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Open File Report 6421

Summary of Field Work and Other Activities, 2025

2025

Ontario

ONTARIO GEOLOGICAL SURVEY

Open File Report 6421

Summary of Field Work and Other Activities, 2025

by

Ontario Geological Survey

Edited by M. Duguet, S. Préfontaine and O.M. Burnham

2025

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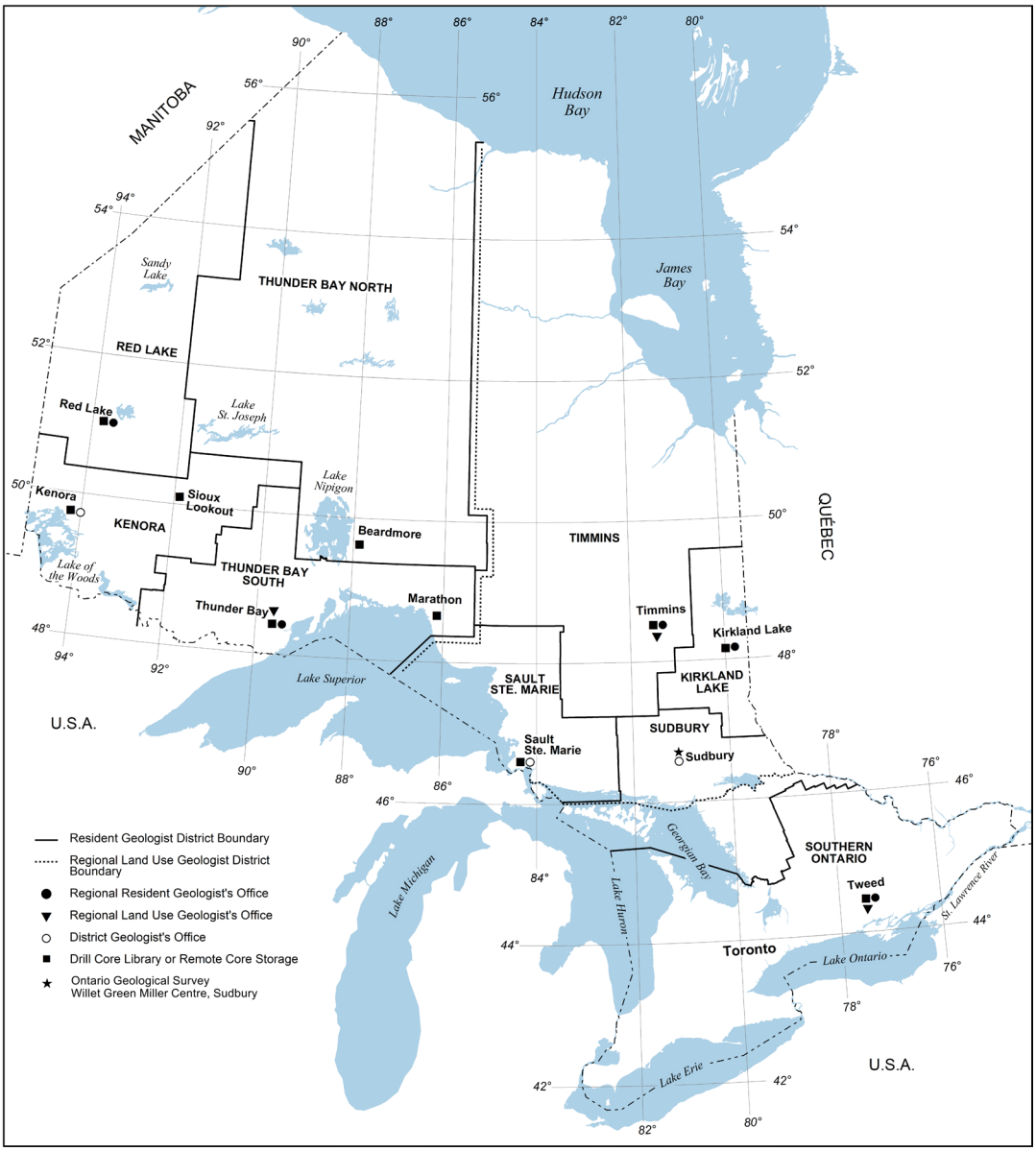
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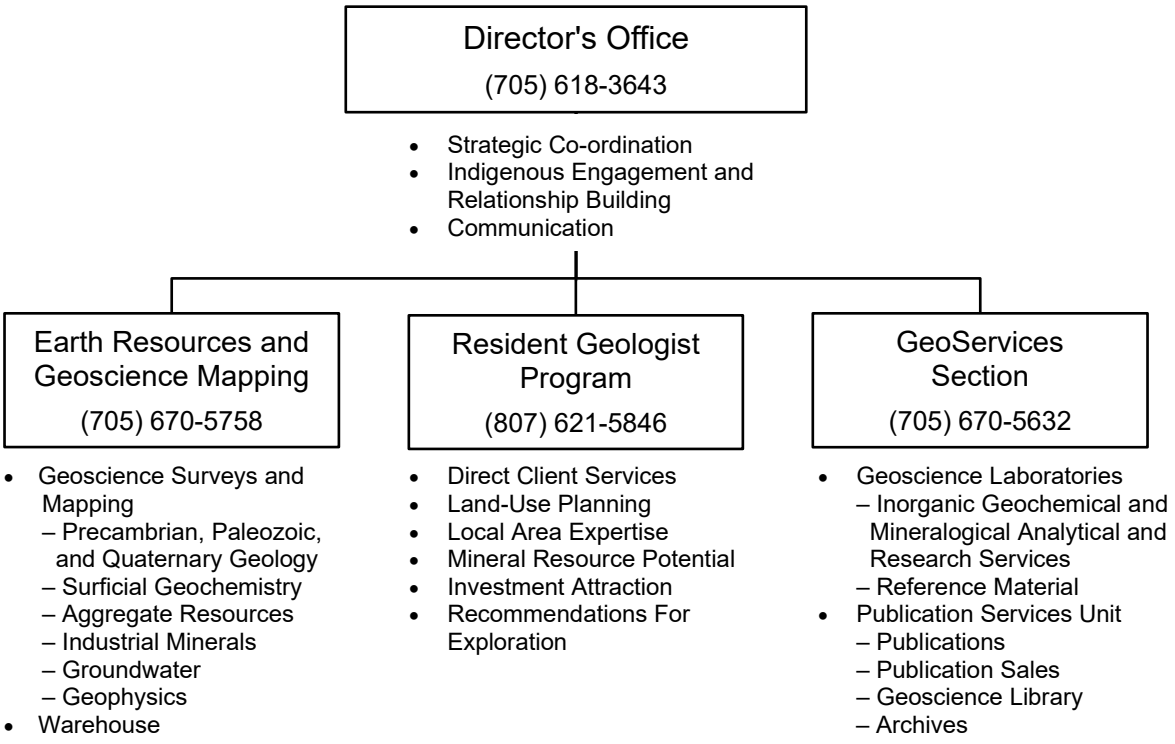


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Ontario Geological Survey Branch



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Office of the Director, Ontario Geological Survey

1. Ontario Geological Survey: Update of Strategic Perspective for 2025–2026



J.H. Hechler[1]

[1]Director's Office, Ontario Geological Survey

INTRODUCTION

This article provides an update on the strategic direction of the Ontario Geological Survey (OGS) based on activities during the 2025–2026 fiscal year.

These strategic priorities include the delivery of relevant, accurate, up-to-date public geoscience data and information about Ontario in order to

- identify economic opportunities;
- safeguard public health and safety related to natural geological factors; and
- inform environmental and land-use planning decisions.

As part of delivering on the strategic plan, the OGS continues to address government priorities and provides public geoscience to the general public, stakeholders and Indigenous partners. This is done to inform and guide decision making in the areas of mineral investment attraction and Earth resources management, land-use planning, healthy communities and energy supply.

THE ONTARIO GEOLOGICAL SURVEY

The OGS is the principal provincial government organization responsible for the collection, interpretation, documentation and dissemination of public geoscience data and information. The geoscience expertise of the OGS focusses on the description of Ontario's bedrock geology, surficial geology, the geological processes that shaped the landscape, and the Earth resources (groundwater, minerals, metals, aggregates, hydrocarbons) that occur within the geological framework. This public geoscience information is used to support and inform decisions related to

- environmental geochemical baseline;
- identification and description of naturally occurring geological hazards that may pose a threat to public health and safety;
- engineering infrastructure factors related to aggregates and terrain;
- changing climate impact and mitigation considerations;
- land-use planning and Earth resources management from a geological perspective;
- biodiversity and habitat as they relate to geology; and
- economic development and stewardship related to groundwater, energy, aggregates, metals and minerals.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.1-1 to 1-12.

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The OGS continues to generate world-class geoscience information, products and services, including the 27 articles in this volume and numerous other publications released by OGS staff. The Resident Geologist Program (RGP) continued to provide information and support to the exploration sector and are on target to release *Recommendations for Exploration 2025–2026* in late January 2026. In 2025, the Geoscience Laboratories continued to provide valuable, high-quality geoanalytical data to the Ontario Geological Survey, as well as to external Non-Tax Revenue (NTR) clients across industry, academia and other government agencies.

VISION, MISSION AND MANDATE OF THE ONTARIO GEOLOGICAL SURVEY

Recent interministerial and divisional reorganization have changed the place of the Ontario Geological Survey (OGS) within the organigram of the Ontario provincial government. Prior to March 2025, the OGS was a branch within the Mines and Minerals Division, in the Ministry of Mines. In March 2025, the Ministry of Mines (MINES) and the Ministry of Energy (ENERGY) were merged, becoming the Ministry of Energy and Mines (MEM). In October 2025, the Mines and Mineral Division (MMD) was renamed the Mines and Minerals Regulatory Division (MMRD), and the Strategic Policy Division (SPD) was renamed the Mining Policy and Sector Development Division (MPSDD). As part of this shift in divisional priorities, the OGS was moved from the now regulatory focussed MMRD to the policy and sector development focussed MPSDD. The OGS, which this year celebrated its 134th anniversary, continues to deliver its strong geoscience-based mandate, as reflected in its continuing Vision, Mission, and Mandate statements.

The OGS vision, mission and mandate statements remain identical, however, and are as follows:

Vision: The OGS is "a leading provider of reliable, credible, accessible public geoscience data, information and expert knowledge for the public good".

Mission: The OGS sustains and supports Ontario's quality of life, economic prosperity, environmental quality and public safety by providing Ontario's citizens, institutions and Indigenous Peoples with public geoscience data, information and expert knowledge to inform decision making.

Mandate: The OGS collects and disseminates public geoscience data and information and provides expert knowledge to attract and guide mineral sector investment, as well as inform a broad range of government policy priorities, including mineral investment attraction, land-use planning, healthy communities and energy supply.

