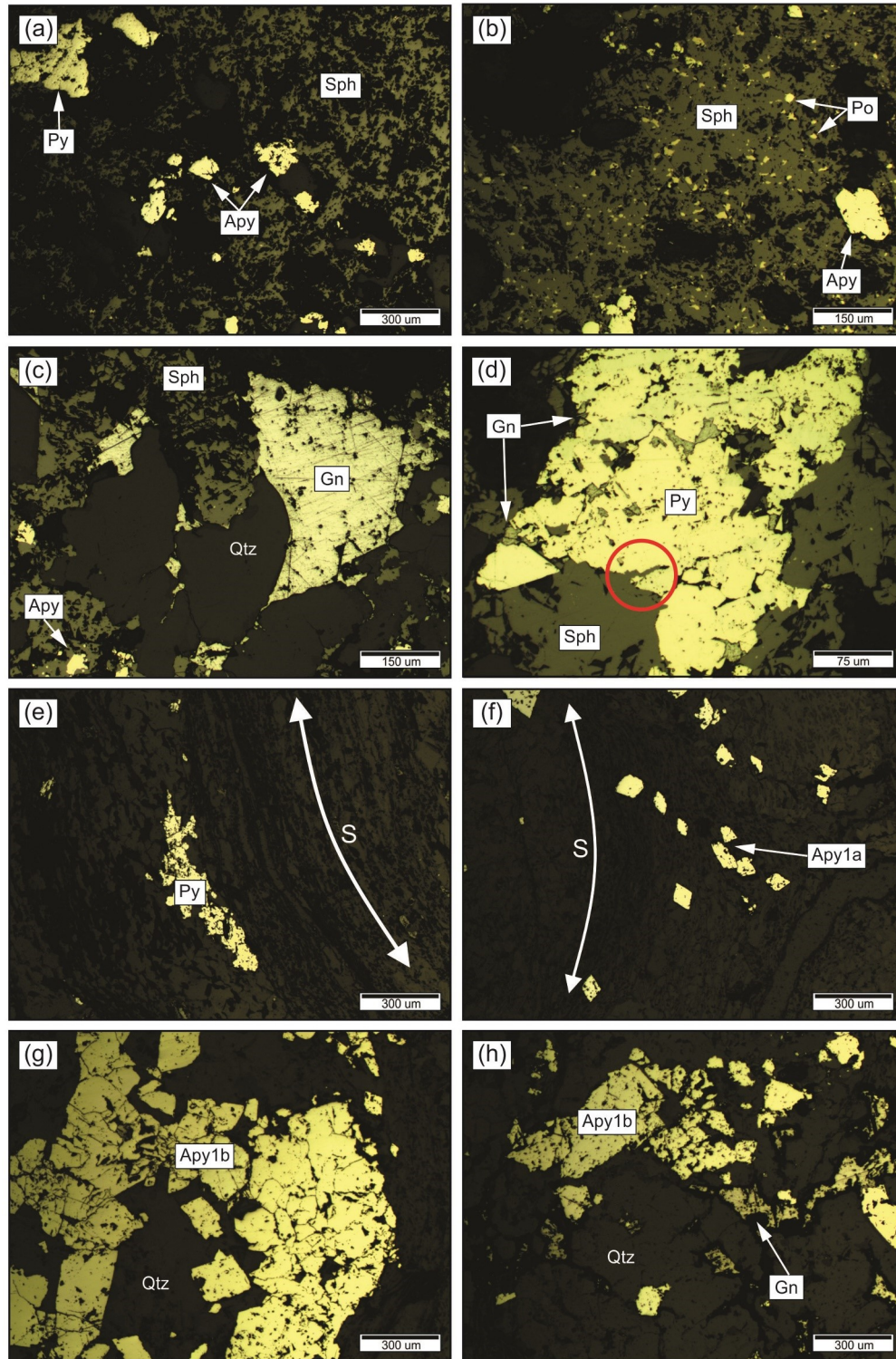


Figure 4. Representative photomicrographs of MZ-1 (a-e) and MZ-2 (f-h) sulphide mineralization in samples from the Galena Mine occurrence. All photographs were taken in reflected light. (a) Pyrite (Py) and arsenopyrite (Apy) inclusions within massive sphalerite (Sph). (b) Very fine-grained pyrrhotite (Po) blebs occurring in massive sphalerite. (c) Galena (Gn) appears to have infilled open spaces and occurs along the edges of sphalerite and quartz. (d) Large pyrite with galena occurring along the grain margins. Sphalerite infills fractures in the pyrite (red circle). (e) Elongated pyrite parallel to foliation (S). (f) Fine-grained arsenopyrite 1a (Apy1a) in mica-rich bands. (g) Medium- to coarse-grained arsenopyrite (Apy1b) and quartz (Qtz). (h) Galena occurring along grain boundaries of granoblastic quartz and in close association with Apy1b.

Pyrite grains display the same textural characteristics as arsenopyrite, but fractures in the pyrite are infilled with sphalerite (Fig. 4d). Galena typically occurs as small inclusions within pyrite (Fig. 4d), but rare, larger grains (up to 200 μm) are present along the margins of massive sphalerite and interstitial to granoblastic quartz (Fig. 4c). These larger galena grains have sharp boundaries that suggest deposition in open spaces. Trace amounts of chalcopyrite are present in close association with pyrite. Trace amounts of pyrrhotite are present as < 25 μm blebs in sphalerite (Fig. 4c). In the sphalerite-poor bands (Fig. 2e), sulphide minerals (arsenopyrite + pyrite + sphalerite + chalcopyrite) form 1 to 2 volume per cent in clusters parallel to foliation (Fig. 4e).

MZ-2

MZ-2 consists of millimetre-scale layers of arsenopyrite (Fig. 2f), which constitutes 3 to 5 volume per cent of the mineralization, and trace amounts of galena and pyrite. Arsenopyrite is fine- to medium-grained (10–800 μm), euhedral to subhedral, and weakly to moderately sieved and fractured (Figs. 4f, g, h). As at the Core Shack occurrence, two textural varieties of arsenopyrite (Apy1a, 1b) are present at the Galena Mine occurrence. Apy1a is typically associated with mica-rich bands, but in contrast to the Apy1 at Core Shack, the sulphides are not parallel to the foliation (Fig. 4f). Larger arsenopyrite grains (Apy1b) occur in clusters associated with granoblastic quartz (Figs. 4g, h). Galena is a trace phase in close association with Apy1b and interstitial to granoblastic quartz (Fig. 4h). Like galena, trace amounts of pyrite are present and occur with Apy1b.

Based on the petrographic observations, the paragenetic sequence of sulphide mineralization for the Core Shack and Galena Mine occurrence is similar and is summarized in Figure 5.

Whole Rock Geochemistry

Core Shack

Bulk rock geochemical results from three samples of banded disseminated to semi-massive sulphide mineralization from the Core Shack mineral occurrence indicate significant concentrations of base and precious metals (Table 1). Gold

concentrations are relatively enriched in all three samples and range between 5.6 and 8.6 ppm (g/t) with an average value of 6.7 ± 1.6 ppm. Silver is also enriched, ranging between 26.9 and 46.0 ppm ($\sim 36.9 \pm 9.6$ ppm). Arsenic is above the analytical confidence limit (>1 weight per cent) in all three samples and Zn is above the analytical confidence limit (>1 weight per cent) in two of the three samples. Lead concentrations range from 1090 to 5590 ppm ($\sim 3400 \pm 2250$ ppm) and Cu between 620 and 7720 ppm ($\sim 3990 \pm 3560$ ppm). Other elements of notable enrichment include Cd ($\sim 210 \pm 196$ ppm), Bi ($\sim 43.2 \pm 34$ ppm), Sb ($\sim 489 \pm 117$ ppm), and Se ($\sim 2.2 \pm 1.0$ ppm).

Both Au and Ag have weak positive correlation with S content (Figs. 6a, b) indicating that both of these precious metals may be present within sulphide minerals as either micro- or nano-inclusions or as a solid solution in the sulphide mineral structure. Gold does not show a positive correlation with any major metal, but given the high abundance of arsenopyrite and the amount of gold that can be dissolved in its structure (~ 1000 ppm, Vaughan and Kyin, 2004; Fig. 6c), it is plausible that arsenopyrite is the prominent host of gold in these samples. For example, sample CW18-060-B has Au concentration of 5.6 ppm and contains ~ 15 volume per cent arsenopyrite. If 20 ppm Au is present in solid solution in the arsenopyrite structure, then the total Au contributed by arsenopyrite to the bulk sample would be ~ 5.7 ppm. Therefore, it is likely that the bulk of the Au in the Core Shack occurrence samples is hosted in arsenopyrite. Silver has a positive correlation with Pb, indicating that galena may be the main host for silver in these samples (Fig. 6d).

Galena Mine

Bulk rock geochemical results from Galena Mine samples show similar enrichments in base and precious metals as in the Core Shack occurrence samples. Gold concentrations from MZ-1 vary between 0.12 and 2.27 ppm ($\sim 1.03 \pm 0.7$ ppm; $n = 7$) and Ag ranges from 4.4 to 83.8 ppm ($\sim 25.8 \pm 31.9$ ppm; $n = 6$), with one sample having Ag above the range of the analytical confidence (>100 ppm; Table 1). Zinc is above the analytical confidence in all samples from MZ-1 (>5000 ppm) and Pb is above analytical confidence in three of seven samples (>5000 ppm). In the other four samples, Zn ranges from 260 to 590 ppm. Arsenic is also above analytical confidence (>1 weight per cent) in

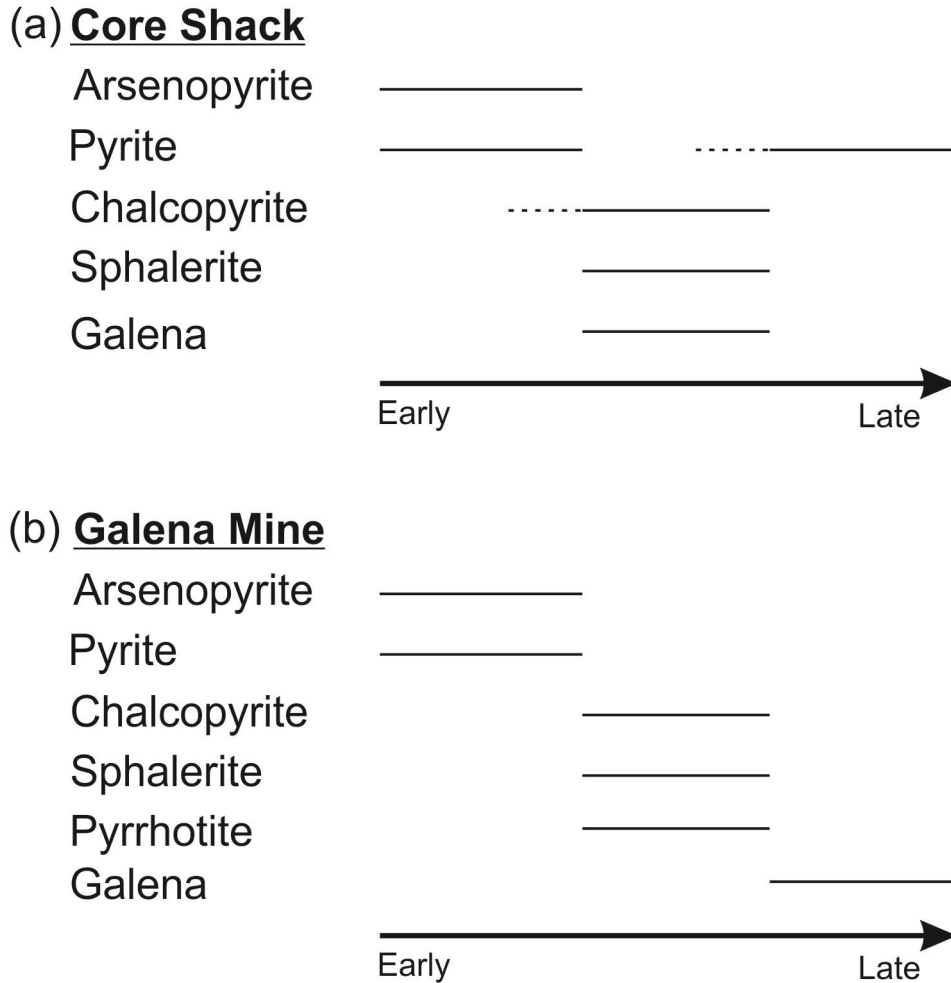


Figure 5. Sulphide mineral paragenetic sequence for the (a) Core Shack and (b) Galena Mine occurrences.

three samples, and it ranges from 1690 to 7180 ppm in the other five samples. Copper ranges from 260 to 760 ppm ($\sim 510 \pm 215$ ppm; $n = 7$).

Cadmium is over analytical confidence (>1000 ppm) in two samples, both of which are also over analytical confidence in Zn and Pb. Cadmium concentration in the other samples ranges from 72 to 950 ppm. Other elements of notable enrichment include Se ($\sim 2.08 \pm 1.7$ ppm), Bi ($\sim 35.2 \pm 59$ ppm), and In ($\sim 36 \pm 52$ ppm).

Gold concentrations from MZ-2 range from 0.07 to 3.8 ppm ($\sim 2.29 \pm 1.97$ ppm; $n = 3$) and Ag ranges from 3.29 to 8.43 ppm ($\sim 6.17 \pm 2.63$ ppm; $n = 3$). Arsenic is over analytical confidence (>1 weight per cent) in two of three samples, and is 2420 ppm in the third. Overall, Zn and Pb have lower concentrations in MZ-2 compared with MZ-1.

Copper ranges between 150 and 174 ppm (average 160 ± 12 ppm; $n = 3$).

It is not as evident as at the Core Shack occurrence, but there appears to be weak positive correlation of Au and Ag with S content as well as with Ag and Pb concentrations (Fig. 6). Gold does not show any correlation with any major metal but could be hosted in arsenopyrite (see above). Like the Core Shack occurrence, the highest Ag concentrations are associated with high Pb values which suggests that galena is the dominant host for Ag (Fig. 6d).

Summary

Although the geology in the Chéticamp area is structurally complex, based on field and petrographic evidence the main phase of

Table 1. Assay data from the Galena Mine and Core Shack mineral occurrences.