ONTARIO GEOLOGICAL SURVEY: DELIVERING GLOBALLY SIGNIFICANT PUBLIC GEOSCIENCE

The OGS has maintained an international reputation for independent, credible, public geoscience expertise. The following examples highlight recent achievements of OGS technical professionals:

- publication of ambient groundwater geochemical and isotopic data for northeastern Ontario, 2016–2018 (Miscellaneous Release—Data 401);
- publication of Ontario geophysical survey, ground gravity data, grid and point data (ASCII and Geosoft®) and vector data, Guelph area (Geophysical Data Set 1090, Map 80 487);
- publication of the groundwater geoscience in southern Ontario 2025 Open House program and abstracts (Open File Report 6414);
- publication of 2021–2024 indexes to publications (Miscellaneous Paper 177 Interim Supplement 2021–2024 and Miscellaneous Paper 178 Interim Supplement 2021–2024);

- publication of updated geodatabases for Preliminary Maps P.3787, P.3797, P.3803 and P.3814 in the Michipicoten greenstone belt, northeastern Ontario;
- publication of the Borden Lake multimedia geochemical survey, northeastern Ontario (Open File Report 6344);
- publication of the stream sediment, lake sediment, lake water and till geochemical data, Borden Lake area, northeastern Ontario (Miscellaneous Release—Data 367);
- publication of the geology of Briggs Township, Temagami greenstone belt, northeastern Ontario (this volume, Article 5);
- publication of the geology of Haultain, Van Hise and Nicol townships, Abitibi greenstone belt, northeastern Ontario (this volume, article 6);
- publication of the geology of Ridout Lake and Little Ridout Lake, Greenlaw Township, Swayze area, Abitibi greenstone belt, northeastern Ontario (this volume, Article 7);
- publication of a re-evaluation of the lithostratigraphic nomenclature for the Gunflint and Rove formations in the Animikie Basin, northwestern Ontario (this volume, Article 8);
- publication on new microfossil localities in the Paleoproterozoic Gunflint Formation, northwestern Ontario (this volume, Article 9);
- publication of a study on the potential of zirconium and rare earth elements of a Grenville Province gneiss north of Verner, northeastern Ontario (this volume, Article 10);
- publication on till sampling and striation measurements between Nipigon and Thunder Bay, northwestern Ontario (this volume, Article 12);
- publication on a newly recorded late-glacial varved clay deposit, Sudbury, northern Ontario (this volume, Article 13);
- publication on Quaternary geological mapping of the Lake Nipissing Basin, northeastern Ontario (this volume, Article 14);
- publication of an updated surficial sediment and landform mapping in the City of Ottawa, eastern Ontario (this volume, Article 15);
- publication on the provincial-scale compilations of landslides and abandoned glacial lake shorelines based on regional lidar data (this volume, Article 16);
- publication of an update of the lake sediment and surface water geochemistry program: Chapleau–Montreal River–Mississagi River, northeastern Ontario (this volume, Article 17);
- publication of preliminary results of the ambient groundwater geochemistry project in the Bancroft, Madawaska Highlands and North Frontenac region, southern Ontario (this volume, Article 18);
- publication of preliminary results of the Mount Forest drilling program, southern Ontario (this volume, Article 19);
- publication of preliminary results of the Guelph drilling program, southern Ontario (this volume, Article 20);
- publication of preliminary results of the core logging project in the region of Waterloo, southern Ontario (this volume, Article 21);
- publication of preliminary results of the core logging project in Norfolk County, southern Ontario (this volume, Article 22);

- ongoing delivery of airborne and ground-based geophysical data and ongoing support to the Earth Resources and Geoscience Mapping Section (ERGMS) bedrock geology mapping and groundwater programs, as well as support to the Resident Geologist Program (RGP) (this volume, Article 11)
- development and validation of various new analytical test methods as well as ongoing delivery of the services of a world-class inorganic geochemical laboratory, which supports the OGS geochemical program (*see also* this volume, Articles 23, 24, 25, 26 and 27);
- publication of *Recommendations for Exploration 2024–2025*;
- delivery of the 2024 OGS Virtual Showcase, held November 26 to 28, a free, public, three-day event held via Microsoft® Teams® Live that highlighted OGS activities and projects;
- ongoing delivery of the Resident Geologist Program (RGP), which delivers local expert geoscience knowledge and front-line service to clients, stakeholders, Indigenous Peoples and the general public across Ontario.

To date, the OGS has published a variety of geoscience information in different formats, including 10 396 maps, 3660 reports, 683 data releases and 2 video releases. In the period November 1, 2024 to October 31, 2025, the OGS published 9 new reports, 1 new map, 3 new data releases and 1 new video product.

From November 1, 2024, to October 31, 2025, numerous publications and data files were downloaded or accessed:

- downloaded from our GeologyOntario Hub Web sites:
  - in excess of 59 169 maps (34 729) and reports (24 440) in portable document format (*.pdf*) and image (*.jpg*) format
  - 12 386 compressed (*.zip*) files
- downloaded from our OGSEarth Web site:
  - 26 956 master *.kml* and/or *.kmz* files, and 1445 compressed (*.zip*) files
  - Resident Geologist Program databases and recommendations:
    - Ontario Mineral Inventory (OMI) (updated monthly) 604 *.kml* files and 461 *.zip* files
    - Ontario Assessment File Database (OAFD) (updated monthly) 642 *.kml* files and 337 *.zip* files
    - Ontario Drill Hole Database (ODHD) (updated monthly) 686 *.kml* files and438 *.zip* files
    - OGSFocus (quantifies data from OMI, OAFD and ODHD) (updated bi-weekly) 204 *.kml* files and 113 *.zip* files
    - OGS GeoData listing (quantifies data from OGS publications, OMI, OAFD and ODHD) 378 *.kml* files
    - *Recommendations for Exploration* 765 *.pdf* files, including the *Special Edition: Critical Minerals Compilation*.
      The current *2024–2025 Recommendations for Exploration* was 253 (33.1%), 2005–2023 was 377 (49.3%), the *Special Edition: Critical Minerals Compilation* was 20 (2.6%) and the *Introduction to Ontario's Critical Minerals* was 115 (15%).
- downloaded, viewed and accessed from our OGSEarth RGP Activity Reports – Mineral Exploration (AR–ME), compiled by the district offices and updated monthly:
  - AR–ME *.kml* file on OGSEarth Web page downloaded 1934 times
  - AR–ME Web page list, including individual pages for the district offices accessed 2921 times (through the AR–ME Web page list)

CURRENT TRENDS THAT WILL SHAPE THE FUTURE OF THE ONTARIO GEOLOGICAL SURVEY

Trends that continue to influence the OGS geoscience program include the following:

- Long-term global growth, largely driven by the need for mineral resources: having up-to-date inventories of Ontario's geology and Earth resources is a key aspect of attracting and fulfilling this investment potential.
- Mineral resource exploration and development continue to push geographic and technological frontiers: the Far North, "deep search" for mineral resources, potential for renewable and non-renewable energy sources, and quality and quantity of groundwater resources.
- Expectations for governments to provide robust guidance on management, mitigation and adaptation to the challenges of a changing climate require geoscience to help frame and inform some of those decisions, including drought mitigation and the identification and protection of vulnerable groundwater aquifers.
- Population growth across southern Ontario, which requires geoscience for land-use planning and the identification of groundwater aquifers and aggregate construction materials.
- Emphasis on evidence-based decision making requiring the inclusion of geoscience to fully assess risk and to support decision making.
- Increasing societal need to understand, identify and reduce disaster risks posed by natural geological features and, in a geological context, protect Ontario's natural environments. For each action, the OGS has a vital role to play in ensuring Ontario is well positioned to face these challenges through the provision of geological data and information.
- Standards and expectations for environmental responsibility continue to grow. A sound understanding of the geological features of the Earth is critical to ensuring a geochemical baseline is in place, that the material to be sampled for geochemical analysis is understood, and that the "geological container" that holds the Earth resources, such as groundwater, is described.
- Land-use planning across the Far North and municipalities elsewhere in Ontario will continue; this process requires the consideration of geology in order to assess health, safety, infrastructure, geochemical baseline, source-water protection and economic potential options.
- Expectations for rapid, evidence-based policy analysis and user-friendly data discovery, access and handling will continue to grow through an "open spatial data" climate.
- Engagement, relationship-building, collaboration and notification of Indigenous Peoples and citizens of Ontario related to the delivery of OGS geoscience project activities is an essential part of operating with a social licence and is an integral part of the operations of the OGS geoscience program where a multi-year presence on the land is required.
- Jurisdictions across the globe have started assessing not only the vulnerability of their respective economies to the supply of critical minerals, but also to the availability within their borders. The OGS is positioned to provide the geoscience knowledge, data and information to support exploration and understanding of critical minerals in Ontario.
- Ontario's Critical Minerals Strategy, launched in March 2022, provides an opportunity for the continued role of the OGS in enhancing geoscience information and supporting critical minerals exploration in the province.

ONTARIO GEOLOGICAL SURVEY CLIENTS, STAKEHOLDERS AND PARTNERS

The OGS works closely with Indigenous Peoples in anticipated and planned geoscience project areas to engage, to build meaningful relationships and to discuss potential impacts and implications of OGS projects. The OGS practice is to work collaboratively with Indigenous communities on topics of mutual interest that can be the basis of a collaboration and/or partnership related to a geoscience project. This practice has matured since the OGS implemented changes in 1999 to its Indigenous engagement practices. In 2016, the OGS Director's Office recruited 2 Indigenous Geoscience Liaison positions based in Sudbury and Thunder Bay. A summary of the activities of the Indigenous Geoscience Liaisons during 2024–2025 are described by Levesque (this volume, Article 3).

The OGS also has clients who formulate and implement policy and who are regulators in provincial, municipal and local governments. In fiscal 2024–2025, the OGS continued to support the application of geoscience information into broader government decision making by guiding other provincial ministries in applying public geoscience to help inform their decisions. The OGS continues the ongoing strengthening of collaboration and communication among government geoscientists and users of geoscience, through co-ordinated cross-ministry efforts that support the exchange of information, and the expansion of the knowledge and expertise with respect to the application of geoscience in government.

In addition, public geoscience data, information and knowledge are used by municipalities, academia and a variety of private sector organizations to inform business-related decisions. The OGS conducts annual client surveys (*see* Kalmo, this volume, Article 2) to measure 6 performance indicators including the percentage of decision makers who state that their use of OGS products and services increased their decision-making efficiency and effectiveness by focussing their efforts on areas of interest identified by public geoscience. The performance and effectiveness of the OGS geoscience program, based on client input, is measured and tracked from year to year (*see* Kalmo, this volume, Article 2).