Sample	15GB0380 ¹	15GB0381 ¹	15GB0382 ¹	15GB0383A ¹	15GB0383B ¹	15GB0383C ¹	15GB0383C ²	15GB0383D ¹	15GB0383E ¹	15GB0383E ²	CW18-060A ²	CW18-060B ²	CW18-060C ²
Analysis year	2015	2015	2015	2015	2015	2015	2018	2015	2015	2018	2018	2018	2018
Location	GM-MZ-1	GM-MZ-2	GM-MZ-1	GM-MZ-1	GM-MZ-1	GM-MZ-1	GM-MZ-2	GM-MZ-1	GM-MZ-1	GM-MZ-1	CS	CS	CS
S (wt%)	8.22	0.59	0.93	3.57	3.86	3.33	3.75	2.30	3.45	3.90	13.9	15.9	10.1
Au (ppm) ^a	n.c.	n.c.	n.c.	n.c.	n.c.	n.c.	3.44	n.c.	n.c.	1.17	8.55	5.60	6.07
Au ^b	1.16	0.07	0.29	1.15	1.19	2.99	3.8	0.12	2.27	1.0	10.8	6.8	7.0
Ag	>100	3.29	8.59	83.8	43.1	8.43	6.80	9.27	5.88	4.40	37.9	46.0	26.9
Cr	7.00	17.0	22.0	10.0	14.0	7.00	n.c.	23.0	5.00	n.c.	n.c.	n.c.	n.c.
Co	22.1	12.7	11.5	45.2	45.5	63.4	76.0	14.9	20.6	23.1	20.6	13.4	12.0
Ni	2.80	14.3	12.8	10.4	15.3	1.40	1.50	24.2	1.50	1.00	2.70	6.30	1.60
Cu	478	158	434	672	729	151	174	759	239	262	616	3641	7716
Zn	>5000	3200	>5000	>5000	>5000	762	878	>5000	>5000	>10000	3766	>10000	>10000
Ga	2.97	4.30	4.34	3.52	4.18	2.14	15.1	4.97	3.76	15.5	4.10	4.40	6.60
Ge	<0.1	<0.1	<0.1	<0.1	<0.1	2.30	n.c.	<0.1	1.10	n.c.	n.c.	n.c.	n.c.
As	>10000	2420	1690	6830	7180	>10000	>10000	3240	>10000	>10000	>10000	>10000	>10000
Se	3.90	<0.1	<0.1	3.80	3.20	<0.1	<0.5	0.10	0.30	1.20	1.60	3.30	1.70
Mo	1.22	1.09	1.16	1.27	1.65	1.18	1.10	2.59	1.00	1.00	2.00	0.60	0.60
Cd	>1000	26	72.3	>1000	950	5.45	6.60	102	167	195	26.9	417	185
In	1.87	0.58	4.42	114	91.1	0.25	n.c.	5.13	0.78	n.c.	n.c.	n.c.	n.c.
Sn	18.1	2.71	4.83	5.22	6.39	3.17	18.0	3.27	3.73	13.0	12.0	28.0	24.0
Sb	201	2.77	3.82	11.9	13.2	112	84.9	4.81	55.7	29.0	556	557	354
Te	0.03	<0.02	0.03	0.25	0.19	<0.02	n.c.	0.04	<0.02	n.c.	n.c.	n.c.	n.c.
W	0.1	0.2	0.2	0.1	0.2	0.2	1.7	0.3	0.2	1.5	1.1	<0.5	1.0
Tl	0.45	0.35	0.36	1.43	0.87	0.19	0.10	0.30	0.44	0.40	0.30	0.20	0.20
Pb	>5000	48.6	374	>5000	>5000	2090	2404	259	577	592	5586	3527	1086
Bi	1.31	1.25	12.2	160	63.0	1.51	1.40	7.91	0.90	0.80	82.5	24.2	22.9
Hg (ppb)	0.53	<10	0.08	2.38	1.76	0.03	0.04	0.13	0.22	0.24	0.16	3.52	1.49

Notes: n.c. = not collected, GM = Galena Mine, CS = Core Shack; ^a analysis by Aqua Regia-MS; ¹ Analyses completed at Activation Laboratories Ltd., Ancaster, Ontario, L9G 4V5; ² Analyses completed at Bureau Veritas Commodities Canada Ltd., Vancouver, British Columbia, V6P 6E5.

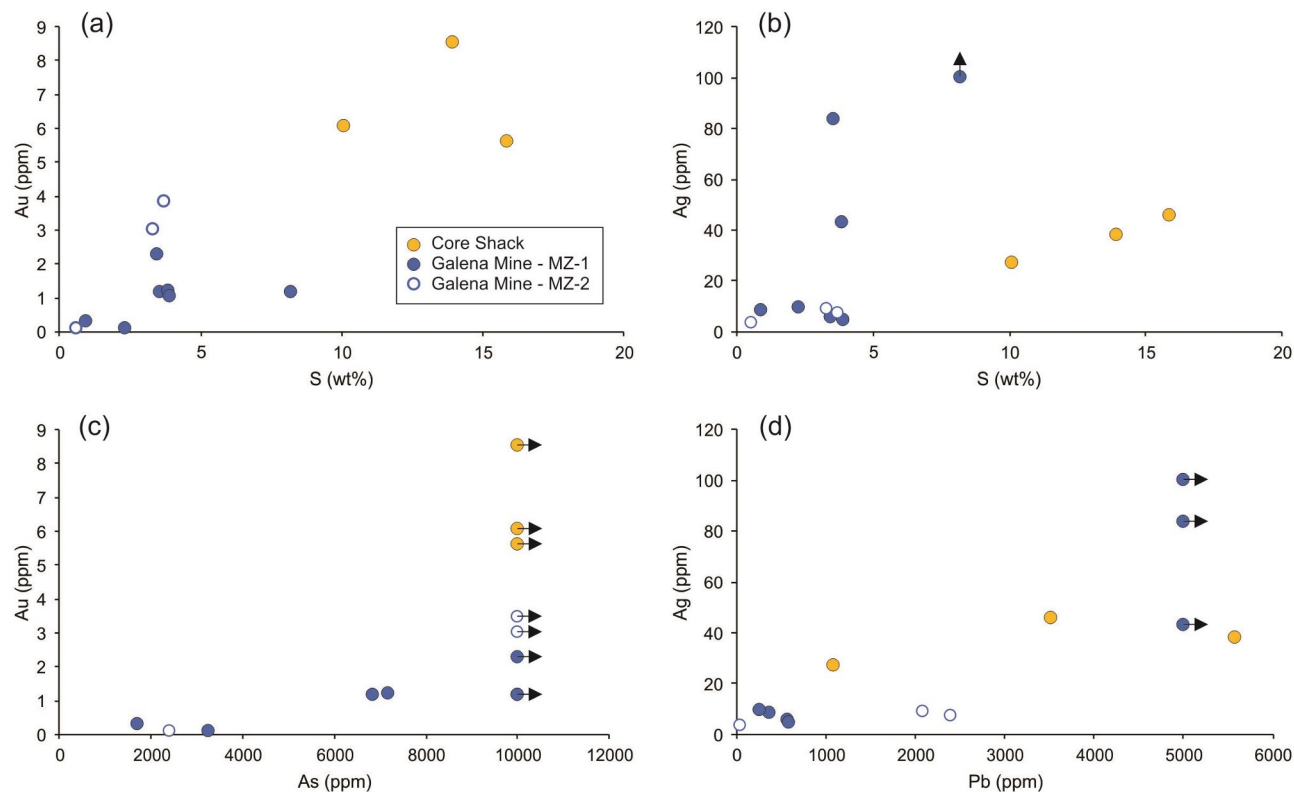


Figure 6. Plots of select precious and base metals in samples from the Core Shack and Galena Mine occurrences. Arrows in B, C, and D represent analyses above analytical confidence; therefore values plotted represent minimum concentrations. (a) Au (ppm) vs. S (weight per cent) content. (b) Ag (ppm) vs. S (weight per cent) content. (c) Au (ppm) vs. As (ppm). (d) Ag (ppm) vs. Pb (ppm).

mineralization at both Core Shack and Galena Mine occurred prior to deformation and metamorphism. The most abundant sulphide minerals recognized in the two occurrences are arsenopyrite, sphalerite, and galena, whereas chalcopyrite, pyrrhotite, and pyrite are found in lesser amounts. The presence of abundant arsenopyrite suggests that the original depositional environment of the Jumping Brook Metamorphic Suite may have been favourable for the deposition of gold. Petrographic and geochemical studies indicate that gold is hosted in arsenopyrite and silver in galena.

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Drill Core Library Activities, April 2018 to March 2019

M. J. O'Neill

Introduction

The Nova Scotia Department of Energy and Mines (DEM) Drill Core Library in Stellarton acquires and archives drill cores, well cuttings, and other geological sample materials obtained from exploration, evaluation, and development projects throughout Nova Scotia. The main intent is to facilitate further investigation and research of the province's geology and its geological resources, such as industrial and metallic minerals; energy resources, such as oil, gas and coal; and infrastructure commodities, such as aggregate resources.

These sample materials are derived from various exploration and development projects conducted by the private sector, as well as from DEM field work and other government or academic sources. The DEM Core Library also acts as the repository for core and well cuttings obtained from drilling done under the jurisdiction of the Nova Scotia Department of Energy and Mines.

The Core Library's large collection of valuable drill core currently totals about 700 000 m from more than 7,500 holes drilled throughout the province. In addition, the archived materials include well-cuttings (predominantly from oil and gas drilling), rock slabs, geochemical samples (silts, till, soils, lake sediments and biogeochemical materials), and large samples of various industrial mineral commodities, such as limestone, barite and building stone. All core and cuttings (unless held confidential) are available for examination by interested parties and may be sampled subject to certain constraints and conditions.

All visitors are advised to make contact well in advance by phoning (902) 752-4842 or by e-mailing Mick.ONeill@novascotia.ca. Clients should note that safety policies require that they bring and wear work boots at the facilities when viewing sample materials. Safety glasses are provided for clients during their use of core splitters and saws. Clients are generally required to do their own layout and pick-up of core boxes, which may involve some

heavy lifting. The use of work gloves is recommended.

Facilities and Services

The main Core Library facility is located centrally in Nova Scotia at 105–109 Acheron Court in the Stellarton Industrial Park, Pictou County, which is 2 km off the Trans-Canada Highway (Highway 104) at exit 23.

Six buildings occupy close to 5000 m², including 375 m² of laboratory space and 120 m² of office space. Most of the buildings are more than full, making it difficult to acquire core from new exploration work. Free parking is available at the Core Library.

Most core is stored in standard 1.5 m long (5 ft.) wooden boxes or trays with capacities of 4.6 to 7.6 m (15 to 25 ft.) of core, depending on the core diameter. The majority of boxes weigh from 15 to 35 kg per box, although some are as much as 45 kg. Much of the drill core in storage was measured and marked in imperial units when drilled, so the boxes and depth markers are often labelled in feet rather than metres. Boxes of core are stored by strapping them onto custom-made wooden pallets—generally about 20 to 50 boxes per pallet—and the pallets are stacked vertically in rows. The storage areas only have basic lighting and are unheated. Individual pallets are retrieved by forklift from storage as needed and are transferred by DEM staff to the core examination labs, where the core boxes may be laid out for viewing on benches, portable stands, or the floor. A large paved yard may also serve as a core box layout area during good weather. The Core Library is equipped with a binocular microscope, a portable UV light, weighing scales, a specific gravity balance, core-splitters, and diamond saws, which are all available for use by clients. Clients are responsible for carrying out and documenting their own sampling, subject to the approval and guidance of Core Library staff. Analyses and other data generated from sampling

must be forwarded by clients to Core Library staff by e-mail within 60 days of sampling.

In the summer of 2016, the Nova Scotia Mineral Incentive Program, using funds left over from the 2015-16 program, funded the purchase of an XRF analyzer by the Nova Scotia Prospectors Association (NSPA). It is a Niton XL3t 950 GOLDD+ Mining XRF analyzer with Soils and Mining Modes. It will be capable of analyzing up to 37 elements with the additional purchase of REE Element Suite (Y, La, Ce, Pr, Nd, U and Th) in the Mining Mode.

The XRF analyzer is owned by the NSPA, which will oversee its use and handle all bookings for the unit. The analyzer is stored at the Nova Scotia Department of Energy and Mines Drill Core Library in Stellarton. The analyzer will only be used to test samples from Nova Scotia. The analyzer will not be rented or provided to a third party for a fee. The department will be provided with results and location data for all samples run on the unit.

A small reference library area with tables, chairs and a microfiche reader/scanner/printer is available for clients and staff. The library collection includes a complete set of microfiche for older exploration Assessment Reports, Open File Reports and Maps. The Geoscience and Mines Branch no longer microfilms any reports; all Assessment Reports received and released from confidential status have been electronically scanned and are now available free of charge as downloadable PDFs via NovaScan on the Branch website. Unpublished information (logs, sections, maps, reports, analyses etc.) is available at the Core Library for some drillholes.

A public WiFi Internet connection is now available at the Core Library.

New Acquisitions and Re-organization of Core Storage

The Core Library acquired core from six drillholes between April 1, 2018, and March 31, 2019. Some quick notes on these holes are mentioned here, as they have not been properly catalogued for the Core Hole Database yet.

Core from two holes was picked up from the Ingonish area, from the Globex Mining Enterprises

drilling in 2008. Both holes were drilled in the Faribault Brook area, Inverness County.

Core from two holes was retrieved from drilling done by John Wightman. The core included three pallets of hole ER-17-02, drilled at Egypt Road in Yarmouth County, and seven boxes of the mineralized section of hole DOM-15-01, drilled at Dominique, also in Yarmouth County.

Core from two holes, drilled in 2016, was brought to the Library from drilling done by Glencoe Resources at Glencoe, Cape Breton Island.

Additionally, fifteen boxes of core were brought back to the Core Library from Saint Mary's University. This core was part of the Chaswood Formation, Cretaceous rocks drilled in 1997 by Kao clay Resources and in 2002 by the GSC and Saint Mary's University. This core has been extensively studied by David Piper and Georgia PePiper.

Finally, some more rocks, slabs, and powders were received from Sandra Barr of Acadia University on projects Sandra has conducted in Nova Scotia over the last thirty years.

Drill core donated to the Core Library is often in poor condition due to neglect and poor stewardship. Everyone should be aware that the *Mineral Resource Regulations* under the *Mineral Resources Act* state that drill core must be retained in standard core boxes at the drill site or at a core storage facility and that precautions must be taken to secure the drill core against weather and vandalism. The boxes should be identified with weatherproof labels that indicate the drillhole number, core interval represented, and the date and name of the company for which the drill core was obtained.

Students were hired for the last four years at the Core Library to catalogue the approximately 150 pallets of non-core material and the cabinets of geochemical samples. The Core Library contains numerous soil, till, rock, and many other types of samples. When the cataloguing is complete, a separate database will be created to capture this information and released to the public.

Client Activity

Clients typically include private sector geologists and prospectors working in the mineral exploration sector or in the oil and gas sector, as well as

Table 1. Client Activity at the Core Library in recent years.

Year	Person days: lab activities	Person days: other visitors
2009	72	48
2010	225	55
2011	110	36
2012	155	50
2013	141	48
2014	106	30
2015	183	39
2016	120	69
2017	80	49
2018	171	47

geologists with the Geological Survey of Canada and DEM (Geoscience and Mines Branch). University students and research staff, consultants, architects and engineers also make use of the facilities.

Client activity for period was 171 person-days for use of core, cuttings or other samples. An additional approximately 47 person-days was for various reasons, including access to information and equipment, including the XRF, which arrived in the Core Library in the summer of 2016 (Table 1). The figures should not be analysed too critically as many factors influence the number of clients and the days spent in the lab.

Core Library Database

The department's Drill Core Database provides basic information on all drill core held at the Core Library facilities, including operational data such as storage location and number of boxes per hole. The Drill Core Database is linked to the Drillhole Database, which provides more detailed information about each hole and includes links and references to logs, maps and reports.

The Drill Core Database can be searched by single or multiple fields, for example by place name, company name, hole number, map sheet, or year. The database is updated continually, and at the end of March 2019 it contained records for

approximately 6,690 surface holes having core or cuttings in the Core Library. There are also nearly 600 underground and offshore holes stored at the Core Library. An on-line version of the Drill Core Database (https://gesner.novascotia.ca/dcdh/core_querysearch/corequerysearch.aspx), based on Microsoft SQL Server, was released in 2016.

Queries should be directed to the Core Library geologist for all drill core information and core data searches. Even with the new and updated holes recently added to the database, there are still holes in the Core Library's collection of archived core for which data are not yet available in the Drillholes Database or for which a match has not yet been identified.

Drillholes Database

As of March 31, 2019, the department's Drillholes Database contained records for 27,840 surface drill holes. Approximately 10,000 new holes have been added to the Drillholes Database in the last nine years.

The lack of co-ordinates in many older Assessment Reports, where drillhole collars were referenced only to a local grid, resulted in inaccurate or missing data in the database. Using the GIS software program ArcMap, maps from these reports were scanned and georeferenced to determine the required co-ordinates for the drillhole collar locations. Over the last nine years 3,600 existing records were updated with better collar locations.

Over the course of about 100 years ending in 1996, the government of Nova Scotia operated a diamond drilling division that drilled 8,048 holes, either as a contractor to the mining and other industries or for its own purposes. While much of these data are already in the Drillholes Database, there is a need to capture information for holes that have not yet been included. To this end, a spreadsheet is being populated with existing data from the Drillholes Database and from *Drilling Logs of Government Core Drills* to use as a tool to identify what data remain to be found or updated. The Core Library contains survey data for some of the more recent government drilling (1975 to 1996), and these data are being added to the Drillholes Database to give more accurate collar locations for some holes.