CURRENT STRATEGIC PRIORITIES

Despite the change of the OGS position in the organization, the strategic priorities have not been modified. Four strategic priorities continue to be the focus of the OGS for the fiscal year out to 2026.

What Will the OGS Do Strategically?

- **Priority 1** Establish a geoscience baseline for all of Ontario in order to identify economic opportunities, safeguard public health and safety, and inform environmental and land-use planning decisions.
- **Priority 2** Contribute to the maintenance and enhancement of Indigenous relations.
- **Priority 3** Contribute to mineral development investment attraction.
- **Priority 4** Inform users about the value and relevance of OGS goods and services.

Results to Date

PRIORITY 1

Priority 1. Establish a geoscience baseline for Ontario in order to identify economic opportunities, safeguard public health and safety, and inform environmental and land-use planning decisions.

Strategic Objective: Provide modern, independent and credible geoscience data, information and knowledge to support decision making by government, Indigenous communities, citizens and industry.

Ontario Geological Survey public geoscience goods and services provide support for economic, social and environmental public policy decisions in a variety of areas:

- Economy: metal, mineral (including aggregate), water (groundwater) and energy resources;
- Environment: inorganic geochemical baseline, geological habitat that influences biodiversity, waste management and climate change mitigation and adaptation;
- Public health and safety: groundwater quality, geological hazards (e.g., landslides, karst, geochemical, gas, radioactivity); and
- Community: infrastructure planning, land-use planning, resource stewardship.

Multi-year priorities are established and reviewed annually during the OGS project planning process. The Geological Survey of Canada (Natural Resources Canada–Lands and Minerals Sector) is also an important part of the annual geoscience priority planning. These inputs are in addition to geoscience needs that are identified by public and private stakeholders and clients. The resulting geoscience projects are distributed across all of Ontario (*see* Robichaud et al., this volume, Article 4).

Results

To deliver on the strategic priorities, different roles and responsibilities are distributed across the OGS Branch (Table 1.1). Some notable results of the key technical mapping commitments are the following:

- two- and three-dimensional geological mapping projects continued in various regions across Ontario to attract mineral investment, to inform land-use planning related to Indigenous communities and municipalities in northern and southern Ontario, to assess mineral, energy and groundwater resource potential and to support resource and infrastructure development decisions;
- published geochemical survey data, including groundwater characterization, to continue to assist in the identification of natural factors in the environment, water-quality issues and geohazards;
- continuing updates to the Ontario Mineral Inventory (OMI) and its online database;
- an airborne geophysical survey conducted in northeastern Ontario;
- continuing updates to the Aggregate Resources of Ontario (ARO) database; and
- continuing updates to the Geochronology Inventory of Ontario (GeochrON) database.

A number of technical initiatives are achieving these results (*see* Robichaud et al., this volume, Article 4).

Table 1.1. Summary of OGS strategic objectives for public geoscience.

Strategic Objectives – Public Geoscience Information				
Outcomes	**Strategic Objectives**	**Activities**	**How?**	**Who? ***
Ontario geoscience portfolio recognized as a relevant resource to inform economic opportunities, health and safety, environmental and land-use planning decisions Land-use and environmental decisions informed by public geoscience Mineral investment decisions informed by public geoscience Enhanced efficiency and effectiveness and reduced risk of economic investment decisions and land-use and environmental decisions Public awareness about the value and relevance of public geoscience	Establish a geoscience baseline for Ontario to identify economic opportunity	Establish geoscience priorities based on public policy direction and input from stakeholders and clients	Gap analysis meetings with external clients, stakeholders, and with OGS staff who serve as proxy for external clients	Director's Office, ERGMS, RGP
			Project planning	ERGMS, RGP, GeoServices
	Establish a geoscience baseline for Ontario to safeguard public health and safety	Collect, analyze, advise and archive geoscience information	Mapping (OGS and collaborative projects with external collaborators or other governments)	ERGMS, GeoServices, RGP
			Property or site visits: mineral and aggregates	RGP
			Geochemistry	ERGMS, RGP, GeoServices
			Geophysics	ERGMS
			Receive third-party geoscience information	RGP, ERGMS
			Geoscience Library	GeoServices
	Establish a geoscience baseline for Ontario to inform environmental and land-use planning decisions	Provide access to OGS geoscience goods and services in a form that meets client needs	Geoscience Library	GeoServices
			GeologyOntario, OGSEarth and OGS Geoscience Atlas	GeoServices, RGP, ERGMS
			OGS expert technical staff participation in third-party technical meetings	ERGMS, RGP, GeoServices
		Inform users about the value and relevance of OGS goods and services and facilitate application of public geoscience to address priority issues faced by government, industry, and citizens	Multi-ministry committees	Director's Office, ERGMS, GeoServices, RGP, other MEM business units
			Provide geoscience information at technical meetings, symposia, workshops, and through direct client visits	ERGMS, RGP, GeoServices

***Abbreviations:** MEM = Ministry of Energy and Mines; ERGMS = Earth Resources and Geoscience Mapping Section; GeoServices = GeoServices Section; OGS = Ontario Geological Survey; RGP = Resident Geologist Program.*

PRIORITY 2

Priority 2. Contribute to building collaborative relationships with Indigenous communities.

Strategic Objective: Continue to maintain and build meaningful and respectful relationships with Indigenous Peoples and organizations as a foundation for OGS geoscience program activities.

Within the Ministry of Energy and Mines, Mining Policy and Sector Development Division (MPSDD), the OGS contributes to the Divisional and Ministry goal for engagement and relationship-building with Indigenous Peoples, at a community level, and with organizations (Table 1.2).

Table 1.2. Strategic objectives for Indigenous relations.

Strategic Objectives – Indigenous Relations				
Outcomes	**Strategic Objectives**	**Activities**	**How?**	**Who? ***
Strong and meaningful relationships between MEM and Indigenous Peoples and organizations	Continue to maintain and build meaningful and respectful relationships with Indigenous Peoples and organizations as a foundation for OGS geoscience program activities	Engagement and relationship-building with Indigenous Peoples, at a community level, and with organizations	Seek social licence for OGS geoscience projects through engagement and relationship-building Offer OGS geoscience topic area expertise Raise awareness about geoscience and its application to Indigenous interests Help build capacity related to geoscience and mineral industry-related careers Serve as a bridge between Indigenous Peoples and government and non-government topic experts	Director's Office, ERGMS, RGP

****Abbreviations:** MEM = Ministry of Energy and Mines; ERGMS = Earth Resources and Geoscience Mapping Section; OGS = Ontario Geological Survey; RGP = Resident Geologist Program.*

Results

Focus during the 2024–2025 fiscal year was to continue collaborations and relationship building with Algonquins of Ontario, Anishinabek Nation, Atikmaneksheng Aninshinabek First Nation, Beausoleil First Nation, Beaverhouse First Nation, Chapleau Cree First Nation, Dokis First Nation, Fort William First Nation, Grand Council Treaty #3, Keewaytinook Okimakanak Tribal Council, Lac des Mille Lacs First Nation, Marten Falls First Nation, Matachewan First Nation, Mattagami First Nation, Métis Nation of Ontario, North Spirit Lake First Nation, Missanabie Cree First Nation, Mississaugi First Nation, Mushkegowuk Tribal Council, Nipissing First Nation, Pays Plat First Nation, Red Sky Métis Independent Nation, Sagamok First Nation, Sand Point First Nation, Six Nations of the Grand River First Nation, Taykwa Tagamou Nation, Temagami First Nation, Weenusk First Nation, and Whitefish River First Nation (*see* Levesque, this volume, Article 3).

The Director's Office includes 2 Indigenous Geoscience Liaison positions based in Sudbury and Thunder Bay. These positions report to the Director and engage, build and maintain relationships with Indigenous Peoples in remote and non-remote communities across Ontario.

PRIORITY 3

Priority 3. Contribute to mineral development investment attraction.

Strategic Objective: The OGS contributes to 2 mineral investment-related objectives that are the primary responsibility of the Mining Policy and Sector Development Division (MPSDD):

- promoting the products and services of Mining Policy and Sector Development Division (MPSDD), as well as promoting Ontario's geology through educational and/or informational tools;
- monitoring Ontario's exploration and mining industries and providing information and/or data and analysis on Ontario's mineral sector.

The OGS participates in the promotion of mineral development opportunities in Ontario by promoting the geology and mineral potential of the province, as well as the public geoscience data and information resources. The OGS brings geoscience data, information and expert knowledge to the investment attraction and promotional activities led by the Mining Policy and Sector Development Division (MPSDD) (Table 1.3).

Table 1.3. Strategic objectives for mineral development investment and opportunities.

Strategic Objectives – Mineral Development Investment and Opportunities				
Outcomes	**Strategic Objectives**	**Activities**	**How?**	**Who? ***
Identification of investment opportunities and/or advantages that maximize mineral resource potential for Ontario's economic development Sustain and increase investment in Ontario's mineral sector	Promote the products and services of Mining Policy and Sector Development Division (MPSDD) and Ontario's geology Monitor Ontario's exploration and mining industries Provide data and analysis on the mineral sector	Identify, assess, and promote mineral investment opportunities to industry (and local governments, conservation authorities, and groundwater-related interest groups)	Participate in provincial, national and international marketing and promotional events	RGP, ERGMS, GeoServices, Director's Office

****Abbreviations:** ERGMS = Earth Resources and Geoscience Mapping Section; GeoServices = GeoServices Section; RGP = Resident Geologist Program.*

In addition, OGS technical experts support the investment attraction efforts by providing

- geoscience knowledge of available mineral properties in a region;
- knowledge of Ontario geology and the potential for different types of mineral resource opportunities across all of Ontario (for example, regional geochemical maps that highlight areas of enhanced mineral potential); and
- knowledge of key players in the mineral industry and facilitating relationships between interested clients.

Results

The staff of the OGS participated in-person at the Association for Mineral Exploration (AME) Annual Mineral Exploration Roundup 2025, and the Prospectors and Developers Association of Canada (PDAC) 2025 Annual Convention. The OGS supported the 2025 Ontario Geological Survey–Geological Survey of Canada–Conservation Ontario Geoscientists Open House, although in-person attendance was not possible during this time when the Ontario government had entered a writ period. The OGS published the Abstract Volume (OFR 6414) and supported event logistics where possible within the writ's constraints. Staff also participated in-person at the 2025 Lithium Pegmatite Short Course given during PDAC 2025; the Canadian Mining Expo 2025 Big Event; the Central Canada Resource Expo 2024; the 2025 Ontario Prospector's Exploration Showcase; the Geological Association of Canada–Mineralogical Association of Canada–International Association of Hydrogeologists–Canadian National Chapter 2025 Meeting; the 2025 Northeastern Ontario Mines and Minerals Symposium; and the 2025 Eastern Ontario Geoscience Open House.

PRIORITY 4

Priority 4. Inform users about the value and relevance of OGS goods and services.

Strategic Objective: The objective is to raise awareness and understanding about the relevance, value and application of OGS public geoscience to inform decision-making for government, clients, stakeholders, Indigenous Peoples and the public.

The OGS role is to communicate the existence, relevance and application of public geoscience and provide a broad range of products and services to deliver geoscience information to users, including two- and three-dimensional geological maps, reports, data sets and databases, technical posters, technical presentations and expert knowledge and advice.

All geoscience publications are available for free download through the GeologyOntario Hub site (www.hub.geologyontario.mines.gov.on.ca). In addition, the redesigned Hub site features new geospatial and text search tools, making it easier to search for, discover and download Ontario's geoscience data and information. Some key data sets, searchable using the expanded geospatial search tool on the GeologyOntario Hub site, are also available through OGSEarth (www.geologyontario.mndm.gov.on.ca/ogsearth.html), which uses the Google Earth™ mapping service (with *.kml* files) to view public geoscience data and information in a geographic context. The Resident Geologist Program (RGP) has also enhanced access to data using both the GeologyOntario Hub site and OGSEarth by adding mineral deposit and assessment file information, as well as increasing online accessibility to non-assessment geoscience information in the RGP offices.

Geoscience Library Refresh: Physical and Digital Holdings: The Geoscience Librarian, Digital Typesetter and the Digital Publication Coordinator of the Publication Services Unit are currently leading a project to reduce the Geoscience Library physical footprint by consolidating duplicate publications held in the 2 publication libraries — the Publication Services Library, available to OGS staff, and the Geoscience Library, available to the public. As part of this initiative, publication staff are decreasing the hard-copy publication inventory from 2 copies to 1, retaining only the most current, accurate and best-preserved version of each publication. This clean-up process will eliminate duplicate and damaged copies, resulting in a more refined and accessible collection. Once the physical review is complete, Publication Services staff will ensure that the digital versions of publications available on GeologyOntario accurately reflect the OGS publication holdings. As part of this digital version verification, publication staff are also reviewing and updating the internal publications database to capture any errata, revisions and other related materials associated with each publication.

Results

The OGS continued to use a variety of communication channels to deliver its products, raise awareness about geoscience and improve access to data, including

- social media, such as X (formerly Twitter®), Facebook®, and Linkedln® professional networking service and internal communication channels;
- formal public presentations that describe the value, relevance and application of geoscience;
- support of the GeologyOntario Hub site featuring a spatial search tool and a redesigned text search tool to improve and enhance usability, accessibility and searchability of OGS geoscience data, and including updates and improvements;
- improving the Ontario Mineral Exploration Information System, which is an internal process to improve and streamline processing and uploading of assessment files, drill-hole data and other geoscience information; and
- hosting the 2025 OGS Virtual Showcase in November 2025, a free, public, three-day event held via Microsoft® Teams® to highlight OGS activities and projects from this year.

Priorities Linked to Ontario's Critical Minerals Strategy

Ontario's Critical Minerals Strategy, which is a five-year strategy, comprises 6 pillars that will solidify Ontario's position as a global leader of responsibly sourced critical minerals. The OGS plays a foundational role in "Pillar 1: Enhancing geoscience information and supporting critical minerals exploration". OGS activities that have been initiated or completed in the past year to support Ontario's Critical Minerals Strategy are listed in Table 1.4.

Table 1.4. OGS activities in support of Ontario's Critical Minerals Strategy.

Goal	Geoscience Activity	Status
Undertake new geoscience initiatives that target underexplored areas of Ontario in partnership with Indigenous communities where potential partnership opportunities may exist	New bedrock mapping projects, airborne geophysics, lake sediment surveys in underexplored areas of Ontario with high critical mineral potential, as well as laboratory method development studies for the measurement of critical minerals	Ongoing (this volume, Articles 5, 7, 11, 14, 15, 18)
	Recommendations for Exploration published	Completed annually
Initiate a mine waste sampling project to help identify critical mineral content in tailings and waste rock, to support redevelopment of historic deposits	An introduction to the critical minerals mine waste sampling project	Ongoing
Expand advanced analytical capabilities through new laboratory technologies and for enhanced mineral analysis	Development of metaborate fusion methods for acid-insoluble critical minerals (chromite, tin, rare earth elements, niobium, tantalum)	Ongoing, expected to be completed 2026–2027 fiscal year
	Revision of the Geo Labs XRF-W01 method to determine fluorine (in fluorspar) in high concentrations	Ongoing (summary of progress: this volume, Article 23)

THE FUTURE

Building on the work initiated under the 2018–2019 OGS Strategic Plan, the OGS management team continues to support its mandate by continuing to

- implement a geoscience program based on accurate, modern, credible, public geoscience data, information and knowledge to help inform decision making;
- identify naturally occurring geological features and phenomena relevant to public health and safety;
- publish and promote information about Ontario's Earth resources, including its mineral, energy and water resource endowments, especially regarding Critical Mineral potential;
- develop new geoscience products that help present our complex geoscience data in a form that is understood by non-geoscience users, including the development of products that broaden the access and awareness of OGS geoscience goods and services to both traditional and non-traditional users;
- utilize social media.

The OGS public geoscience goods and services play an important role in helping support public-policy decision makers, investors and other users. Societal needs are increasingly complex and require a sound and objective understanding of geoscience to help assess and frame the complex options available. Geoscience is an essential element of social, environmental and resource management decision-making processes.

STAFFING CHANGES IN THE DIRECTOR'S OFFICE

In April 2025, Rob Cundari was the successful candidate for the Resident Geologist Program Senior Manager position within the Ontario Geological Survey.

2. Ontario Geological Survey: Measuring Success



K.J.J. Kalmo[1]

[1]Director's Office, Ontario Geological Survey

INTRODUCTION

The Ontario Geological Survey (OGS) Branch has 3 program outcomes:

- Short-Term Outcome: Clients, stakeholders and Indigenous communities have awareness of the value, relevance and application of available geoscience information;
- Intermediate Outcome: Geoscience knowledge and information are valued and used to inform decisions related to economic, environmental and social priorities;
- Long-Term Outcome: People and communities in Ontario benefit from the informed use of Ontario's land and Earth resources.

To help achieve these outcomes, as well as to measure program success, the OGS has 6 performance indicators that it measures and tracks:

1. Percentage of decision makers who state that their use of OGS products and services increased their decision-making efficiency and effectiveness by focussing their efforts on areas of interest identified by OGS geoscience.
2. Percentage of decision makers who used OGS products and services to support their mineral investment or environmental decisions.
3. Percentage of decision makers who were satisfied with OGS products and services to support their decision-making.
4. Indigenous communities who were satisfied with OGS products and services.
5. Percentage of clients and stakeholders satisfied with value-added OGS geoscience information (e.g., laboratory services, publication services, prospecting courses, groundwater meetings, OGS Showcase).
6. Annual number of square kilometres mapped by the OGS based on results of the OGS project proposal evaluation process.

The OGS conducts a large annual client survey by email to measure each of the performance indicators. Performance is also measured by surveying participants who attend OGS presentations and information sessions; documenting the completion of major project milestones; and documenting testimonials from Indigenous communities. All of these data are collected, tracked and monitored to ensure that the OGS is providing high-quality, relevant geoscience products and services to its clients, stakeholders, Indigenous Peoples and the general public.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.2-1 to 2-8.

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VALUE-ADDED PRODUCTS AND SERVICES

The GeoServices Section (GSS) of the OGS conducts an annual client survey specific to its program areas using SurveyMonkey®, an online survey platform that is used to create and distribute the survey and to collect and analyze results (Table 2.1).

The OGS, in collaboration with the Geological Survey of Canada and Conservation Ontario (representing the 36 Conservation Authorities in Ontario), organizes the Ontario Groundwater Geoscience Open House, an annual event typically hosted in-person in southern Ontario with an option for virtual attendance. In 2025, just 2 weeks prior to the scheduled event dates, the Ontario government entered a writ period that required the OGS to withdraw from in-person participation. Fulfilling its commitment to event partners, the OGS published the Abstract Volume (OFR 6414: Burt et al. 2025) and supported event logistics where possible within the writ's constraints. Participant feedback was collected using SurveyMonkey®, and overall satisfaction results were recorded (*see* Table 2.1).

Since 2022, the OGS has hosted an annual Virtual Showcase. This free, online event aims to share OGS geoscience data, products and services with its clients, stakeholders, partners and the public, to facilitate, disseminate and advance geoscience in Ontario. Participants were surveyed on their overall satisfaction with the event, using SurveyMonkey®, and results were recorded (*see* Table 2.1). The OGS hosted the Virtual Showcase again in November 2025 and will continue to monitor and report success metrics from such initiatives.

Table 2.1. Feedback survey results for value-added OGS products and services.

Survey Question	Program Area	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021	2021–2022	2022–2023	2023–2024	2024–2025
How satisfied are you with the analyses and services provided by the Geoscience Laboratories?	OGS GeoServices Section	84%	n/a	83%	97%	99%	100%*	87%*	82%*	85%*	81%*
Please rate your overall satisfaction with the Groundwater Open House.	Groundwater Open House	n/a	94%	93%	99%	100%	93%	92%	95%	95%	98%
Please rate your overall satisfaction with the OGS Virtual Showcase.	OGS Showcase	n/a	n/a	n/a	n/a	n/a	n/a	n/a	95%	95%	95%

n/a = no data available.
** Less than 40 respondents.*

ANNUAL CLIENT SURVEY

Method

The 2024–2025 OGS Client Survey was conducted from April 22 to May 30, 2025. A database of 629 clients was compiled by OGS staff, of which 566 had valid contact information. Invitations were sent electronically to clients with a valid email address, directing them to complete the survey online via SurveyMonkey®. Up to 5 follow-up reminders were issued to non-respondents.

A total of 220 responses were captured, resulting in a 39% response rate. This response was a slight decrease from the 2024 rate (41%) and just below the historical range of 40 to 53%.

Survey Results

Ten questions were asked of 2 major OGS client groups: 1) mineral or other resource exploration and/or development; and 2) land-use planning, groundwater or environmental. These clients were further separated into A) product users and B) service users. It should be noted that this was the seventh year since clients have been divided into these categories (client group and type of user); therefore, the results for client representation may be skewed when compared to years prior to 2019. Also note that clients were able to identify as solely using products, solely using services, or a user of both products and services—this separation began in 2019 as well. Table 2.2 shows the results of questions asked of all clients for each client group. Table 2.3 shows results for questions asked of clients who identified as product users; and Table 2.4, the results for those clients who identified as service users.

Table 2.2. Ontario Geological Survey 2024–2025 client survey questions and summary of results for OGS clients.