Many other drillholes are still not recorded in the database, but they will be added as relevant information is obtained. Information sources include a variety of both published and unpublished reports, maps and files, including old annual reports of the Nova Scotia Government and the Geological Survey of Canada, as well as various Open File Reports and even some Assessment Reports that were previously overlooked. Drilling on mine leases is not reported to the department, so old mine records are generally the only source for these data.

Due to a major effort over the last few years, most old exploration Assessment Reports are now available online as downloadable PDFs through

NovaScan. This makes georeferencing historical drilling easier as large maps are now available as one image to bring into ArcMap, from which proper UTM co-ordinates can be determined.

An on-line version of the Drillhole Database, based on Microsoft SQL Server, became available online in 2016 at https://gesner.novascotia.ca/dcdh/Drillhole_querysearch/queryEntry.aspx. This database contains approximately 27,000 drillholes, and there are over 33,000 references associated with these holes. A single drillhole will have one or more references associated with it. This generally consists of a reference when the hole is drilled and subsequent references when further work is done on the hole (e.g. extensions, geophysics, sampling).

Information Services Activities, April 2018 to March 2019

J. C. Poole, J. S. McKinnon, A. L. Barras, C. C. MacMullen, S. L. Cowper and J. S. Saunders

The Information Services group is responsible for developing and maintaining the Geoscience and Mines Branch (GMB) Geographic Information System and associated databases, the NovaScan publications and maps database, for supplying digital data and services to clients and staff, and for developing and maintaining the GMB Internet website. Permanent Information Services staff consists of Jeff Poole (supervisor), Jeff McKinnon (geologist/GIS specialist), Angie Barras (GIS specialist/ cartographer), Courtney MacMullen (geologist/GIS specialist), Sonya Cowper (GIS and map server specialist), and Susan Saunders (web/desktop publishing technician). Diane Webber is the manager for the group. Susan Saunders retired in August 2018 and Sonya Cowper returned from maternity leave in January 2019.

Digital Geoscience Data Products

A collection of digital geology maps, databases, and images of Nova Scotia (in Esri shapefiles, ArcGIS file geodatabase, KML/KMZ, DXF, ARC export, TIFF, JPEG, and MrSID formats in a UTM projection using the NAD83 datum, and in PDF format) has been developed, and is available for viewing or free download from the GMB website (<https://novascotia.ca/natr/meb/download/gis-data.asp>). ArcGIS file geodatabase and Esri shapefiles are now our main data distribution formats. We are no longer producing the ARC E00 export and DXF formats. A licence agreement is issued with all digital data sets. This agreement allows unrestricted use of the data with the understanding that the Nova Scotia Department of Energy and Mines remains the owner of the data and is not transferring copyright to the user. Several of our datasets are also available through the Nova Scotia Government's Open Data Portal (<https://data.novascotia.ca/>).

GIS Development

Information Services GIS staff worked together with other GMB staff on numerous projects in 2018-2019. This included providing advice and assistance as requested, along with developing databases and maps for the projects outlined below.

Valley Aggregate Project: The Valley Aggregate dataset contains more than 9,000 aggregate site observations that are linked to 9,340 photos, 972 sample analyses, and site descriptions. Work was done in finalizing the digital dataset. Release of these data, along with the publication of a preliminary online interactive map application for stone resource potential in western Nova Scotia is anticipated for early in the next fiscal year. This application will provide valuable information to the stone resource industry, public works agencies, and others looking for sources of materials to make stone-based products.

Antigonish Highlands Mapping: Section staff worked with Chris White to produce a 1:75 000 scale bedrock geology map of the Antigonish Highlands and an accompanying digital product. The geology includes new work from a block in the Antigonish Highlands as well as some legacy compilation data. Open File Map ME 2018-001 was released in January 2018 (Fig. 1) and Digital Product ME 479 was released in April 2018.

Parrsboro Map Project: Information Services staff provided GIS support to John Calder while he compiled data for outcrop and fossil locations from Black Rock to Moose River in the Parrsboro region of Cumberland County. Data were collected by Dr. Calder over several years and compiled by GIS staff. Open File Map ME 2019-001 (Fig. 2) was released in March 2019 and Digital Product ME 492 will be released in the spring of 2019.

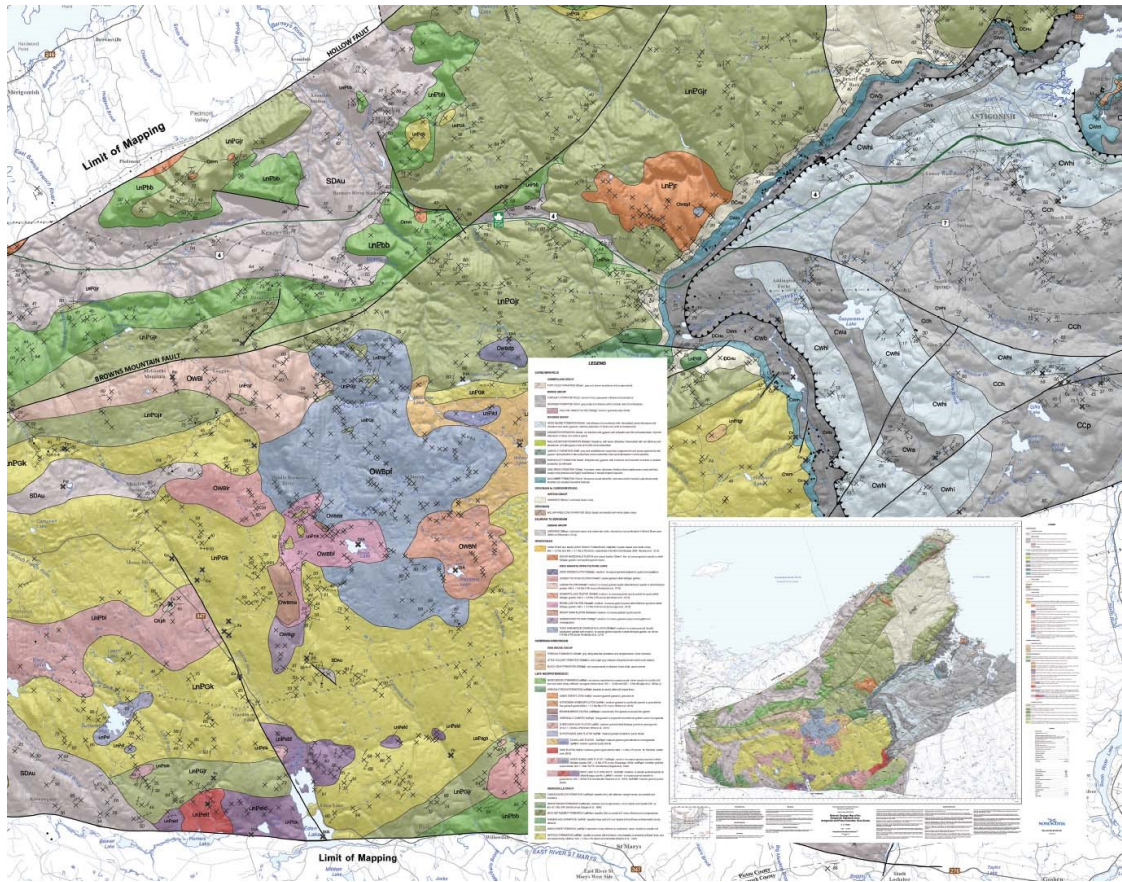


Figure 1. Open File Map ME 2018-001 of the Antigonish Highlands was selected and featured in the 2019 Esri Canada calendar.

Cobequid Highlands Project: Last year, work in the Cobequid Highlands focused on the Warwick Mountain area. This year Information Services staff worked with geologists Trevor MacHattie, Denise Brushett, Geoff Baldwin, Kevin Neyedley, and Chris White on the ongoing compilation of data in the broader Cobequid Highlands project area from Mount Thom to Cape Chignecto. This includes geochemical data from stream sediment, till, and rock samples; the results of bedrock mapping, including structural data; geochronological data; and photographs. These data will be released as reports, maps, and digital products.

GIS Support to Field Staff: The GIS staff provided support to the field geologists in the Branch throughout the year. The group ensures that data are shared readily among branch staff and provides general GIS support and advice as required. This support ranges from simply creating and printing field maps to acquiring and/or processing digital data for staff. These data

generally include satellite imagery, digital orthophotos, and lidar. The GIS group encourages and helps staff to capture their field data digitally using mobile data collection applications such as Collector and Survey123 for ArcGIS.

Some of the projects GIS staff have worked on this year are

- Denise Brushett: till sampling
- Geoff Baldwin: biogeochemical sampling
- Amy Tizzard: processing survey and lidar data on the Oxford sinkhole.

Eastern Shore Project: The GIS staff supported Chris White’s work along the eastern shore of Halifax and Guysborough counties by assisting with the compilation of geological data and by creating 1:10 000 scale field maps that include base layers and SPOT satellite imagery. The group also downloaded and processed lidar imagery in the area provided by GeoNova.

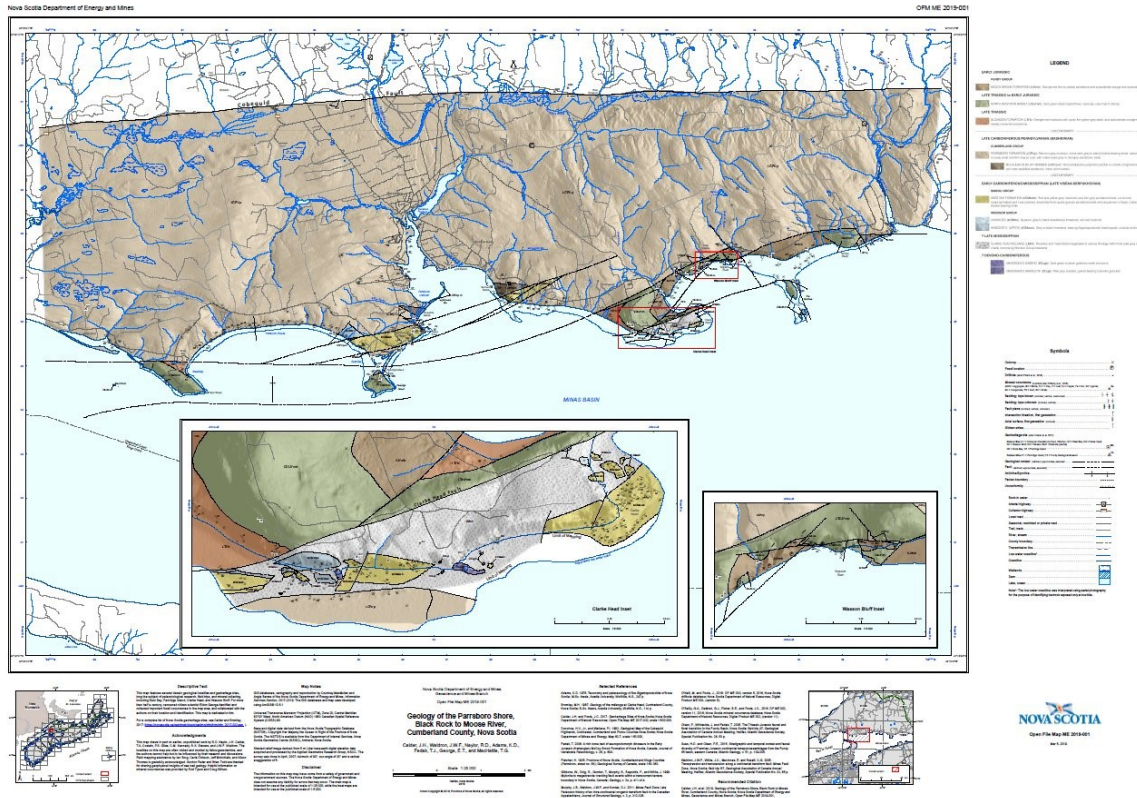


Figure 2. Open File Map ME 2019-001 Geology of the Parrsboro Shore, Black Rock to Moose River, Cumberland County, Nova Scotia.

Geophysical, Geochemical and Lidar Data

Releases: The GIS group processed and released a number of geophysical, geochemical, and lidar datasets last year, including

- Lidar DEM and Shaded Relief Images for the Warwick Mountain Area, Eastern Cobequid Highlands (Digital Product ME 507)
- Magnetic and Radiometric Surveys for the Warwick Mountain Area, Eastern Cobequid Highlands (Digital Product ME 508)
- Ground Gravity Survey, Cobequid-Chedabucto Fault Zone, Northern mainland, Nova Scotia (Digital Product ME 509)
- Airborne Radiometric Images for the Province of Nova Scotia (DP ME 163)
- Sampling of Soils for Background Substances in Urban Areas of the Halifax Regional Municipality (Digital Product ME 514)

Provincial Bedrock Geology Map: GIS staff are working to create a new provincial bedrock geology map. The goal is to compile and integrate the best and most up-to-date bedrock geological mapping for Nova Scotia and thus create a single,

seamless digital dataset. This involves compiling recent mapping projects as well as legacy data from a variety of sources. This project is intended to update our current provincial bedrock map and corresponding databases, which were published in 2000. We are also working with our colleagues in the New Brunswick Geological Survey and the Atlantic Geoscience Society to produce a new geological highway map for the region in 2022.

Process Improvement: Staff have been working on a Workflow Process Improvement Project. This initiative, led by Policy and Planning staff of the former Department of Natural Resources, looked to review and improve our current process of collecting, creating, and compiling data, which are ultimately published. The goal was to make our current processes faster and more efficient, while ensuring that the quality and format of published products are current and useful to our clients. The “GIS Process Improvement” summary report was completed in late 2018 and presented to management in early 2019. The report has two key components: 1) flow diagrams that illustrate the current GIS workflow and the future, more

efficient work-flow, and 2) detailed recommendations to achieve the improved work-flow. Staff are currently implementing the recommendations in the report and will continue to do so over the next several years.

Geoparks: GIS staff continued to work with John Calder for the Cliffs of Fundy aspiring Geopark nomination. Two thematic maps of the nomination area, produced at a scale of 1:100 000, were created in the fall of 2018. These maps were used in the nomination package submitted first to the Canadian National Committee for Geoparks and Canadian Commission for UNESCO, and ultimately to UNESCO.

Karst Risk Project: Work continued with geological staff on the development of a karst risk dataset and an online interactive map. Areas of karst risk, based on 1:50 000 scale bedrock geology maps in the province, have been compiled into a database and ranked according to levels of potential karst risk. A database of mapped karst occurrences in the province has also been compiled. An online interactive map (<https://fletcher.novascotia.ca/DNRViewer/?viewer=karst>) and Digital Product ME 494 were released February 2019.

Registry of Mineral and Petroleum Titles

Database/NovaROC: Staff made updates to several geospatial layers that will be incorporated into the next update of the NovaROC application. Staff also worked with registry staff to maintain the GIS digital product (Digital Product ME 493) Nova Scotia Mineral Rights Database (NovaROC). The product is normally updated daily and released at 2:00 AM. (<https://novascotia.ca/natr/meb/download/dp493.asp>).

Nova Scotia Gypsum Rights: In June 2018 GIS staff assisted staff of the Mineral Management Division to compile an online map (Fig. 3) and digital product indicating land and gypsum rights held by companies that have an interest in gypsum mining. These products will help support and facilitate responsible gypsum resource development in Nova Scotia. Links to the information about gypsum rights, the online map, and the digital product can be found at <https://novascotia.ca/natr/meb/download/dp515.asp>.