Survey Question	Mineral / Resource / Exploration										
	2014–2015	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	**2019–2020**	**2020–2021**	**2021–2022**	**2022–2023**	**2023–2024**	**2024–2025**
What category best describes the majority of work that you conduct?	66%	65%	72%	77%	80%	72%	84%	83%	84%	85%	78%
How would you rate your overall satisfaction with the OGS?	85%	80%	85%	73%	81%	86%	83%	84%	89%	89%	90%

Survey Question	Land-Use Planning / Groundwater / Environmental										
	2014–2015	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	**2019–2020**	**2020–2021**	**2021–2022**	**2022–2023**	**2023–2024**	**2024–2025**
What category best describes the majority of work that you conduct?	34%	35%	28%	23%	20%	28%	16%	17%	16%	15%	22%
How would you rate your overall satisfaction with the OGS?	95%	94%	93%	96%	90%	96%	86%	95%	91%	91%	85%

SUCCESSES WITH PRODUCTS AND SERVICES

The OGS also measures the success of its products and services by monitoring exploration companies working in Ontario that reference OGS data to make an informed decision. Between September 2024 and August 2025, the OGS recorded 41 mineral sector activities where OGS data had an impact and/or was referenced. Recent significant successes are described as follows.

1. VR Resources Ltd. advanced multiple exploration projects in northwestern Ontario over the past year, citing OGS products and services as critical drivers. In September 2024, the company announced the acquisition and expansion of the Empire nickel-copper-platinum group elements (PGE) property (7512 hectares total) as a result of a property examination (Westwood) published in the 2023 Thunder Bay South Report of Activities (Campbell et al. 2024). The company credited the initial mineralization discovery to work following up on anomalous palladium results from an OGS lake sediment sampling program (Dyer 2002). That same month, VR Resources acquired the Silverback copper-silver-gold property in northwestern Ontario (4442 hectares total) referencing a property examination published in the 2022 Thunder Bay South Report of Activities (Campbell et al. 2023). The company initiated a drilling program and highlighted local OGS geological mapping, lake sediment sampling (Allan 2001), and a 1980s geophysical survey (Ontario Geological Survey 1980) as critical inputs.

   (VR Resources Ltd., news releases, September 12, September 24, October 22, and October 24, 2024, www.vrr.ca/news)

Table 2.3. Ontario Geological Survey 2023–2024 client survey questions and summary of results for OGS product users.

Survey Question	Mineral / Resource / Exploration										
	2014–2015	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	**2019–2020**	**2020–2021**	**2021–2022**	**2022–2023**	**2023–2024**	**2024–2025**
Percentage of clients who used OGS products within the past 12 months	90%	94%	90%	89%	94%	92%	84%	93%	92%	90%	92%
Overall satisfaction with the quality of OGS products	n/a	n/a	88%	79%	80%	85%	86%	90%	92%	88%	92%
Percentage of clients who used OGS products to make a decision	69%	80%	68%	54%	57%	50%	62%	63%	57%	69%	63% [1]
Did OGS products allow clients to focus their efforts on areas of higher potential and/or interest?	74%	76%	73%	50%	62%	77%	76%	74%	70%	72%	86% [2]
Did OGS products reduce the time and cost to advance to the next stage of exploration or decision making?	61%	65%	50%	38%	32%	33%	32%	38%	42%	41%	35% [2]
Did the use of OGS products improve clients' exploration models or strategies?	80%	76%	55%	46%	40%	46%	51%	54%	47%	57%	65% [3]
Did the use of OGS products reduce clients' decision risks?	74%	65%	60%	39%	28%	34%	36%	33%	38%	40%	40% [3]
Did the use of OGS products provide evidence of the presence or absence of critical features, target deposit type or topic of interest?	72%	57%	59%	41%	43%	48%	46%	51%	50%	44%	49% [3]

Survey Question	Land-Use Planning / Groundwater / Environmental										
	2014–2015	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	**2019–2020**	**2020–2021**	**2021–2022**	**2022–2023**	**2023–2024**	**2024–2025**
Percentage of clients who used OGS products within the past 12 months	85%	94%	91%	89%	90%	89%	86%	93%	90%	89%	91%
Overall satisfaction with the quality of OGS products	n/a	n/a	91%	97%	89%	95%	94%	88%	97%	97%	92%
Percentage of clients who used OGS products to make a decision	90%	91%	78%	77%	77%	71%	74%	83%	76%	73%	80% [1]
Did OGS products allow clients to focus their efforts on areas of higher potential and/or interest?	83%	58%	83%	57%	64%	66%	63%	71%	79%	83%	76% [2]
Did OGS products reduce the time and cost to advance to the next stage of exploration or decision making?	83%	58%	56%	60%	55%	54%	66%	58%	59%	66%	61% [2]
Did the use of OGS products improve clients' exploration models or strategies?	80%	58%	50%	69%	64%	86%	77%	71%	59%	70%	66% [3]
Did the use of OGS products reduce clients' decision risks?	78%	36%	50%	60%	34%	36%	42%	37%	59%	52%	47% [3]
Did the use of OGS products provide evidence of the presence or absence of critical features, target deposit type or topic of interest?	83%	53%	64%	74%	45%	52%	45%	53%	48%	33%	59% [3]

[1] An open-ended question asking respondents if there was a specific reason why they did not use OGS products to make a decision. Mineral/resource/exploration clients: 13% had no specific reason why; 38% said the information was used for other purposes than decision-making (i.e., academic, educational, etc.). Land-use/groundwater/environmental clients: 43% said the information was used for other purposes than decision-making; 14% had no specific reason why.

[2] Option for respondents to select "Other" where they could provide further comments on how products increased the efficiency of their decision-making: 18% of mineral/resource/exploration clients and 6% of land-use clients responded.

[3] Option for respondents to select "Other" where they could provide further comments on how products increased the effectiveness of their decision-making: 20% of mineral/resource/exploration clients and 9% of land-use clients responded.

n/a = no data available.

Table 2.4. Ontario Geological Survey 2023–2024 client survey questions and summary of results for OGS service users.

Survey Question	Mineral / Resource / Exploration										
	2014–2015	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	**2019–2020**	**2020–2021**	**2021–2022**	**2022–2023**	**2023–2024**	**2024–2025**
Percentage of clients who used OGS services within the past 12 months	n/a	n/a	96%	85%	53%	54%	42%	44%	52%	53%	63%
Overall satisfaction with the quality of OGS services	n/a	n/a	91%	82%	84%	81%	80%	85%	91%	89%	89%
Percentage of clients who used OGS services to make a decision	69%	80%	68%	54%	48%	32%	35%	46%	47%	54%	64% [4]
Did OGS services allow clients to focus their efforts on areas of potential and/or interest?	74%	76%	73%	50%	50%	75%	76%	71%	67%	58%	78% [5]
Did OGS services reduce the time and cost to advance to the next stage of exploration or decision making?	61%	65%	50%	38%	32%	34%	33%	39%	32%	39%	33% [5]
Did the use of OGS services improve clients' exploration models or strategies?	80%	76%	55%	46%	46%	56%	53%	53%	50%	55%	67% [6]
Did the use of OGS services reduce clients' decision risks?	74%	65%	60%	39%	25%	32%	32%	40%	32%	30%	43% [6]
Did the use of OGS services provide evidence of the presence or absence of critical features, target deposit type or topic of interest?	72%	57%	59%	41%	37%	50%	41%	38%	37%	32%	39% [6]

Survey Question	Land-Use Planning / Groundwater / Environmental										
	2014–2015	**2015–2016**	**2016–2017**	**2017–2018**	**2018–2019**	**2019–2020**	**2020–2021**	**2021–2022**	**2022–2023**	**2023–2024**	**2024–2025***
Percentage of clients who used OGS services within the past 12 months	n/a	n/a	100%	97%	75%	68%	48%	39%	52%	59%	43%
Overall satisfaction with the quality of OGS services	n/a	n/a	91%	97%	87%	100%	89%	100%	89%	95%	84%
Percentage of clients who used OGS services to make a decision	90%	91%	78%	77%	77%	74%	47%	86%	69%	48%	75% [4]
Did OGS services allow clients to focus their efforts on areas of potential and/or interest?	83%	58%	83%	57%	67%	90%	58%	73%	58%	60%	75% [5]
Did OGS services reduce the time and cost to advance to the next stage of exploration or decision making?	83%	58%	56%	60%	56%	52%	75%	60%	53%	50%	31% [5]
Did the use of OGS services improve clients' exploration models or strategies?	80%	58%	50%	69%	59%	83%	75%	71%	58%	58%	71% [6]
Did the use of OGS services reduce clients' decision risks?	78%	36%	50%	60%	23%	40%	44%	29%	53%	32%	18% [6]
Did the use of OGS services provide evidence of the presence or absence of critical features, target deposit type or topic of interest?	83%	53%	64%	74%	44%	50%	56%	43%	26%	16%	35% [6]

** Less than 40 respondents. n/a = no data available.*

[4] An open-ended question asking respondents if there was a specific reason why they did not use OGS services to make a decision. Mineral/resource/exploration clients: 36% said that the information was used for other purposes than decision-making (i.e., academic, educational, etc.); 13% had no specific reason why. Land-use/groundwater/environmental clients: 67% said that the information was used for other purposes than decision-making.

[5] Option for respondents to select "Other" where they could provide further comments on how services increased the efficiency of their decision-making: 24% of mineral/resource/exploration clients and 6% of land-use clients responded.

[6] Option for respondents to select "Other" where they could provide further comments on how services increased the effectiveness of their decision-making: 26% of mineral/resource/exploration clients and 12% of land-use clients responded.

2. In September 2024, Focus Xplore PLC (formerly Katoro Gold PLC) staked the White Pine uranium project in northwestern Ontario, covering 8036 hectares, and began reconnaissance field work in November 2024. The company cited highly anomalous uranium values identified in OGS lake sediment geochemistry data sets (Jackson 2003; Russell 2004; Felix 2005) as a key support for this decision. CEO Patrick Cullen stated in the news release: "We have compiled various spatial data available on the Ontario GeoHub and lake sediment sampling data and airborne survey reports sourced via the Ontario Geological Survey. These sources provide substantial value."
   (Focus Xplore PLC, news releases, September 9 and November 19, 2024, www.focusxplore.com/investors/regulatory-news; and YouTube video, September 9, 2024, www.youtube.com/watch?v=bhJUWeTV2WU [timestamp: 7:30])

3. In May and July 2025, Winshear Gold Corp. optioned the Thunder Bay gold project (covering 360 km^2 northeast of Thunder Bay), citing Open File Report 5719 (Scott 1990) for showing evidence of gold potential in the area. By September 2025, the company released results from regional-scale geochemical prospecting, identifying promising anomalies and target areas for follow-up work.
   (Winshear Gold Corp., news releases, May 22, July 25, and September 22, 2025, https://winshear.com/news)

4. In July 2025, Highland Critical Minerals Corp. announced an option agreement to acquire 2 properties totalling ~6456 hectares in the Red Lake greenstone belt. The company highlighted an article published in the OGS *RGP Recommendations for Exploration 2020–2021* (Lewis 2021) as part of the rationale for acquisition.
   (Highland Critical Minerals Corp., news release, July 11, 2025, https://highlandcritical.com/press-release)

5. In August 2025, Critical One Energy Inc. announced the expansion of its Howells Lake property by 67%, acquiring 9979 hectares of new claims for a total project size of 24,887 hectares. The company cited antimony and gold anomalies identified in lake sediment samples originally delineated by the OGS (Ontario Geological Survey 2001) as the driver for this expansion.
   (Critical One Energy Inc., news release, August 28, 2025, www.criticaloneenergy.com/news)

For more information: mineral exploration activity across the province is monitored by the Resident Geologist Program, with monthly updates provided through the GeologyOntario "Exploration Activity" layer. Annual exploration activity summaries are also published for each Resident Geologist District in the RGP's annual *Report of Activities* (www.geologyontario.mndm.gov.on.ca/report_of_activities_en.html).

SUCCESSES WITH INDIGENOUS COMMUNITIES

The OGS measures its success with Indigenous communities through qualitative data collection (e.g., collaborations, blessings, testimonials). Between October 2024 and September 2025, the OGS collaborated with multiple Indigenous communities, delivering 8 presentations to communities, conducting a total of 3 days of field mapping with local community members, and was invited to host a booth and/or participate in 11 major community events. The following successes were documented (for a full summary about OGS community engagement activities in 2024–2025, *see also* Levesque, this volume, Article 3).

1. Temagami First Nation highlighted a successful collaboration with the OGS in the September 2024 issue of their *B.I. Blast* newsletter, featuring a field mapping and knowledge-sharing day held on August 8, 2024, as part of OGS Temagami Bedrock Mapping Project (*see also* MacDonald, this volume, Article 5). Precambrian Geoscientist Peter MacDonald guided staff from the community's Lands and Resources Department on a field tour to explore the local bedrock geology. The newsletter described the initiative as a collaborative effort that "underscores the importance of combining modern scientific methods with local knowledge," and noted that the insights gained "will contribute to a deeper understanding of n'Daki Menan's [the Temagami region's] geology, helping to guide future conservation efforts and potential resource management in a way that honours both the land and its cultural significance". This initiative exemplifies the impact of meaningful engagement and collaboration.
   (Temagami First Nation, B.I. Blast newsletter, September 2024, p.21, www.temagamifirstnation.ca/communications/bi-blast)
2. On May 6 and 7, 2025, Lands and Resources staff from Nipissing First Nation accompanied the OGS Indigenous Geoscience Liaison and Andrea Marich, Quaternary Geoscientist, for 2 days of field mapping (*see also* Marich, this volume, Article 14). The excursions focussed on sharing knowledge about local landforms and the Quaternary geology of the project area, and provided an opportunity to demonstrate OGS field mapping methods and data collection practices.

NEXT STEPS

The OGS will continue to

- collect performance measures data that include baseline values, target values and actual values;
- take steps to address gaps and downward trends and to continually improve products and services;
- communicate the value and relevance of public geoscience information;
- improve the integration of geoscience information into broader government and public decision-making; and
- build strong and successful collaborations and relationships with Indigenous communities.

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3. Activities of the Indigenous Geoscience Liaison in 2024–2025



M.D. Levesque[1]

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INTRODUCTION

The Ontario Geological Survey (OGS) is committed to building meaningful, collaborative and long-term relationships with Indigenous communities for anticipated and ongoing geoscience project areas. One of the current OGS mandates is to "encourage and facilitate Indigenous participation in Ontario's economy in a way that recognizes and is respectful of Indigenous rights and culture" and our work within Indigenous communities aims to meet and exceed this mandate. Since 2016, the OGS Indigenous Geoscience Liaisons (IGL) have been focussed on engaging, building and maintaining strong, respectful relationships with First Nations and Métis communities across Ontario that have measurable and realistic outcomes. One of the key responsibilities of the IGL position is to engage with our treaty partners in co-development, co-design, and implementation of geoscience projects and to discuss application and potential impacts of OGS geoscience project work and results. Additionally, we function as pivotal liaisons, hearing the directions and priorities of First Nations and Métis communities and translating those priorities to ministry employees to ensure projects and participation is developed and facilitated in a way that is appropriate to each individual community. The 2025 field season resulted in the notification of 14 OGS projects. As a result of these projects, over 50 individual Indigenous communities were notified. The following article will outline some of these key interactions.

INDIGENOUS ENGAGEMENT BY THE INDIGENOUS GEOSCIENCE LIAISON

Table 3.1. Indigenous Community engagements by the OGS Indigenous Geoscience Liaison. Listed by date of visits.

Community	Visits(s)	Description
Temagami First Nation	September 2024	As a result of previous events, Temagami First Nation published an article in their community newsletter "B.I. Blast" focussed on OGS mapping project in the area. For more details, *see* Kalmo (this volume, Article 2).
Grand Council Treaty #3	October 17, 2024	Meeting in Kenora where RGP presented advanced mineral exploration projects in their region.
Rainbow District School Board	October 22, 2024	Yearly IGL presentation introducing Ontario Indigenous Woodland Art to grade 5 and 6 art class. *See* "Woodland Art Presentations".
Interim Field Activity Letters	November 2024	Yearly report-back letter to provide mapping project information and pictures from the field season. Addressed individually to over 50 Indigenous communities. *See* "Informal Notifications and Virtual Presentations".

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.3-1 to 3-4.

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Community	Visits(s)	Description
North Spirit Lake First Nation	November 6, 2024	In-community OGS booth set up with rock displays to provide information about the geology in their area.
Anishinabek Nation	November 20, 2024	Anishinabek Nation GIS day. IGL and RGP presented an in-person tutorial how to access and use OGS data.
Laurentian University	December 5, 2024	IGL presented at Laurentian University's "Walking Together" Indigenous conference. Presentation focussed on OGS Indigenous engagement.
Anishinabek Nation Joint Advisory Committee	December 10, 2024	Roundtable meeting to provide OGS updates and maintain positive relationships. IGL focus on listening to and gaining a greater understanding of the participating Indigenous communities' priorities and directions.
Anishinabek Nation Southeast and Southwest Regional Roundtable	December 11, 2024	In-person regional roundtable meeting to provide OGS updates and maintain positive relationships. IGL and RGP presented and showcased rock displays geology from the region.
Anishinabek Nation Northern Superior Roundtable	January 15, 2025	Regional roundtable meeting to provide OGS updates and maintain positive relationships. IGL focus on listening to and gaining a greater understanding of the participating Indigenous communities' priorities and directions.
Mineral Development Advisor Training	February 4, 2025	IGL and RGP presented virtually on topics such as "Mineral in our Lives" and traditional uses of minerals.
Informal and formal notification letters for proposed mapping projects	March 2025	Informal and formal notifications were sent for 15 Earth Resources and Geoscience Mapping Section (ERGMS) mapping projects. OGS contacted over 50 Indigenous communities notifying them of proposed projects in their traditional land use area and offering a presentation. IGL presented to many individual Indigenous communities sharing information about ERGMS mapping projects in their traditional land use area along with informal conversations. *See* "Informal Notifications and Virtual Presentations".
Keewaytinook Okimakanak Tribal Council	March 17, 2025	IGL and RGP attended Keewaytinook Okimakanak Treaties, Lands and Resources Summit. OGS booth with rock display, presentations about our careers and how we can help communities.
Keewaytinook Okimakanak Tribal Council	March 27, 2025	As a follow up to Keewaytinook Okimakanak Treaties, Lands and Resources Summit, IGL was invited to Keewaytinook Okimakanak Tapiola outdoor education centre to tour the facilities and talk about ways OGS can support future geology programming.
Temagami First Nation	April 7, 2025	Meeting with Mineral Development Advisor to discuss future groundwater and lake sediment mapping in the region. ERGMS also in attendance.
Lac des Mille Lacs First Nation	April 7, 2025	Mapping presentation: virtual meeting with Lands and Resources staff to discuss ERGMS mapping project in the area. Will co-ordinate next field season to arrange for Lac des Mille Lacs staff to participate during mapping in their region.
Missanabie Cree First Nation	April 23, 2025	Mapping presentation: virtual meeting with Lands and Resources staff to discuss ERGMS geophysical mapping project in the area. Initial meeting to gain and maintain social licence for the project. We were requested and developed a geophysical mapping notification for their community newsletter.
Andy Fyon Event	May 30, 2025	Event for OGS staff to learn about a retired OGS Director, Andy Fyon's new book "Walking Together" which focusses on Indigenous engagement. *See* "Walking Together Event".
Nipissing First Nation	May 6–7, 2025	IGL and ERGMS mapper spent a few days mapping with Nipissing First Nation Lands and Resources staff. Able to gain insight and access areas we could not have otherwise. For more details, *see* Kalmo (this volume, Article 2).
Sagamok First Nation	May 8, 2025	IGL and RGP attended in-person Sagamok First Nation education fair. Booth display focussed on youth. This event led to future invites.

Community	Visits(s)	Description
PDAC Student–Industry Mineral Exploration Workshop (S-IMEW) presentation	May 12, 2025	In-person presentation on how OGS approaches Indigenous Engagement. Follow-up request to have IGL present in person rather than virtual pre-recorded presentation the previous year.
Chapleau Cree First Nation	May 22, 2025	Virtual meeting with Lands and Resources staff to discuss lake sediment sampling locations. ERGMS also in attendance.
Sagamok First Nation	May 22, 2025	RGP booth set up for Sagamok First Nation Career fair. Booth and materials modified to focus on careers in geology.
Atikameksheng Anishnawbek	June 10, 2025	RGP booth set up for in-community Atikameksheng Anishnawbek Job Fair.
Matachewan First Nation	June 18, 2025	In-community Mine Expo. Follow-up invite from last year's youth event. Booth set up with geoscience activities for youth, "Minerals in our Lives", local rock display and handouts.
Métis Nation of Ontario	June 19, 2025	RGP led in-person field trip in the Sudbury area for Métis Nation of Ontario staff.
Mattagami First Nation	June 26, 2025	Virtual meeting to discuss future mapping locations in the region and areas of sensitivity. Planning to bring Lands and Resources staff out for a day of mapping next field season.
Sagamok First Nation	July 3, 2025	RGP led in-community field trip to discuss radon and show staff soil sampling techniques.
Beausoleil First Nation	July 14, 2025	OGS staff were invited to continue collaborating with the Water First organization on a summer school program that provides youth living on reserve with the opportunity to complete a high school credit on reserve during the summer. RGP staff attended the event and provided a day-long session on geology, with a focus on their region. The day included both in class and outdoor activities.
Beaverhouse First Nation	August 13, 2025	IGL and RGP attended in-person Beaverhouse First Nation Family Gathering. Set up booth with rock displays and geoscience activities for youth.
Weenusk First Nation	August 26–27, 2025	Set up OGS booth with "Minerals in our Lives" display and other geology resources and handouts.
Grand Council Treaty #3	September 9, 2025	Attended bi-lateral meeting to offer OGS support for prospector training and discussing OGS mapping projects in their region.