GeoNova and Government IT Initiatives: In 2018 GIS staff of the GMB, other branches of the former Department of Natural Resources (DNR, Now Lands and Forestry), and GeoNova were

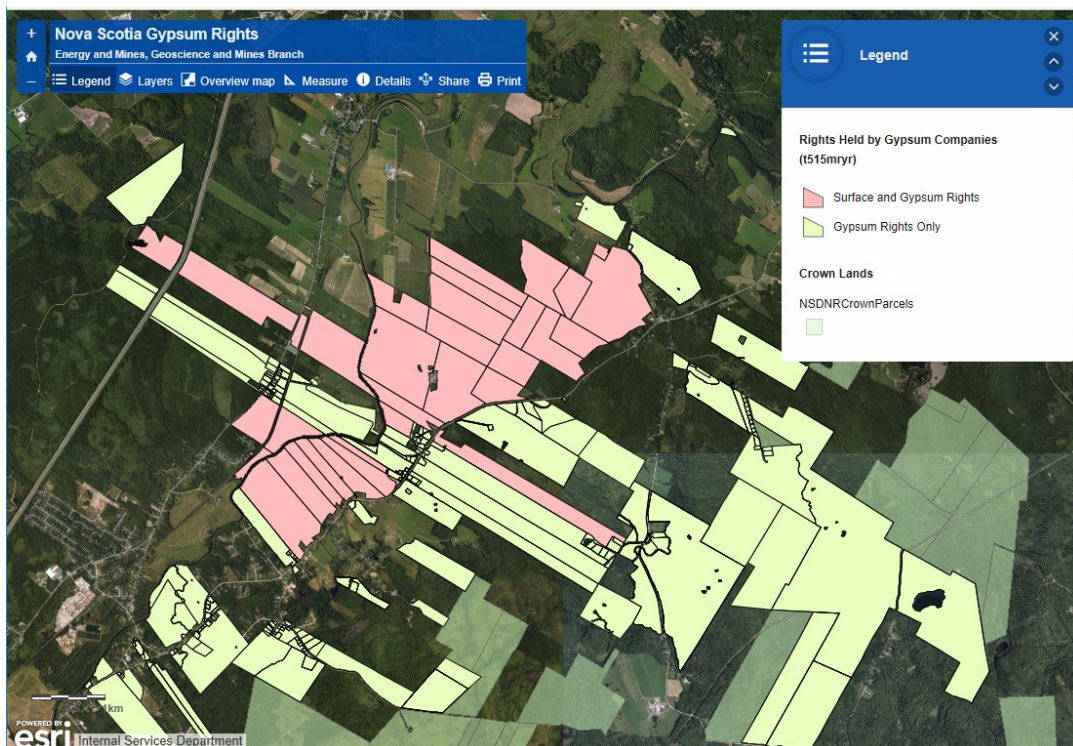


Figure 3. An example of the Nova Scotia Gypsum Rights web map application.

involved with the testing of the latest versions of ArcGIS Desktop 10.51 and ArcGIS Pro 2.x. At the same time, there was a government-wide plan to move all computer systems to the Windows 10 operating system, and GMB GIS staff were involved with a testing group for DNR. GMB GIS staff were also involved in government-wide discussions with GeoNova on ArcGIS Portal, the latest map server technology for delivering maps, data, and applications to clients and the public on the Internet.

Internet Map Server Applications

The section continues to maintain three primary public Internet Map Server (IMS) interactive map applications: the Geoscience Atlas, the Groundwater Atlas, and the Mineral Resource Land-Use Atlas. All the applications are built using ArcGIS Server and Geocortex and have a common 'look and feel.' These applications all use HTML5, which makes them compatible with most browsers on many devices, such as PC's, laptops, tablets, and handhelds.

The Geoscience Atlas application (Fig. 4) provides the public with a single geographic compilation of geoscience maps, databases, and images. The application displays a number of different layers from previously released digital products. Mineral occurrences, drillholes, and abandoned mines openings are present along with the provincial bedrock geology map and shaded relief imagery. Mineral rights information is available in the application through a connection to NovaROC and is up-to-the-minute in its currency. We also added private property and Crown land layers to the application in 2016. Layers were updated as required and included the Abandoned Mine Openings layer in July 2017. The URL link to the Geoscience Atlas application is <https://fletcher.novascotia.ca/DNRViewer/?viewer=Geoscience>.

The purpose of the Groundwater Atlas application (Fig. 5) is to provide the public with an interactive map application containing layers of spatially referenced maps, databases, grids, and images of interest to hydrogeologists, particularly those interested in the hydrogeological properties associated with the identified groundwater regions. Private property and wetlands layers were added to

the application in 2016. There were updates to a number of layers in this application this year. The month and year are indicated at the end of many layer names to indicate their currency. The URL link to the Groundwater Atlas application is <https://fletcher.novascotia.ca/DNRViewer/?viewer=Groundwater>.

The main purpose of the Mineral Resource Land-Use Atlas (MRLU) interactive map application is to provide the public with a single geographic compilation of mineral resource and related land-use information at a reasonably detailed scale of 1:50 000. A key objective is to create a useful reference for practitioners working in land-use and environmental planning, geotechnical firms, and groups involved in community economic development. The MRLU displays the location and distribution of mineral and energy resources, activities related to these resources, and aspects of environmental geology that relate to land-use and environmental planning. Special land-use designations on Crown and some privately owned land are shown to indicate how Nova Scotia's land-base varies regarding the ability of mineral resource interests to access land and hold secure tenure. A major update of several protected land layers was made in the fall of 2016. The URL link to the Mineral Resource Land-Use Atlas application is <https://fletcher.novascotia.ca/DNRViewer/?viewer=MRLU>.

The GIS group also maintains a number of simple but more focused applications for the Branch that use ArcGIS Server technology. These applications are HTML5 Geocortex applications. These are the Potential for Radon in Indoor Air application (<https://fletcher.novascotia.ca/DNRViewer/?viewer=Radon>), the Bedrock Acid Rock Drainage Potential for Southwestern Nova Scotia application (<https://fletcher.novascotia.ca/DNRViewer/?viewer=ARD>), and the Southwest Nova Bedrock Map application (<https://fletcher.novascotia.ca/DNRViewer/?viewer=SouthWestNova>). In 2017 the Arsenic Risk in Bedrock Water Wells application was added to the website (https://fletcher.novascotia.ca/DNRViewer/?viewer=As_Risk_Wells). The Potential Impact of Drought to Private Wells application was updated over the summer and fall of 2018 (<https://fletcher.novascotia.ca/DNRViewer/?viewer=DroughtIndex>). New this year is the Karst Risk Map application (<https://fletcher.novascotia.ca/DNRViewer/?viewer=Karst>).

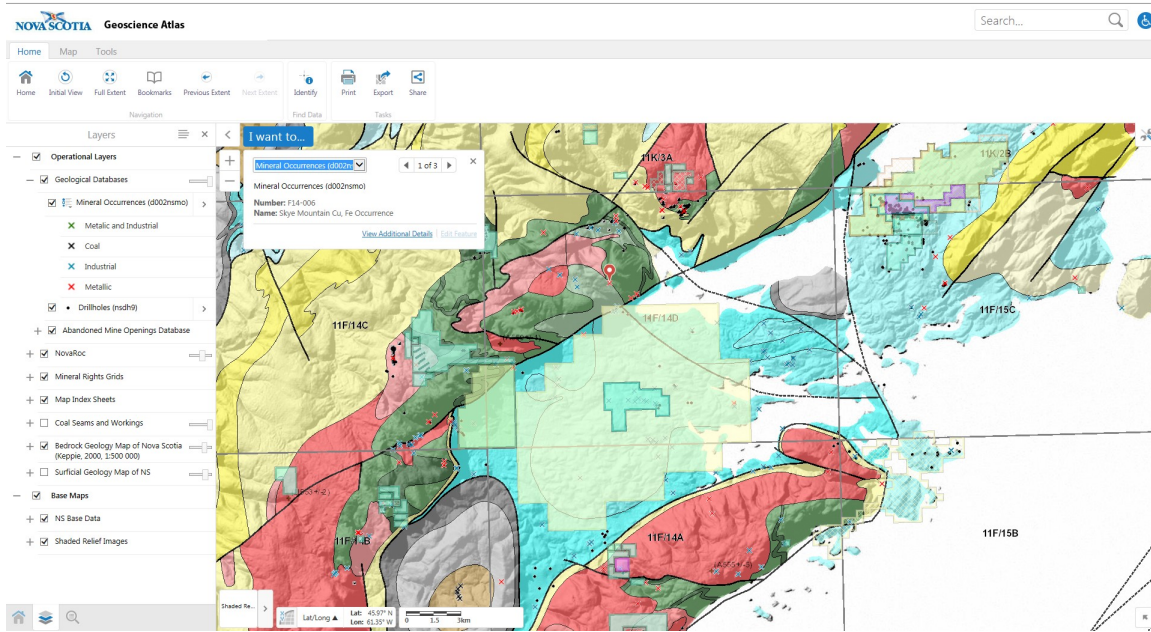


Figure 4. An example of the Geoscience Atlas application with shaded relief imagery turned on, transparency adjusted for the bedrock geology, NovaROC mineral rights layers turned on, and a mineral occurrence selected.

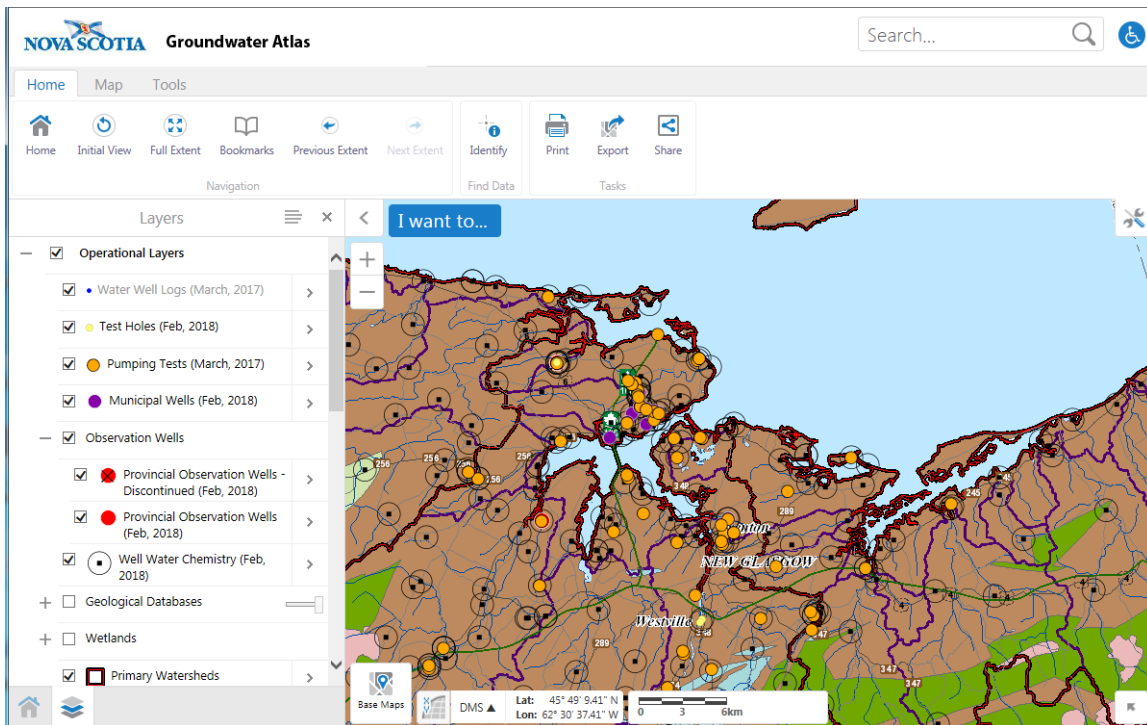


Figure 5. An example of the Groundwater Atlas application zoomed into the New Glasgow area.

The Potential for Radon in Indoor Air application (Fig. 6) was developed to show areas in the province where people are more likely to be exposed to hazardous radon in indoor air. This application has an address and postal code search capability to help users find their home on the map. It provides a simple high-, medium-, and low-risk ranking scheme but emphasizes that the only way to know for sure how much radon is in your home is to test for it no matter where you live.

The Bedrock Acid Rock Drainage Potential for Southwest Nova Scotia application shows the potential of bedrock to generate acid rock drainage (ARD) if it is physically disturbed or exposed. This map uses a simple high, moderate, and low ranking scheme to inform landowners and planners about the hazards of ARD if they plan to excavate to bedrock in a given area.

The Southwest Nova Bedrock Map application is an interactive map showing the compilation of geological data in southwestern Nova Scotia by Chris White (https://novascotia.ca/natr/meb/geoscience-online/sw_nova_about.asp). It shows many map layers, including bedrock geological units, geological contacts, age dates, anticlines/synclines, drillholes, dykes, faults, fossils, bedrock

geological units, geological contacts, gold districts, mines, mineral occurrences, outcrops, quarries, shafts, stockworks, structural data, and shear zones.

The Arsenic Risk in Bedrock Water Wells application (Fig. 7) was developed to show areas of Nova Scotia where there is a relative high, medium, or low risk of arsenic in bedrock water wells. It is emphasized that testing your well is the only way to find out whether arsenic is a concern in your well no matter where you live.

The Potential Impact of Drought to Private Wells application (Fig. 8) was developed to show areas of Nova Scotia where private-well owners are more likely to experience water shortages (especially owners of shallow wells) if drought conditions develop in the summer and fall of a given year. The application presents a new map every month in the summer and early fall and currently maintains an archive of past maps for the summer and fall of 2016, 2017, and 2018.

The Karst Risk Map Application (Fig. 9) was developed to show areas of Nova Scotia where there is a relatively high, medium, or low risk of encountering karst and naturally occurring sinkholes caused by soluble bedrock. For more

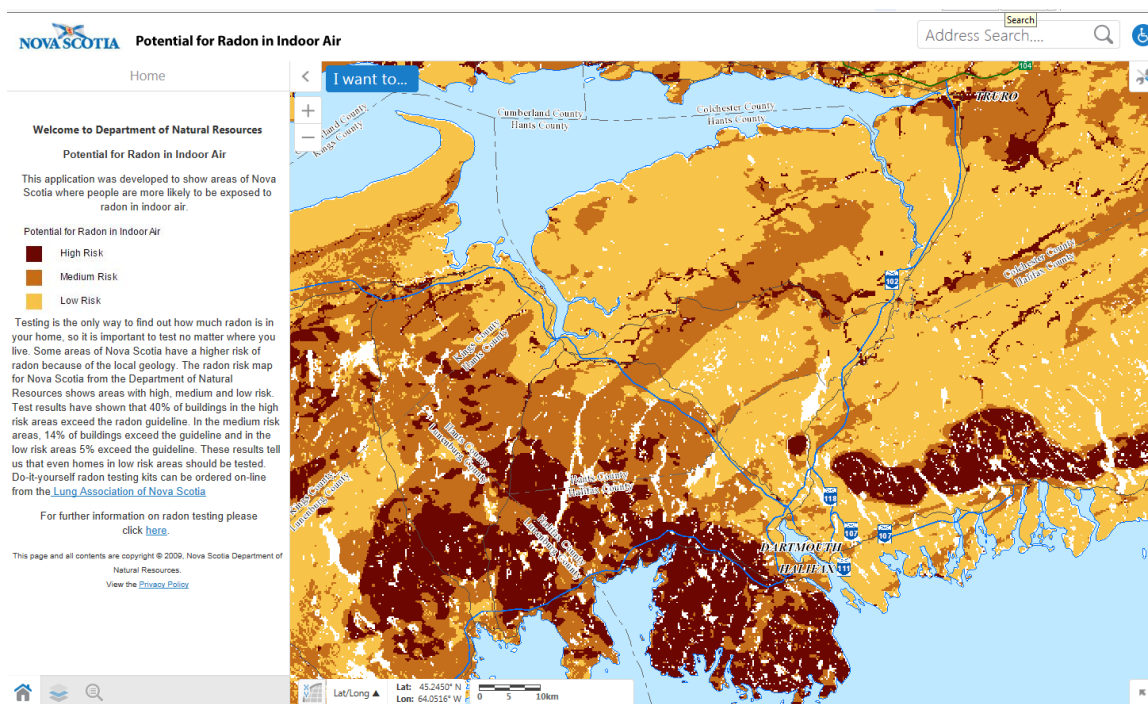


Figure 6. An example of Potential for Radon in Indoor Air application zoomed into central Nova Scotia. Address searches are possible with this application by typing in an address or postal code in the box in the upper right of the application.