***Abbreviations**: ERGMS, OGS Earth Resources and Geoscience Mapping Section; IGL, OGS Indigenous Geoscience Liaison; OGS, Ontario Geological Survey; PDAC, Prospectors and Developers Association of Canada; RGP, OGS Resident Geologist Program.*

MONTHLY INDIGENOUS LEARNING ACTIVITIES

During monthly OGS section staff meetings, the IGL has been presenting Indigenous learning activities. Presentations have covered topics such as

- Introductions to Indigenous Groups Across Ontario
- Social Licence Updates
- OGS Activity Updates
- Cultural Events

These short presentations and activities help introduce staff to various Indigenous topics and aim to promote awareness of different cultures and increase inclusivity. These 15-minute monthly presentations are enjoyed by staff, and IGLs often receive positive feedback and follow-up conversations on each

respective topic. During each session, staff are encouraged to do their own follow-up research, contact the IGL for more information and resources and participate in one of the learning activities if they have something to contribute. These activities are set to continue in the fall and winter of 2025–2026 with input from staff on topics they are interested in learning more about.

WOODLAND ART PRESENTATIONS

Throughout the year, the IGL has given presentations on Indigenous woodland art. This year, presentations have been given internally to staff and to the Rainbow District School Board as a yearly event. The presentation is focussed on introducing woodland art and demonstrating the multiple ways of interpreting the art using paintings from the IGL personal collection. The Rainbow District School Board students requested a second presentation this year to learn about an Indigenous Legend that can only be told during the winter, when the lakes are frozen. Woodland art is used as an avenue to share Indigenous history and customs and explain why the IGL role is essential to the organization.

INFORMAL NOTIFICATIONS AND VIRTUAL PRESENTATIONS

For the 2025 field season, the IGL continued with our process of "informal notifications" for communities with geological mapping projects occurring on their traditional land use area. These informal notifications are personalized emails to community contacts, and provide communities advance notice of projects, with opportunities for them to provide input, ask questions or request specific information about projects before field work for the OGS projects start. This initiative continued to be highly successful in that the IGL received many requests for presentations, opportunities to participate in field trips, extensions of mapping areas, and collaborations. Many of the meetings from this year and last year led to invitations to community events, as highlighted in Table 3.1. The IGL also started sending yearly interim field activity update letters to over 50 individual Indigenous communities in our mapping project areas to keep them up to date between notifications and offer further support.

The IGL worked very closely with ERGMS staff to develop the presentations about their projects, to design and deliver imaginative and targeted field trips, to extend project boundaries, and to plan collaborations. The ERGMS staff brought their knowledge and passion about geology across Ontario, and the IGL helped ensure that staff knowledge and passion were targeted, relevant and relatable. Our efforts over the past years have led to incredible achievements in relationship building with Indigenous communities across Ontario. These strengthening relationships are evidenced through the requests for participation in field trips, project extensions, community visits and reserve mapping. We all worked very hard on tight timelines to make the entire process successful and send our thanks to all staff members for adeptly incorporating and growing this process while juggling other competing tasks!

WALKING TOGETHER EVENT

In May 2025, the OGS organized a virtual event for all OGS staff. Retired OGS Director Andy Fyon shared Indigenous Engagement stories from his new book "*Walking Together: Engagement Lessons from My First Nations Learning Journey*". Andy shared stories from the book and answered many questions during the question and answer portion. Hearing a retired OGS Director speak of the importance of Indigenous Engagement in our geoscience work really resonated with our staff. For a retired OGS Director to be dedicating his retirement to this journey highlights the importance of this journey that we are all taking together.

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Earth Resources and Geoscience Mapping Section

4. Earth Resources and Geoscience Mapping Section: 2025–2026 Program and Projects Overview



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GOAL AND RESPONSIBILITY OF THE SECTION

The goal of the Ontario Geological Survey's (OGS) Earth Resources and Geoscience Mapping Section (ERGMS) is to improve the understanding of the geology, geochemistry and Earth resources of the province and to convey this knowledge to the public through multi-year, multi-disciplinary geoscience projects that address key geoscience problems. These studies may be delivered as part of the ERGMS geoscience mapping function or through collaborative geoscience projects or initiatives.

The ERGMS is responsible for

- mapping Ontario's Precambrian and Phanerozoic bedrock geology and assessing its inherent resources at a regional scale;
- mapping and sampling of Quaternary sediments for the purpose of mineral resource assessment, land-use planning, aggregate delineation, geotechnical applications, etc.;
- three-dimensional (3-D) mapping of Quaternary and Phanerozoic hydrostratigraphic units and their contained groundwater resources at a regional scale; and determining the relationship between aquifer composition and regional groundwater geochemistry;
- collecting regional ground and airborne geophysical data and producing derivative products in support of bedrock geology and groundwater mapping projects, mineral exploration and land-use planning;
- collecting regional surficial geochemistry data from water and other surficial media (e.g., lake and stream sediments, peat, etc.) to support mineral exploration, mapping of bedrock and sediments, land-use planning, assessment of watershed quality and the establishment of natural baseline databases;
- mapping aggregate and industrial minerals to provide up-to-date inventories and quality assessments of potential aggregate and industrial mineral resources; and
- mapping bedrock that hosts traditional and unconventional non-renewable energy resources to identify new energy sources and opportunities for carbon storage.

The program direction and strategies of the ERGMS address the strategic objectives and core business of the Ontario Geological Survey Branch, which, in turn, are linked to those of the Mining Policy and Sector Development Division of the Ministry of Energy and Mines. Ministry and Government priorities are achieved through specific ERGMS strategies and initiatives that consist of one or more projects. Staff of the OGS conducts an annual, project planning exercise, including project proposals

Summary of Field Work and Other Activities, 2025,
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development, evaluation and selection. This project planning exercise is designed to achieve alignment of individual projects with higher level Divisional, Ministry and Government priorities. This article reports on the current activities of the ERGMS.

The ERGMS supported 87 active projects during the 2025–2026 fiscal year, which includes 71 active core projects and 16 active collaborative projects (Table 4.1). The collaborative projects include 3 projects with other provincial ministries; 1 project in collaboration with the Mineral Exploration Research Centre (MERC) at Laurentian University, Metal Earth and the Royal Ontario Museum (ROM); 1 project in collaboration with the Geological Survey of Canada (GSC) and Queen's University; and 11 graduate thesis projects with universities. Locations of projects for which there are corresponding articles in this volume are depicted in Figure 4.1.

From December 1, 2024 to December 1, 2025, inclusive, ERGMS produced 3 Open File Reports, updates to geodatabases for 4 previously published Preliminary Maps, 1 Miscellaneous Release—Data, 1 Geophysical Data Set (GDS), 1 ground gravity geophysical survey map and 18 presentations as part of OGS Virtual Showcase 2024 (11 of which were available online in video format through GeologyOntario for a limited time in 2025) (*see* "List of Publications" in this article for a complete listing of these publications). The ERGMS has several online databases, including the Aggregate Resources of Ontario (ARO) compilation, the Lake Geochemistry of Ontario (LakeGeochemON) compilation, and the Geochronology Inventory of Ontario (GeochrON), which are available for download through GeologyOntario and for viewing in the Google Earth™ mapping service by downloading the appropriate *.kml* file through the OGSEarth Web site. The ERGMS staff presented several technical talks and posters at various geoscience forums and meetings, including virtual geoscience meetings, throughout the year.

ERGMS STRATEGIES AND OBJECTIVES

The Earth Resources and Geoscience Mapping Section (ERGMS) strategies and objectives are derived from OGS strategic priorities, which stem from the Mining Policy and Sector Development Division Strategic Framework and Ministry business goals.

The purpose of ERGMS strategies and objectives is to focus staff and resources in key geological areas or geoscience themes, over a period of 3 to 5 years, to contribute to

- expanding the geoscience database of Ontario;
- supporting sustainable development and effective land-use planning;
- providing the geoscience framework for groundwater use and source water protection, public health and safety and the public good; and
- supporting and attracting new mineral investment.

To successfully deliver these strategies, ERGMS is fully engaged in building new and strengthening existing collaborations with Indigenous communities, the private sector, academia, federal agencies and other provincial ministries on initiatives of mutual interest.

The ERGMS main strategies consist of applying geoscience techniques

- to assess Earth resource potential to meet societal and government priorities;
- in areas of environmental priority to identify natural hazards related to geology;
- in areas of aggregate resource priority to meet societal and government priorities; and
- in areas of groundwater priority to meet societal and government priorities.

The ERGMS program is organized into 5 objectives based on the collection, interpretation, synthesis, and distribution and communication of geoscience data and information as follows:

- provide the geological framework to support Earth resource exploration (minerals, metals, groundwater, aggregates, industrial minerals and energy), land-use planning, economic and infrastructure development and provide a geoscience baseline to help assess cumulative impacts of development;
- provide the geologic context to assess energy potential in the south and Far North;
- provide the geologic context to identify and interpret natural hazards to the environment and public health and safety;
- provide the geoscience framework to identify and inventory aggregate and industrial mineral resources for land-use planning, and resource and infrastructure development; and
- provide the geoscience framework to identify and inventory groundwater resources for use, protection and planning.

CORE GEOSCIENCE PROGRAM

The ERGMS strategies and objectives are addressed through its core geoscience program, which consists of a series of initiatives built upon one or more projects (*see* Table 4.1). In addition, the ERGMS participates in several collaborative projects to complement existing staff skills and capacity and to expand the amount of geoscience data available for the province. Collaborative projects are an important means to extend government resources and to capitalize on resources and expertise available in other organizations.

Initiatives

The ERGMS initiatives are based on geographic or functional groupings and are made up of

- team initiatives (i.e., Geology of Northeastern Ontario Initiative) consisting of individual projects that are designed to meet an overall goal; and
- individual, focussed projects.

The major initiatives of the ERGMS are subdivided into 6 broad categories outlined below and in Table 4.1.

➤ Initiatives involving geoscience mapping projects and the identification of Earth resources based on geographic area or geological region (note that all of these initiatives take into account Ontario's Critical Mineral Strategy (Ontario 2022));

- Far North Land Use Planning;
- "Ring of Fire";
- Geology of Northeastern Ontario;
- Geology of Northwestern Ontario;
- Proterozoic initiative;
- Paleozoic initiative;
- Surficial Geochemistry of Northern Ontario;
- Surficial Mapping of Northern Ontario;

- Surficial Geochemistry of Southern Ontario;
- Surficial Mapping of Southern Ontario.