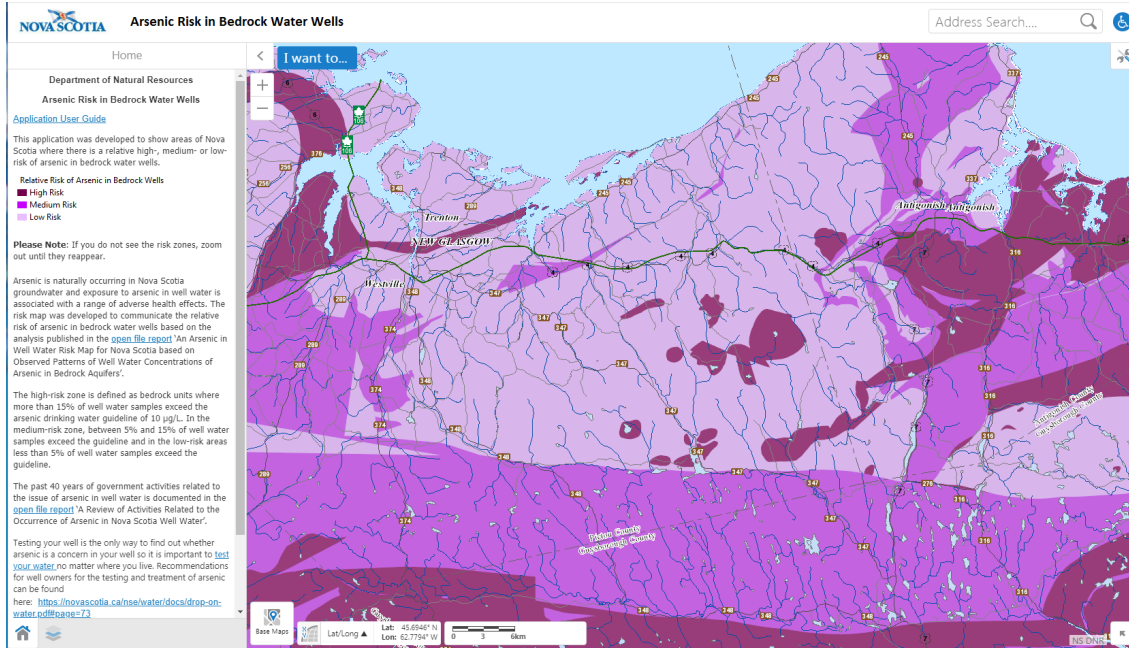


Figure 7. An example of Arsenic Risk in Bedrock Water Wells application zoomed into central Nova Scotia.

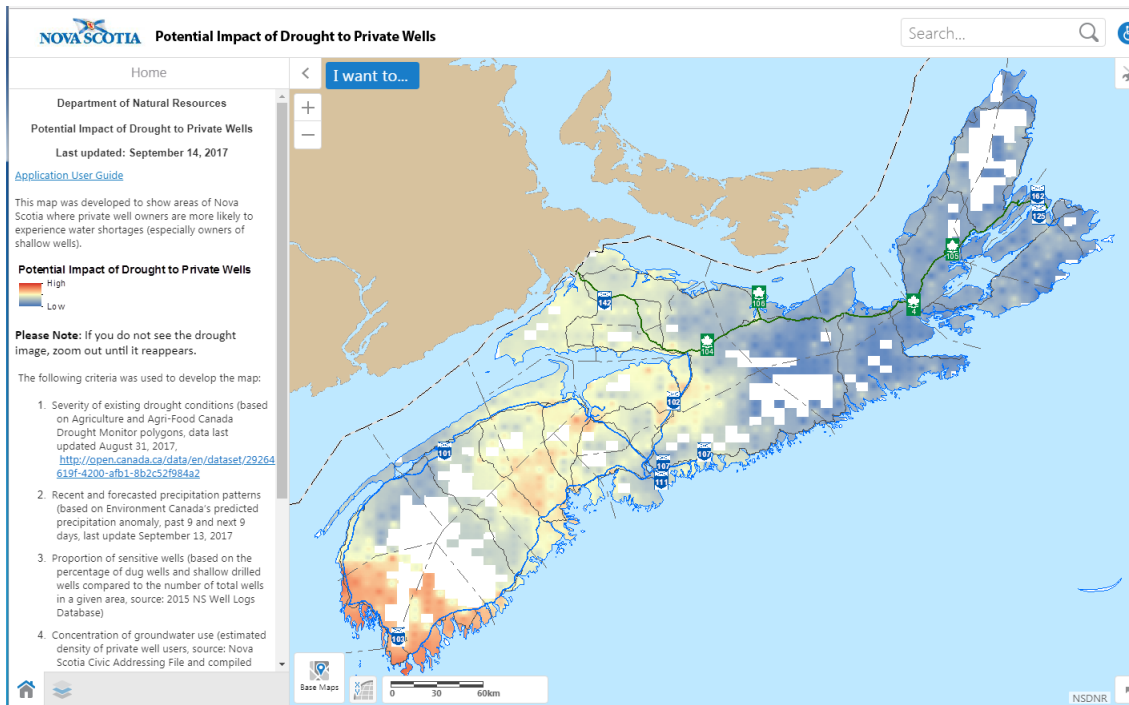


Figure 8. An example of the Potential Impact of Drought to Private Wells application. The map in this example shows an archived image from September 2016, a particularly dry month.

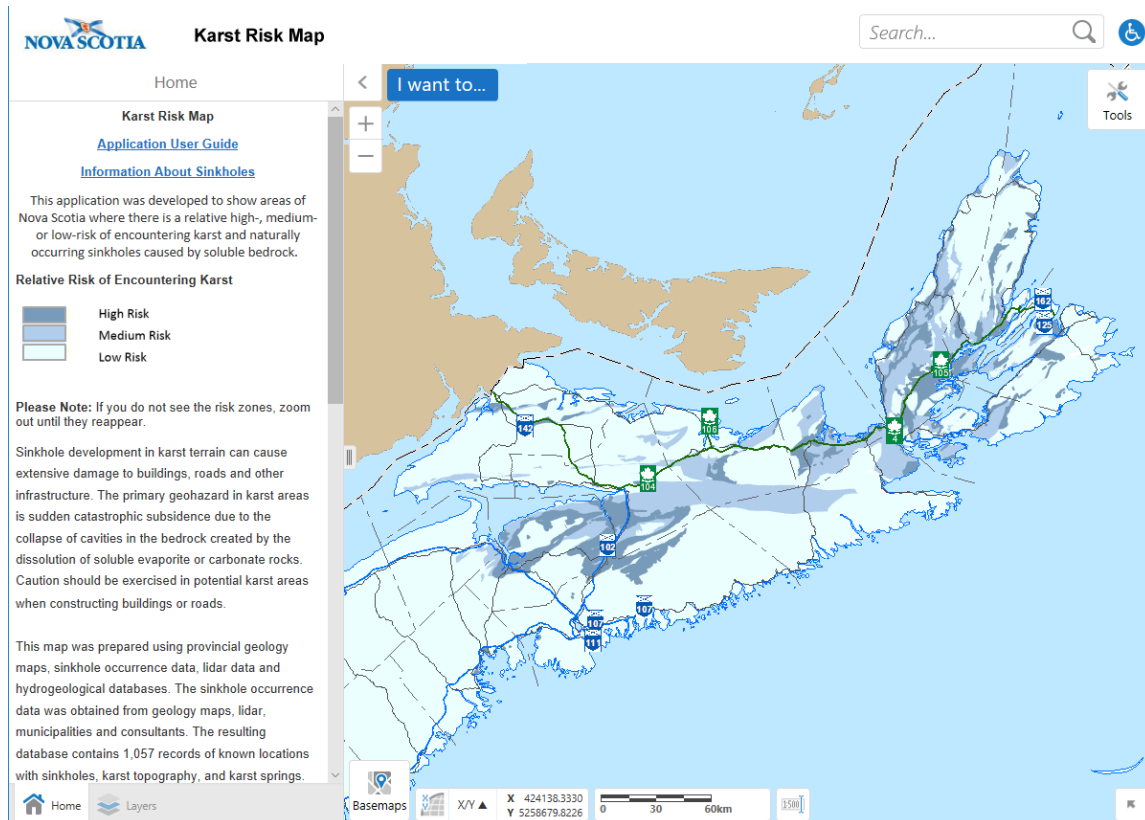


Figure 9. An example of the Karst Risk Map application.

information about karst and sinkholes in Nova Scotia and a report that describes the derivation of this karst risk map, please visit <https://novascotia.ca/natr/meb/hazard-assessment/sinkholes.asp>.

NovaScan

NovaScan is the geoscience publications and maps database on Nova Scotia and its offshore regions. As of March 23, 2018, the database contained 17,899 records, consisting of 8,895 mineral exploration assessment and property reports, 4,051 publications, 1,425 open file reports, 2,127 maps and illustrations, 867 theses, 280 contribution series, 214 digital products, and 32 outside publications.

In order to provide better service to our staff and clients, the Branch maintains a public search application that allows the public to query records in the NovaScan database using an Internet browser. NovaScan can be searched by title, author/organization, subject, area, map sheet (NTS), map type, licence type, licence number, document type, document number, year, and map

scale. NovaScan is updated monthly as new geoscience maps, publications, open files and theses become available. The search interface can be accessed at <https://gesner.novascotia.ca/novascan/DocumentQuery.faces>.

Products Released in 2018-2019

The following new digital products and maps were released in 2018-2019. All digital products can be downloaded for free from the URL listed with the product.

Digital Products

DP ME 163, Version 1, 2018, Airborne Radiometric Images for the Province of Nova Scotia, (50 m x 50 m Resolution). Digital product compiled by M. S. King. Available in JPEG format. Available as a free download from the GMB website at <https://novascotia.ca/natr/meb/download/dp163.asp>

DP ME 470, Version 1, 2018. Digital Version of Nova Scotia Department of Natural Resources Open File Map ME 2018-001, Bedrock Geology Map of the Antigonish Highlands Area, Antigonish and Pictou Counties, Nova Scotia, scale 1:75 000, by C.E. White, 2018. Digital Product by C.E. White, A.L. Barras and J.S. McKinnon. Available in SHP and GDB format. Available as a free download from the GMB website at <https://novascotia.ca/natr/meb/download/dp470.asp>

DP ME 507, Version 1, 2018. Lidar DEM and Derived Shaded Relief Images for the Warwick Mountain Area, Eastern Cobequid Highlands, Nova Scotia. Digital product compiled by J. C. Poole. Available in TIFF and JPEG formats. Available as a free download from the GMB website at <https://novascotia.ca/natr/meb/download/dp507.asp>

DP ME 508, Version 1, 2018, Airborne Magnetic and Radiometric Surveys for the Warwick Mountain Area, Eastern Cobequid Highlands, Nova Scotia. Available in GDB, GRD, and TIFF formats. Available as a free download from the GMB website at <https://novascotia.ca/natr/meb/download/dp508.asp>

DP ME 509, Version 1, 2018, Ground Gravity Survey, Cobequid-Chedabucto Fault Zone, Northern mainland, Nova Scotia. Available in SHP and JPEG formats. Available as a free download from the GMB website at <https://novascotia.ca/natr/meb/download/dp509.asp>

DP ME 514, Version 1, 2018. Sampling of Soils for Background Substances in Urban Areas of the Halifax Regional Municipality, Nova Scotia. Digital product compiled by G.W. Kennedy, L. King, C. Lake, P. Currie and J. Drage. Available in SHP, GDB and XLS format. Available as a free download from the GMB website at <https://novascotia.ca/natr/meb/download/dp514.asp>

DP ME 515, Version 1, Nova Scotia Gypsum Rights. Available in SHP, GDB and KML format. Available as a free download from the GMB website at <https://novascotia.ca/natr/meb/download/dp515.asp>

Open File Maps

Open File Map ME 2018-004, Mineral Resources Development Fund Approved Grants: 2018-2019; scale 1:2 000 000, by J. C. Bonaparte, 2018. Available as a free PDF download from the Geoscience and Mines Branch website: https://novascotia.ca/natr/meb/data/mg/ofm/pdf/ofm_2018-004_mrdf_dp.pdf

Open File Map ME 2019-001, Geology of the Parrsboro Shore, Black Rock to Moose River, Cumberland County, Nova Scotia; scale 1:25 000, by J. H. Calder, J. W. F. Waldron, R. D. Naylor, K. D. Adams, T. J. Fedak, E. T. George, T. G. MacHattie, 2018. Available as a free PDF download from the Geoscience and Mines Branch website: https://novascotia.ca/natr/meb/download/mg/ofm/html/ofm_2019-001.asp

An Overview of Work on the Oxford Sinkhole, 2018-2019

A. Tizzard, G. J. Demont, and D. M. Brushett

Introduction

In late July, 2018, a small area of subsidence was observed by members of the Oxford Area Lions Club near the western end of the parking lot in the privately owned Lions Parkland in Oxford, Cumberland County (Fig. 1). The circular depression was described as approximately 60 cm deep by 100 cm wide. On August 9, 2018, approximately 12 tonnes of shale were used to fill the depression back to surface grade. On August 10, the area again subsided, resulting in a square-shaped depression approximately 1.5 m² and 30 cm deep. The area was cordoned off and monitored until August 20, when a witness described the sound of rushing water, a loud “whump” noise and felt the ground shake as a result of sudden collapse, leading to the development of the sinkhole. At that time, emergency responders were called to the scene and the park was closed to the public. From August 20 to early September, 2018, the sinkhole grew rapidly from a few metres to approximately 40 m in diameter (Fig. 2). The underground extent of the collapsed cavern is presently unknown.

The location of the sinkhole relative to surrounding infrastructure is of concern to the public and stakeholders in the area. Highway 321 is the primary access route to the Town of Oxford from the TransCanada Highway (104), providing efficient regional accessibility for the community and emergency first-responders. In addition to the local Community Centre at the Lions Parkland, several businesses operate adjacent to the property, including a fuel service station with underground storage tanks. In collaboration with the Oxford Area Lions Club, Regional Emergency Management Organization, and Town of Oxford, the sinkhole was closely monitored by the Department of Energy and Mines to help evaluate when surrounding infrastructure should be evacuated if the sinkhole continued to propagate at the rapid rate first observed.

Regional Geology

The area of the Lions Parkland is underlain by undivided Mississippian rocks of the Windsor

Group, consisting of interstratified redbeds, evaporites, and carbonates. Evaporite and carbonate rocks include gypsum, salt, anhydrite, and limestone, all of which are variably soluble in water. Evaporitic rocks and sinkholes in the Oxford area were recorded in early geological maps by Barlow and Giroux (1886) and Norman and Bell (1938). Bell (1944) attributed the formation of Black, Slade, Vickery, and Park (Salt) lakes to the dissolution of water-soluble bedrock, resulting in groupings of interconnected sinkholes. Subsequent mapping by Ryan et al. (1990) further defined the area as an “area of extensive karst with sinkholes and gypsum outcrop.” Bedrock in the Oxford area is overlain by 3 to 30 m of sand, glacial till, and fluvial deposits, obscuring the surface expression of the karst topography (Stea and Finck, 1988). A thick deposit of gravelly sand conceals bedrock at the sinkhole, but gypsum crops out approximately 400 m to the southwest in an area of extensive karst topography.

In 1924 and 1926, three drillholes were completed in eastern Oxford by the Province of Nova Scotia (Nova Scotia Department of Mines, 1925, 1927). The drillholes intersected 4 to 15 m of overburden above interbedded gypsum, sandstone, and shale. A drillhole completed by the Malagash Salt Company (1953) 4 km east of Oxford intersected salt from 80 m depth to end-of-hole. Numerous salt springs in the Oxford area further support the presence of salt in the underlying stratigraphy (Cole, 1930).

The geology of the Oxford area is structurally complex, and there are few outcrops and few historical well and exploratory drill records to supply subsurface information. The northern and western limits of the Windsor Group in the Oxford area are interpreted to be in fault contact with the Upper Carboniferous Cumberland Group. The nature of the southern and eastern contacts is unknown. Based on the presence of interbedded evaporites, slates, and mudstones, the Windsor Group strata are interpreted to be folded in diapiric structures, regionally expressed in the east-northeast-trending Claremont-Malagash anticline, with localized zones of increased deformation (Boehner, 1986). Regional geophysical surveys help define the extent of the Windsor Group and



Figure 1. Location of the Oxford sinkhole.



Figure 2. Photograph of the sinkhole in September 2018.

diapiric structures in the area, but the information is too limited in scale to model individual voids in the subsurface (see Nova Scotia Department of Energy, 2017, and references therein).

Monitoring Program

Formal identification and measurement of propagation cracks encompassing the Oxford sinkhole began on August 25, 2018. The boundary of the sinkhole was regularly surveyed by the Department of Lands and Forestry using real-time-kinematic GPS (Leica GNSS RTK GS 15). Propagation cracks and survey ground control points were collected using total-station GPS (Leica TS 11 5”). The sinkhole boundary was surveyed with a 7 m offset to operate at a safe distance away from the actively eroding margin. The offset readings were post-processed and corrected to obtain the actual outline of the sinkhole. Cracks located at a safe distance away from the sinkhole margin in the parking lot and surrounding ground surface were identified, numbered, photographed, surveyed, measured, and marked using spray paint. Cracks were then closely monitored for changes in width and depth, in addition to scanning the area for new signs of sinkhole growth. Water levels of both the sinkhole and the surrounding Salt Lake were also surveyed by the Department of Lands and Forestry.

During the course of initial rapid sinkhole development in late August and September, the sinkhole progressed at variable rates predominantly to the northeast toward playground infrastructure and surrounding Salt Lake (Fig. 3). Many cracks grew in width from hairline fractures to tens of millimetres wide to being unsafe to measure or being completely consumed by the sinkhole. The rate of growth of the sinkhole boundary was likely influenced by dense root masses of large trees in an otherwise homogenous sand deposit. The thick sand deposit in the area of the Lions Parkland likely contributed to the rapid growth of the sinkhole, due to the ability of surface and ground water to flow more easily through a permeable medium. Additionally, the steep walls of the sinkhole combined with the low cohesiveness of the sand are conditions favourable to a sudden bank collapse.

Water level in the sinkhole was approximately 10 m below surface at the onset of the collapse and was subsequently surveyed in comparison to the surrounding lake water levels (Table 1; Fig. 4). No

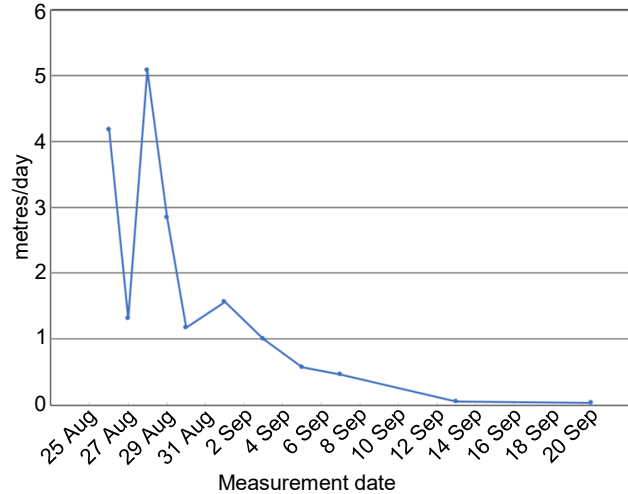


Figure 3. Rate of growth of the Oxford sinkhole, 25 August to 20 September 2018.

Table 1. Water level measurements of the sinkhole and Salt Lake. Note that no survey data were available prior to August 25.

Date (2018)	Salt Lake Water Level (masl)	Sinkhole Water Level (masl)
Aug 25	6.936	No measurement
Aug 26	6.98	5.497
Aug 27	6.967	5.516
Aug 28	6.983	5.875
Aug 29	6.98	5.933
Aug 30	6.94	5.985
Sept 1	6.952	6.041
Sept 3	6.989	6.151
Sept 5	6.963	6.272
Sept 7	6.895	6.318
Sept 10	6.978	6.409
Sept 13	6.987	6.523
Oct 2	6.984	6.874

bedrock was visible in the sinkhole at that time, therefore the overburden was estimated to be greater than 10 m in thickness in the area of the park. The initial difference in the water levels between the sinkhole and the surrounding lake indicates a limited hydraulic connection between the water bodies. At the time of this report, however, the water bodies appear to have equalized. No surveys were completed in the winter of 2019 due to freezing conditions.

Basic parameters of the water in the sinkhole, surrounding Salt Lake and River Philip were measured for a report commissioned by the Town of Oxford (Table 2; FracFlow Consultants Inc., 2018). The high specific conductance of the sinkhole and lake waters is comparable to the chemistry of brine springs in the area reported by Cole (1930).

Water in the sinkhole was extremely turbid at the time of its development. Aerial surveillance of the region was undertaken to examine surrounding water bodies for signs of change (Fig. 5). No unexpected turbidity was noted in surrounding water bodies, indicating no apparent immediate connectivity between the Oxford sinkhole and surrounding sinks or River Philip. The underground extent of fractures, fissures or voids beneath the Oxford sinkhole is unknown.

Examination of regional lidar and satellite imagery clearly demonstrates the karstic terrain in the Oxford area (Fig. 6). Numerous ponded and dry sinkholes are evident in a well-defined karst belt extending from the southern part of the Town of

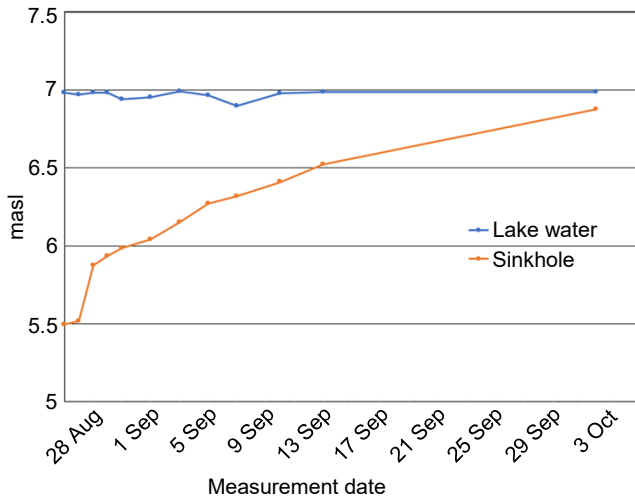


Figure 4. Water level differentials between the sinkhole and Salt Lake.

Table 2. Results of water testing, August 28, 2018 (FracFlow Consultants Inc., 2018; reproduced with permission from the Town of Oxford).

Sampling Point	Temperature	pH	Specific Conductance
Sinkhole	21.3°C	7.94	3580 µS/cm
Salt Lake	25.7°C	8.49	3970 µS/cm
River Philip upstream of karstic terrain	20.6°C	8.60	51 µS/cm
River Philip downstream of karstic terrain	23.5°C	8.79	490 µS/cm

Oxford southwest toward Springhill for a distance of 5 km. Scalloped-shaped lake shorelines within the karstic belt, including Salt Lake, are indicative of coalescing sinkholes.

The sinkhole continues to slowly erode along its margins, but the rate of growth has significantly slowed. Due to the unpredictable nature of natural sinkhole development, and lack of background information, assessment of the stability of the site cannot be confidently ascertained without additional subsurface information. The thick overburden, high water table, and high conductivity of water pose challenges to geophysical investigation of the site, which will require specialized equipment and expertise.

Future Plans

The formation of contemporary, naturally occurring sinkholes like the one recently developed in the Lions Parkland in Oxford is often related to anthropogenic activities that alter the natural state of water, such as diversion of drainage ditches, downspouts, and runoff from surface grade. No apparent linkages can yet be made at the Oxford sinkhole. The Department of Energy and Mines plans to continue to monitor the development of the Oxford sinkhole and surrounding areas for active subsidence. No historical data regarding the depth, extent, or modal size of sinkholes has been found, therefore characterization of regional sinkhole features will help determine the associated risk in the area. Continued site surveying and the compilation and analysis of propagation cracks will be used to further examine the characteristics of an actively developing sinkhole.

A lidar survey was initially collected by the Cumberland Regional Emergency Management Organization (circa 2010) and another by the Province of Nova Scotia in September 2018. The two datasets will be used to examine change and characterize the surficial extent of stabilized

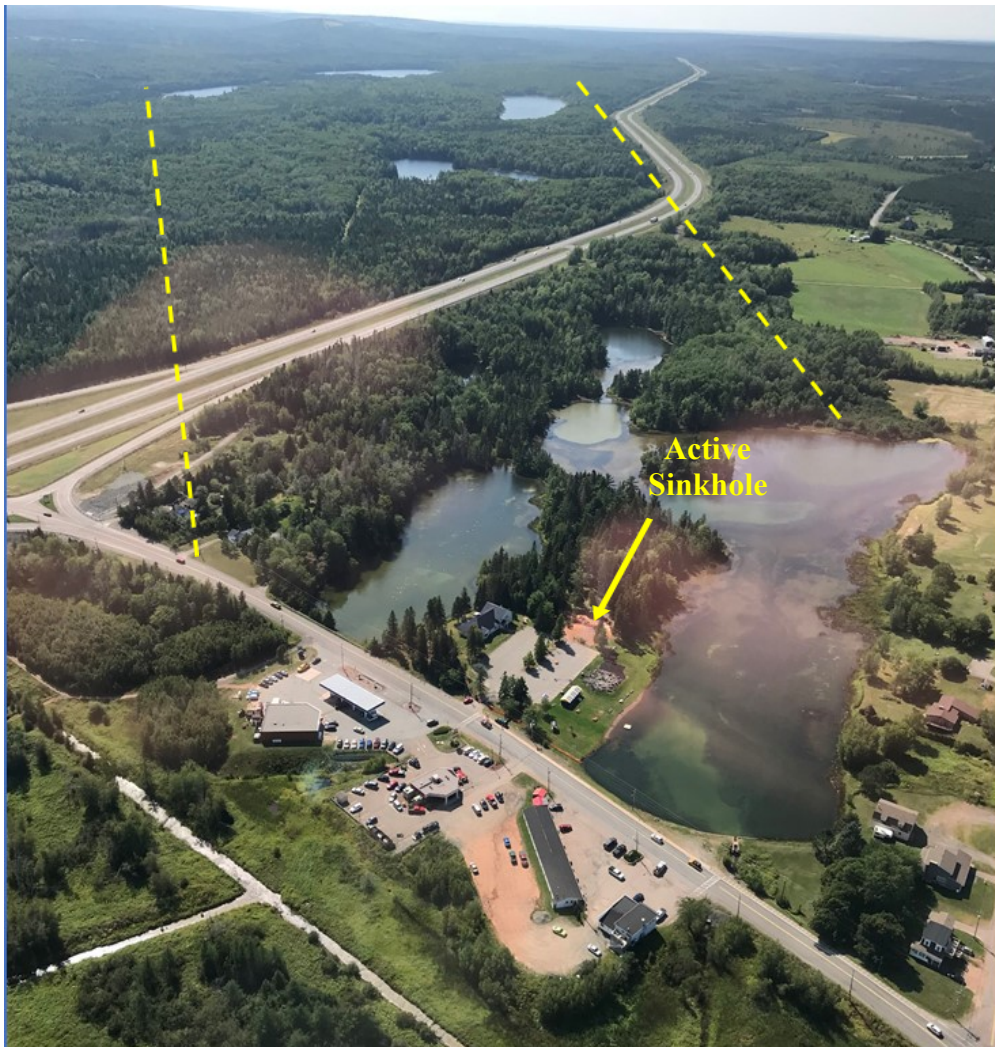


Figure 5. Aerial view of the Oxford sinkhole and regional extent of karstic terrain. View is to the southwest. Photo taken August 29, 2018.

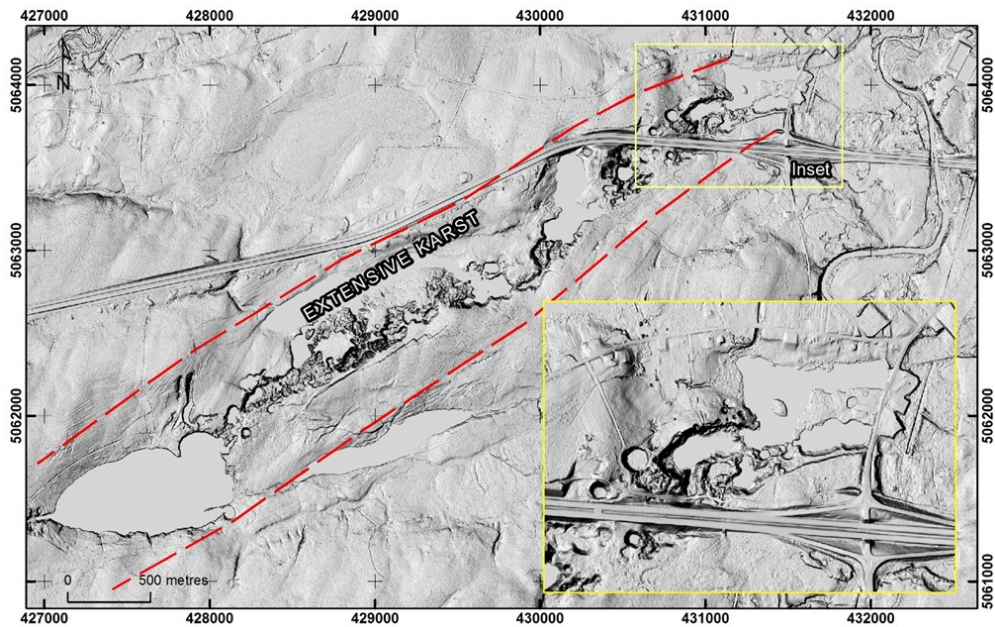


Figure 6. Lidar coverage of the Oxford area, flown September 2018.

sinkholes in the karstic terrain. The Department of Energy and Mines also plans to monitor and model the site using newly acquired drone technology.

Due to the rapid development and unpredictable nature of the sinkhole and karstic terrain, the Lions Parkland has remained closed to the public pending an investigation to better understand the subsurface conditions surrounding the sinkhole. A request for proposals was issued by the Town of Oxford in October 2018 to determine the underground extent of the active sinkhole area, and associated risk, using an integrated geophysical and geotechnical approach. Once the investigation is complete options for site remediation, if any, will be considered.

More information on sinkholes and other geohazards can be found on the Department of Energy and Mines website at <https://novascotia.ca/natr/meb/environmental/geohazards.asp>. The department also released an interactive Karst Risk Map in February 2019 that illustrates the high-risk karst belt transecting the Oxford area. The map can be viewed at <https://fletcher.novascotia.ca/DNRViewer/?viewer=Karst>.

Acknowledgments

Ensuring public safety throughout the development of the Oxford sinkhole was a great collaboration between numerous individuals and organizations. Prior to being present at the active sinkhole, the author relied upon observations and remarks from Oxford Area Lions Club members Bob Oickle and Bruce Selkirk, and Parkland summer student Ty Ingram. Thanks to Mark Rushton for providing images and testimony of the early sinkhole development. Tracy Lenfesty at the Department of Lands and Forestry library was tremendously helpful in tracking down historical documents. Jerry Borden and staff at the Department of Lands and Forestry Oxford office provided ground support at the sinkhole. Thank you to John Drage for insightful conversations about geohazards in Nova Scotia. Finally, the biggest thank-you goes out to Rachel Jones and the Town of Oxford, and Mike Johnson and Cumberland Regional Emergency Management Organization for their exceptional teamwork.

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Geochronological Studies of Pre-Carboniferous Rocks in the Cobequid Highlands, Northern Mainland Nova Scotia

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Introduction

The Cobequid Highlands of northern mainland Nova Scotia occupy a unique position along the outboard part of Avalonia, with the southern boundary marked by the Cobequid Fault and the northern boundary marked by the unconformably overlying sedimentary rocks of Late Carboniferous Cumberland Group (Fig. 1). Previous studies have shown the Highlands to be predominantly Neoproterozoic to Early Carboniferous volcanic, sedimentary and plutonic rocks (e.g. Nance and

Murphy 1990; Murphy et al. 1997; Pe-Piper and Piper 2002). In 2011, geologists of what was then the Mineral Resources Branch of the Nova Scotia Department of Natural Resources began a major, multi-year mapping, geochemical, and geochronological study to better understand the geological evolution of the Cobequid Highlands (MacHattie, 2011, 2013, 2017, 2018; MacHattie and White, 2012, 2014a, b; MacHattie et al., 2013a, b). This report summarizes the new U-Pb zircon geochronological results from pre-Carboniferous units in the Cobequid Highlands.

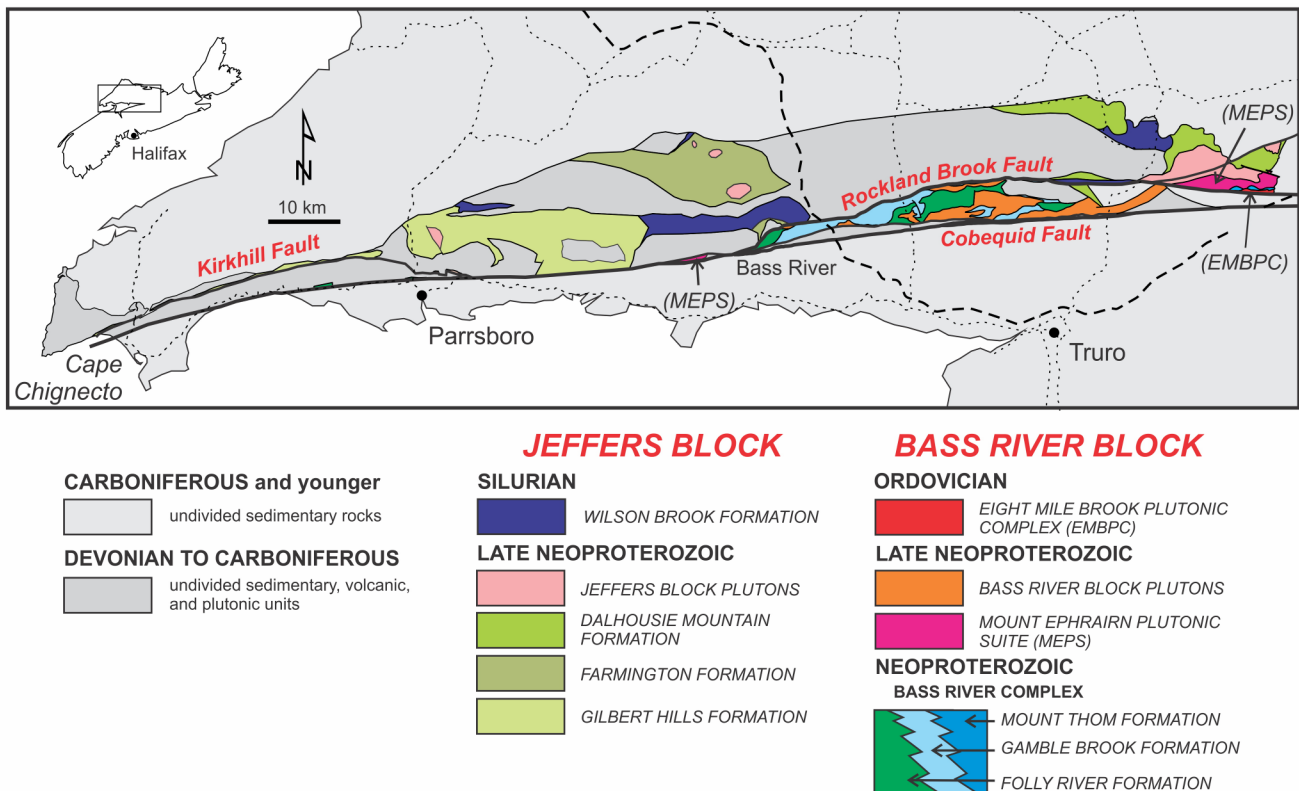


Figure 1. Simplified geological map of the Cobequid Highlands.

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Geological Framework

Bedrock mapping combined with geochemistry and geochronology (MacHattie and White, 2012, 2014b; MacHattie et al., 2013a, b; White et al. 2019) has better defined the distribution of geological units and their stratigraphy in the highlands and confirmed previous interpretations (e.g. Pe-Piper et al. 1996; Pe-Piper and Piper 2002) that the pre-Carboniferous rocks can be divided into two distinct geological assemblages termed the Bass River and Jeffers blocks (Fig. 1).

The Bass River block forms the area between the Cobequid Fault to the south and the Rockland Brook Fault to the north. The Jeffers block is bounded on the south by the Rockland Brook Fault and on the north by unconformably overlying Lower Carboniferous sedimentary rocks of the Cumberland Group. Pre-Carboniferous units in the Bass River block include (1) metasedimentary and metavolcanic rocks of the Gamble Brook, Folly River, and Mount Thom formations of the Neoproterozoic Bass River Complex; (2) the Neoproterozoic Mount Ephraim plutonic suite; (3) the Late Neoproterozoic Frog Lake, Debert River, and McCallum Settlement plutons, collectively termed the Bass River block plutons; and (4) the Ordovician Eight Mile Brook plutonic complex (MacHattie and White, 2014a, b; White et al., 2019). Pre-Carboniferous units in the Jeffers block include Neoproterozoic volcanic rocks of the Dalhousie Mountain, Farmington, and Gilbert Hills formations (together known as the Jeffers Group) and related plutonic units (Gunshot Brook, Six Mile Brook, Jeffers Brook, New Prospect, and McCormack Lake plutons, collectively termed the Jeffers block plutons) (Pe-Piper and Piper, 2002; MacHattie and White, 2014a, b; MacHattie and White 2015; White et al., 2019). A fault-bounded sliver of Neoproterozoic volcanic rocks in the Bass River block is interpreted to be part of the Dalhousie Mountain Formation that was faulted into its present position (White et al., 2019). Overlying or in faulted contact with the older units in the Jeffers block are sedimentary rocks of the Silurian Wilson Brook Formation (MacHattie et al., 2013a, b; MacHattie and White, 2014a, b; MacHattie and White, 2015).

These unit names are currently considered informal as mapping and geochronological work in the Cobequid Highlands have not been completed and may result in the necessity of further changes in terminology.

Geochronological Studies

Introduction

Uranium-lead age determinations from zircon grains in standard polished petrographic thin section and grain mounts were completed using the laser-ablation microprobe–inductively coupled plasma–mass spectrometry (LAM-ICP-MS) method at the University of New Brunswick and the Isotope Geology Laboratory at Boise State University in Idaho following the procedure outlined by McFarlane and Luo (2012), Archibald et al. (2013), and J. Crowley, written communication (2019). These data were integrated with previously published data (e.g. Murphy et al., 1997; Keppie et al., 1998; Barr et al., 2003; Henderson, 2016; Henderson et al., 2016). Previous Rb-Sr, K-Ar, $^{40}\text{Ar}/^{39}\text{Ar}$, and U-Pb geochronological studies in the highlands (up to 1991) were summarized in Murphy et al. (2001) and geologically valid data are incorporated in the probability plots used in this report (Fig. 2, 3).

Bass River Block

Bass River Complex

Single grain detrital zircon analyses (TIMS) from a quartzite bed in the Gamble Brook Formation suggested a maximum depositional age of 1189.3 ± 2.0 Ma (Keppie et al., 1998). A follow-up U-Pb TIMS detrital zircon study on the same sample by Barr et al. (2003) yielded a slightly younger single zircon age of 996.6 ± 2.2 Ma. Henderson et al. (2016) collected two samples from near the same location and, using the LAM-ICP-MS method, defined the youngest population (three overlapping concordant zircon ages) at 975 ± 33 Ma.

During the present study, detrital zircon grains were dated from two quartzite samples and a metawacke sample from the Gamble Brook Formation and quartzite, metawacke, and paragneiss samples from the Mount Thom Formation. The similarity in Mesoproterozoic to Paleoproterozoic patterns (Fig. 2) suggests the same (or similar) source areas for detritus in all of these samples and hence supports field observations that the Gamble Brook and Mount Thom formations are likely correlative (e.g. MacHattie and White, 2012). The patterns are also similar to detrital zircon signatures from basins proximal to and on the West African Craton

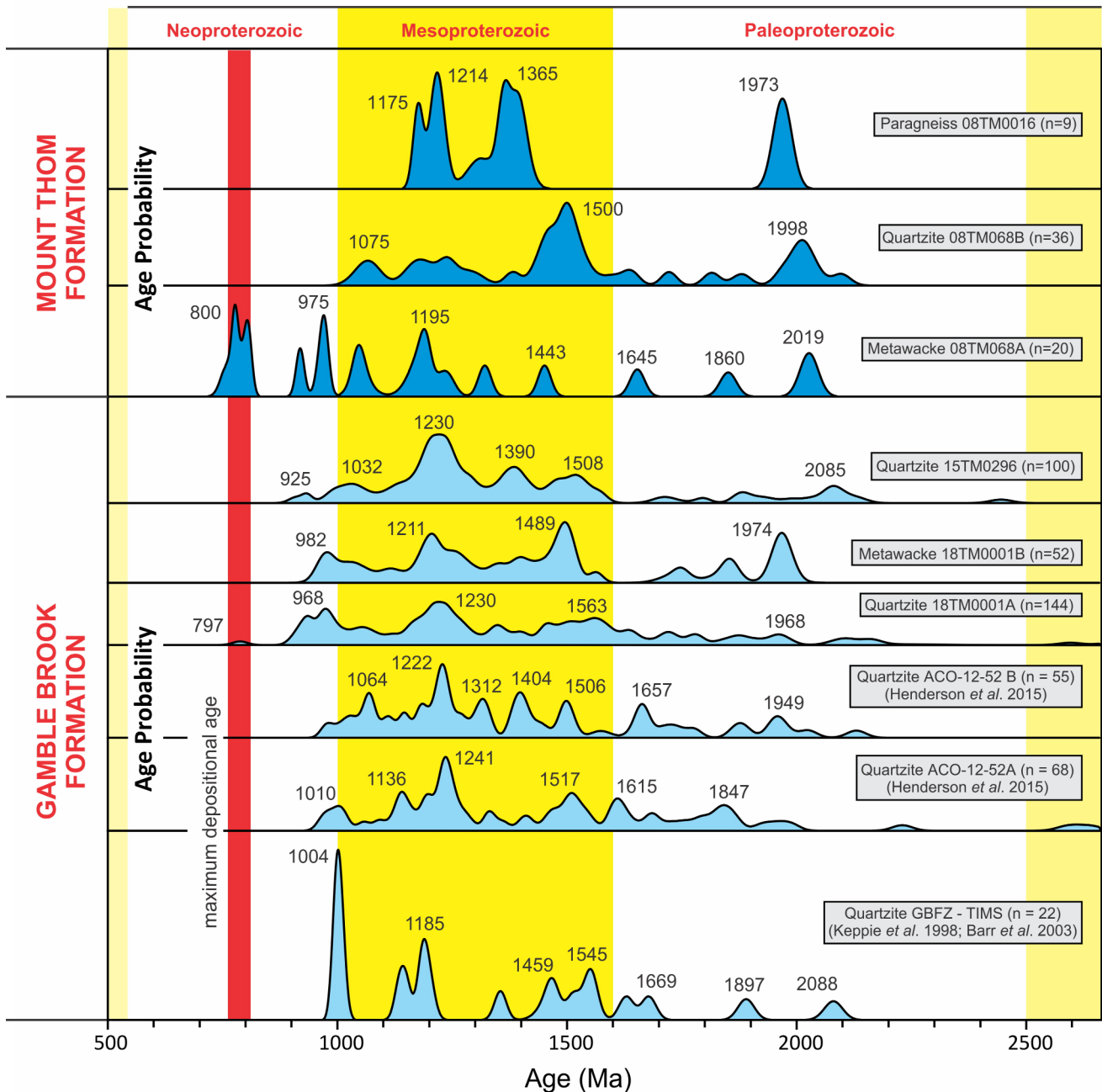


Figure 2. Age probability plots for samples from the Gamble Brook and Mount Thom formations.

(Bradley et al., 2015). The youngest population of detrital zircons from our data suggests a maximum depositional age of ca. 800 Ma. This ca. 800 Ma population of zircon ages are not recorded in the West African data.

Mount Ephrairn Plutonic Suite

The dioritic parts of the Mount Ephrairn plutonic suite were first recognized by Donohoe and Wallace (1982) who considered them to be latest

Neoproterozoic, like the other plutonic units in the block. Pe-Piper and Piper (2005) also considered the suite to be latest Neoproterozoic and included the more granitic and dioritic units with the Debert Lake and Frog Lake plutons, respectively. Based on field observations, MacHattie and White (2012) recognized the distinct character of the suite and dated four samples that yielded concordant LAM-ICP-MS zircon ages that ranged from ca. 755 to 735 Ma, confirming its uniqueness. Two additional samples (monzogranite and gabbro) analyzed at

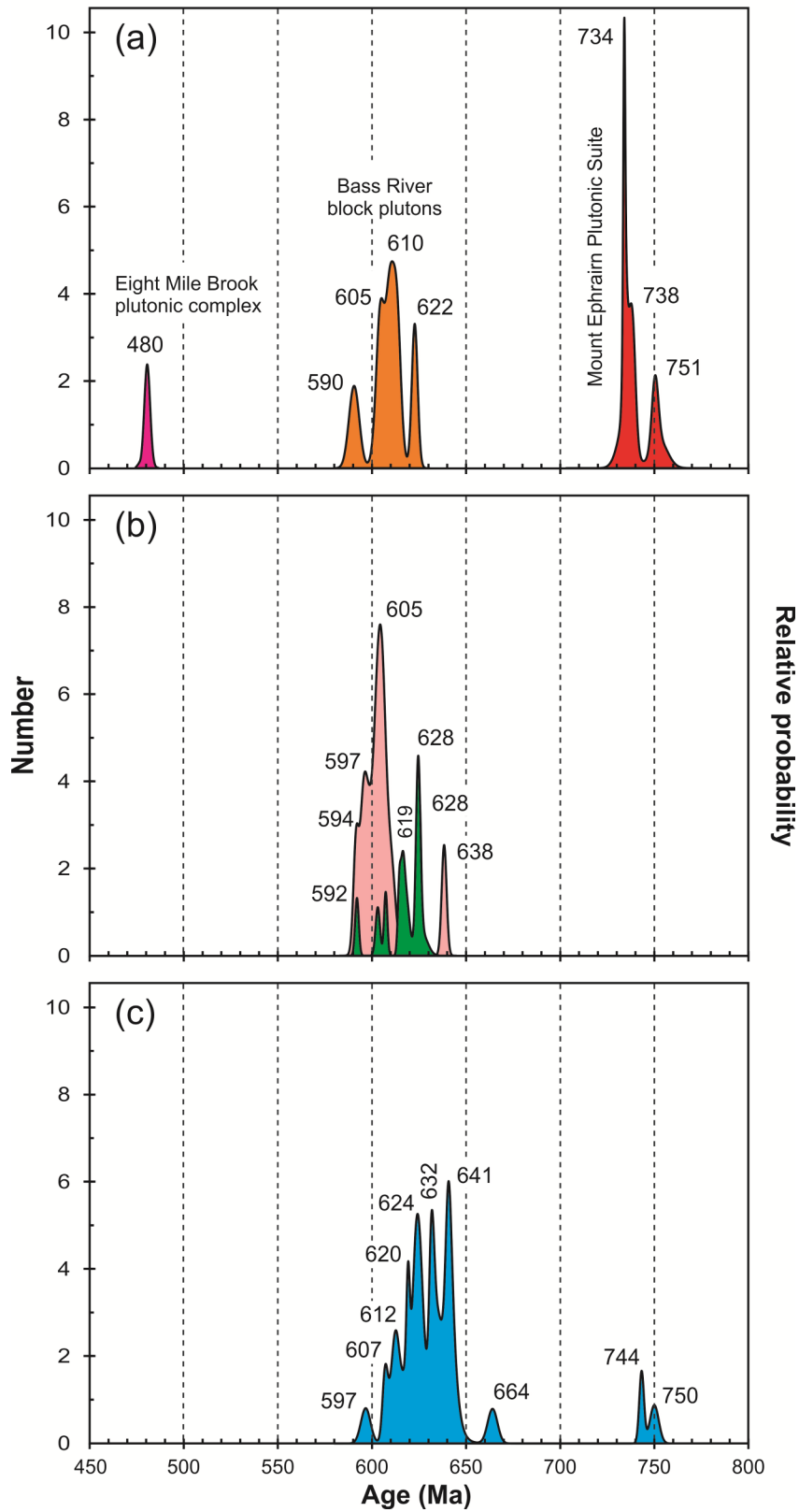


Figure 3. Age probability plots for units in the Cobequid Highlands. (a) Plot of crystallization ages for the Mount Ephraim Plutonic Suite, Bass River block plutons, and the Eight Mile Brook plutonic complex. (b) Plot of crystallization ages for volcanic rocks in the Jeffers Group (green) and related plutonic units (pink). (c) Plot of inherited zircons from the Late Neoproterozoic and Carboniferous volcanic and plutonic units.

Boise State University yielded similar ca. 735 Ma results (Fig. 3a).

Although the Economy River Gneiss was considered to be basement to the Avalon Zone (Nance and Murphy, 1990), it is protomylonitic granodiorite with numerous xenoliths of quartzite and metavolcanic rocks. It yielded a TIMS U-Pb zircon age of 734.3 ± 1.9 Ma (Doig et al., 1991) and a LAM-ICP-MS zircon age population of 733.98 ± 0.96 (Henderson, 2016). Hence, we consider the 'gneiss' to be a more deformed part of the Mount Ephraim plutonic suite (White et al., 2019).

Plutons in the Bass River Block

Based on field relations and geochemistry, the Frog Lake, Debert River, and McCallum Settlement plutons and related smaller intrusions are similar and are collectively referred to as the Bass River block plutons (White et al., 2019). Previous U-Pb zircon and $^{40}\text{Ar}/^{39}\text{Ar}$ amphibole ages on plutonic units have yielded ages that range from ca. 622 to 590 Ma (Keppie et al., 1990; Doig et al., 1991). Combined with the six additional concordant zircon ages from this study, the results show that the Frog Lake pluton is the oldest Bass River block pluton with similar $^{40}\text{Ar}/^{39}\text{Ar}$ amphibole and U-Pb ages of ca. 622 (Fig. 3a). The Debert River and McCallum Settlement plutons fall into a 610 to 605 Ma age range, but exhibits a younger peak at ca. 590 Ma (Fig. 3a) that coincides with the ages of two samples of strongly deformed igneous rocks analyzed by Doig et al. (1991). This younger peak could be attributed to a younger pulse of intrusion but is more likely related to Pb-loss during mylonitization.

Eight Mile Brook Plutonic Complex

The Eight Mile Brook pluton (Donahoe and Wallace, 1982), or plutonic complex (MacHattie and White, 2012), is a suite of co-mingled syenite and gabbro that intrudes the Mount Thom Formation and Mount Ephraim plutonic suite. Donahoe and Wallace, (1982) considered these rocks to be latest Neoproterozoic. Pe-Piper and Piper (2005) also considered them to be Neoproterozoic but included them with metasedimentary rocks in a tectonic-slice unit. To better constrain the age, two alkali-feldspar granite samples and a syenite sample were collected for U-Pb analysis. All three rocks yielded concordant zircon ages of ca. 480 Ma (Fig. 3a) (MacHattie and White, 2012, 2014b). This early Ordovician

plutonic unit is similar to the West Barneys River plutonic suite in the Antigonish Highlands (Archibald et al., 2013; White, 2017)

Jeffers Block

Jeffers Group

The Dalhousie Mountain, Farmington, and Gilbert Hills formations constitute the Jeffers Group and, although geographically dispersed, contain rocks with similar lithological characteristics. They include dacitic to andesitic crystal to crystal lithic tuff and minor rhyolitic lapilli tuff and flows, as well as rare basaltic tuffaceous rocks and flows (MacHattie and White, 2014a, b, 2015; MacHattie 2016). All three formations also include distinctive laminated 'cherty siltstone' interpreted to represent volcanic ash layers (MacHattie and White, 2014a, b), similar to components of the Georgeville Group in the Antigonish Highlands (e.g. White, 2017).

Prior to this study, the only U-Pb zircon age from these formations was from a rhyolite in the Gilbert Hills Formation, which yielded an upper intercept U-Pb zircon age of 628.5 ± 2.6 Ma (Murphy et al., 1997). Eleven additional rhyolitic samples were collected for the present study, consisting of five from the Gilbert Hills Formation, five from the Farmington Formation, and one from the Dalhousie Mountain Formation. The concordant zircon ages form four main peaks on the probability plots at ca. 628, 619, 609 to 605, and 592 Ma (Fig. 3b).

Plutonic Units in the Jeffers Block

Based on field relations and geochemistry, the Gunshot Brook, Six Mile Brook, Jeffers Brook, New Prospect, and McCormack Lake plutons are similar and are collectively referred to as the Jeffers block plutons (White et al., 2019).

In the western Cobequid Highlands, the Gilbert Hills Formation is intruded by the Jeffers Brook pluton (Pe-Piper and Piper, 2002; MacHattie and White, 2015; McCulloch, 2017). Hornblende from dioritic parts of the pluton yielded $^{40}\text{Ar}/^{39}\text{Ar}$ plateau ages of 607.1 ± 3.4 and 604.5 ± 4.4 Ma (Keppie et al., 1990). In the eastern Cobequid Highlands, the Gunshot Brook pluton, which intruded the Dalhousie Mountain Formation, has yielded a U-Pb zircon age of 605 ± 5 Ma (R. Doig in Murphy et al., 2001; no data were published for this age).

To better understand the plutonic history of plutons in the Jeffers block, seven additional samples were collected for U-Pb zircon analysis: three granodiorite samples from the Jeffers Brook pluton; two samples of fault-bounded granodiorite associated with the Kirkhill Fault (New Prospect pluton); one sample of granite from the McCormack Lake pluton that intrudes the Farmington Formation; and one sample from the Gunshot Brook pluton. The resulting concordant zircon ages show that the Gunshot Brook pluton is the oldest at 638.6 ± 2.5 Ma and that the previously reported date of ca. 605 Ma (cited above) may be unreliable. The combined data on the probability plots show additional peaks at ca. 628 and 605 to 594 Ma, similar to the ages of the associated volcanic units (Fig. 3b).

Zircon Inheritance

Many of the Late Neoproterozoic volcanic and plutonic units in the Jeffers block contain abundant older (inherited) concordant zircon grains. These ages, along with those of inherited zircon grains from Carboniferous plutonic and volcanic units, can be used to gain some insight into the geological evolution of the Cobequid Highlands. In this study we used three or more overlapping concordant zircon analyses to justify the definition of ‘population’ following the method cited by Slaman et al. (2017) and use those ages. As a result, 30 inherited ages yielded several peaks (Fig. 3c) that show a cluster between 641 to 597 Ma which covers the crystallization ages for many of the volcanic and plutonic units in the Jeffers and Bass River blocks, the likely sources of these grains. The ca. 750 and 744 Ma peaks are from inherited zircons in volcanic rocks from the Farmington and Gilbert Hills formations; their similarity to the ages of plutons in the Mount Ephraim plutonic suite suggests that the Jeffers block may have been in close proximity to the Bass River block during the Late Neoproterozoic.

Future Work

Results from the new U-Pb zircon analyses are intriguing but retain some ambiguity in terms of understanding relationships of units in both the Jeffers and Bass River blocks and ages of associated plutonic units. Hence work is ongoing to further resolve the remaining uncertainties, including additional litho-geochemical interpretations and isotopic and geochronological studies, with the aim of further characterizing the geological history of the area and its mineral occurrences.

Acknowledgments

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Bedrock Mapping in the Meguma Terrane: a Long Awaited Return to the Eastern Shore of Nova Scotia

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Introduction

After a long hiatus, the Nova Scotia Department of Energy and Mines has resumed a mapping program in the Meguma terrane along the Eastern Shore of Nova Scotia. This multi-year program is aimed at producing a series of 1:50 000-scale geological maps of the Halifax to Canso area, focused on the Goldenville and Halifax groups (Fig. 1). Other than the maps produced by the Geological Survey of Canada, such as maps of the Ecum Secum area (Henderson, 1986) and Canso/Forest Hills areas (Hill, 1991), and the provincially produced map of the Governor Lake area (White and Scallion, 2011), no modern geological map of rocks exposed along the Eastern Shore exists (Fig. 1). In some areas the most recent maps are those published by the Geological Survey Department of Canada by H. Fletcher and E.R. Faribault during the late 19th and early 20th centuries (e.g. Fletcher and Faribault 1893).

This new mapping initiative will build on previous Meguma terrane bedrock-mapping projects completed elsewhere in the province. They included the southwestern Meguma (White, 2010, 2012; White and Barr, 2012; White et al., 2018), central Meguma (Horne et al., 2009a, b, c, d), and parts of eastern Meguma (Governor Lake area by White and Scallion, 2011; Halifax area by White et al., 2014) (Fig. 1). This work will complete the bedrock mapping of the Meguma terrane.

In addition, unpublished mapping data from the Musquodobit Batholith (e.g. MacDonald, 1981; Ham, 1999) and data collected during the regional-contact metamorphic study of rocks in the Eastern Shore by Douma (1988) will be incorporated in this work. The work will include establishing a whole-rock and mineral-chemistry database for the area.

The results of this mapping project, combined with the earlier projects, will provide a better understanding of the sedimentary, igneous,

metamorphic, and deformational history, all of which are important in evaluating the economic potential of the area.

Preliminary Results

During August and September of 2018, 1:10 000-scale mapping was initiated along a strip extending from the Governor Lake map area (White and Scallion, 2011) southward to the Sheet Harbour area (Fig. 1). This swath was chosen because it provides a nearly complete cross-section perpendicular the northeastly strike of the Goldenville and Halifax groups. Large areas of glacial till, however, cover or at best obscure outcrop and hence prevent the construction of a reliable geological cross-section. Mapping along strike away from these till-covered areas is required to enable construction of a cross-section.

Structural data were collected from all outcrops visited during this study, and multiple magnetic susceptibility measures were acquired from each rock type at each outcrop. In addition, approximately 150 samples were collected, slabbed, thin sectioned, and analyzed with the portable XRF (pXRF). Based on field relations, petrography, and geochemistry (pXRF), the lithologies and stratigraphy in the mapped area are similar to those in the Trafalgar area to the north (White and Scallion, 2011). The Cunard Formation, the lowest unit in the Halifax Group, was recognized in the mapped area, although the Glen Brook Formation, noted to overlie the Cunard Formation in the Central Meguma mapping project (Horne et al., 2009a), was not. The Mn-rich Beaverbank Formation, which represents the top of the Goldenville Group, was recognized, as well as the underlying Taylors Head Formation. The presence of the Tangier Formation, recognized farther to the west (Horne and Pelley, 2007), has not yet been verified.

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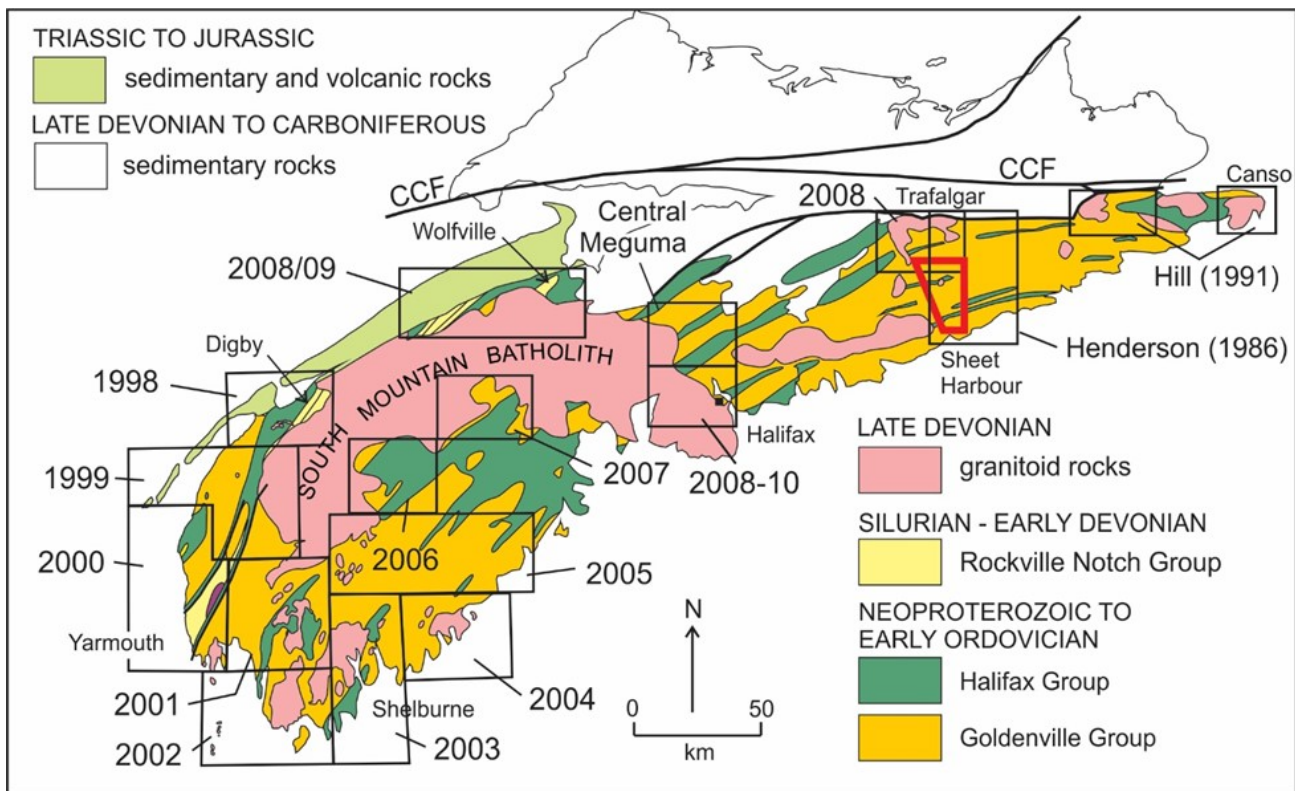


Figure 1. Simplified geological map of the Meguma terrane, southern Nova Scotia, showing the location of the 2018 map area (red box) in relation to other mapped areas (year of mapping indicated). CCF = Cobequid-Chedabucto Fault.

Based on float boulders of coarse-grained monzogranite and rare outcrops of spotted hornfels, the eastern margin of the River Lake pluton has been slightly modified from that of Horne and Pelley (2007) and extended farther to the southeast.

Future Work

Bedrock mapping is planned to continue for the next several years and will focus on (1) the production of 1:50 000-scale maps, (2) establishing chemostratigraphy using both pXRF and certified lithochemical analyses, (3) obtaining better controls on depositional age and source areas of the units using detailed U-Pb detrital zircon and isotopic studies, and (4) producing a metamorphic map to document variations in regional metamorphic grade and establish the presence of buried plutonic units. These new data will result in a better understanding of the distribution of economic mineralization and help to establish a predictive model to increase mineral exploration successes in the area.

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