➢ Initiatives involving identification of overburden and bedrock hydrostratigraphic units and contained groundwater resources at a regional scale; and understanding the geochemical effects of surface and groundwater interactions with rock and surficial media:

- two- and three-dimensional surficial sediment groundwater mapping;
- two- and three-dimensional Paleozoic bedrock geology groundwater mapping;
- ambient groundwater geochemistry.

➢ Initiatives involving aggregate and industrial mineral resource compilation and inventory studies:

- documentation and inventory of potential aggregate resources;
- documentation and inventory of potential industrial mineral resources, including those that are considered Critical Minerals (e.g., fluorspar, graphite).

➢ Initiatives involving geophysical projects:

- application of geophysical techniques in support of bedrock geology mapping;
- geophysics and rock properties data compilation;
- application of geophysical techniques in support of surficial sediment mapping.

➢ Initiatives involving provincial-scale mineral resource compilation and inventory studies:

- documentation of specific types of mineralization, including Ontario's Critical Mineral resources;
- developing inventories of various tectonic settings relevant to mineral exploration, with a focus on developing inventories of Ontario's Critical Mineral resources;
- ongoing maintenance of a database of geochronology work conducted in Ontario.

➢ Initiatives that involve collaborative project agreements with the GSC:

- participating in the bedrock and surficial geology working groups as part of the Canada–3D geological map compilation project for Canada.

To successfully develop and deliver on these initiatives, the ERGMS is engaged in numerous activities to develop, maintain and manage client, stakeholder and Indigenous relationships. The ERGMS is dedicated to maintaining relationships and exchanging technical information with partners, clients, stakeholders, regional prospector and land-owner associations and Indigenous communities. The ERGMS is also part of a number of external and internal committees to ensure these relationships are respectful, strong, long lasting and mutually beneficial.

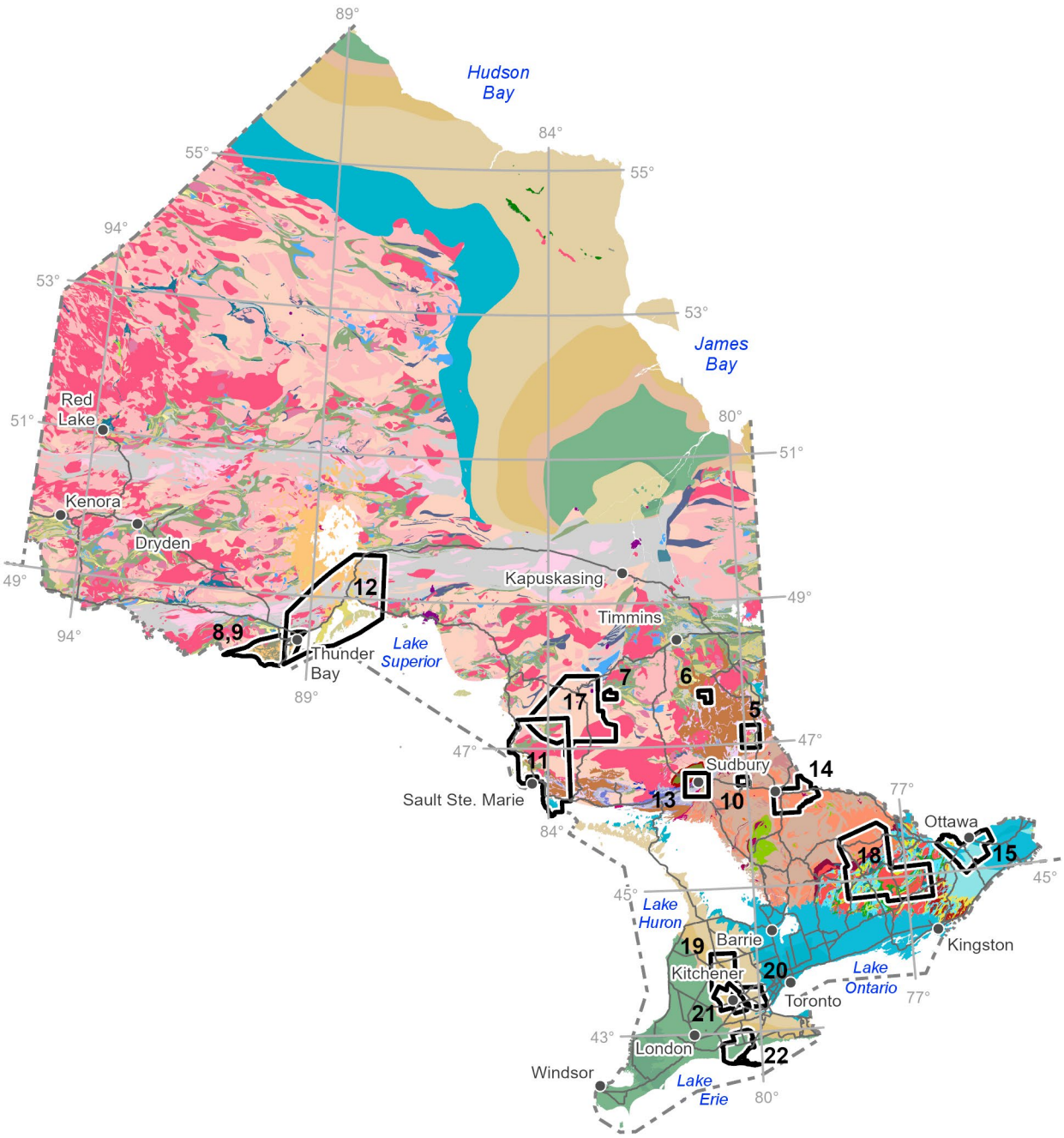


Figure 4.1. Locations of the Earth Resources and Geoscience Mapping Section projects (articles 5 to 8 and 10 to 22) and related research (article 9) in Ontario as described in *Summary of Field Work and Other Activities, 2025*. Numbers correspond to article numbers; note article 11 is provincial in scope, but an area of interest is indicated on the figure. Bedrock geology *from* Ontario Geological Survey (2011).

Table 4.1. Earth Resources and Geoscience Mapping Section collaborative initiatives and projects, 2025–2026.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Geophysical Techniques in Support of Bedrock Geology Mapping Initiative	Airborne magnetic gradiometer and gamma-ray spectrometer survey ▸ Sault Ste. Marie–Montreal River area, northeastern Ontario	ERGMS Core Program	New project – data acquired in June and July 2025; data are currently being processed by contractor
	Ground geophysical survey ▸ Collect gravity data in support of the three-dimensional (3-D) sediment mapping project in the Guelph area	ERGMS Core Program	Completed ▸ *Summary of Field Wor*k article published in 2023 ▸ Geophysical Data Set and map published in 2025
	Magnetic data interpretation ▸ Investigate why parts of the Gowganda Formation, Huronian Supergroup, are magnetic; follow-up to the Sturgeon River aeromagnetic survey	ERGMS Core Program	Ongoing – field work in 2024 and 2023; MRD submitted for publication ▸ *Summary of Field Work* articles published in 2023, 2024
	Airborne gravity and magnetic surveys, Manitouwadge and Hornepayne areas, north-central Ontario ▸ Reprocessing and/or reformatting of donated survey data	ERGMS Core Program (data donated by Nuclear Waste Management Organization)	Completed – Geophysical Data Sets and maps in preparation for publication in 2025
Far North Land Use Planning Initiative	Bedrock geological compilation of the Obabigan–Neawagank lakes area, North Caribou greenstone belt ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – compilation in progress
	Bedrock geological compilation of the Opapimiskan Lake area, North Caribou greenstone belt ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – compilation in progress
	Far North terrain mapping project ▸ Quaternary stratigraphy riverbank mapping along the Attawapiskat River, James Bay Lowland	ERGMS Core Program	Ongoing – field work in 2024 ▸ *Summary of Field Work* article published in 2024
Surficial Geochemistry of Northern Ontario Initiative	Top-to-bottom surficial geochemical characterization of the Great Bear gold deposit, Red Lake	ERGMS Core Program	Ongoing project – field work in 2024 ▸ *Summary of Field Work* article published in 2024
	Lake sediment and water geochemistry program ▸ Batchawana greenstone belt, Chapleau, Montreal River, Mississagi River areas, northeastern Ontario	ERGMS Core Program	Ongoing project – field work in 2025 and 2024 ▸ *Summary of Field Work* article published in 2024) ▸ *Summary of Field Work* (this volume, Article 17)
	Surficial geochemical sampling of the Marathon deposit, northwestern Ontario ▸ Stream sediment and till data from OGS	ERGMS Core Program and collaboration with GSC and Queen's University	Ongoing – field work in 2024 ▸ *Summary of Field Work* article published in 2024

Abbreviations: *GSC, Geological Survey of Canada; MRD, Miscellaneous Release—Data.*

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Surficial Geochemistry of Northern Ontario Initiative, *continued*	Marathon region sediment and water sampling project high-density lake sediment and water geochemistry survey	ERGMS Core Program	Ongoing – MRD in progress
	Till sampling and surficial mapping in the Georgia Lake and Thunder Bay areas, northwestern Ontario	ERGMS Core Program	Ongoing – field work in 2025, 2024 and 2023 ▸ *Summary of Field Work* articles published in 2023, 2024 ▸ *Summary of Field Work* (this volume, Article 12)
	Highway 17 mapping and sampling project	ERGMS Core Program	Ongoing – field work in 2025, 2024, 2023 and 2022 ▸ *Summary of Field Work* articles published in 2022, 2023 (2) ▸ *Summary of Field Work* (this volume, Article 14)
	Surficial geochemistry sampling over the Borden Lake area and Kapuskasing Structural Zone	ERGMS Core Program	Completed – OFR and MRD published in 2025
Proterozoic Initiative	Totten Township bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2024; Preliminary Map, OFR and MRD in progress ▸ *Summary of Field Work* articles published in 2024 (2)
	Hyman Township bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2023 and 2022; Preliminary Map, OFR and MRD in progress ▸ *Summary of Field Work* articles published in 2022, 2023
	Southwest Sudbury Structure bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping of Drury and Denison townships	ERGMS Core Program	Ongoing – Preliminary Map, OFR and MRD for Denison Township in progress ▸ *Summary of Field Work* articles published in 2015, 2016, 2017, 2018 ▸ Preliminary Map, OFR and MRD for Drury Township published in 2018 ▸ Field trip guidebook: Gordon, Généreux and Clarke (2022)
	Geology and mineral potential of the Grenville Front tectonic zone near Sudbury ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2024, 2023, 2022 and 2021; MRD submitted for publication, Preliminary Map in progress ▸ *Summary of Field Work* articles published in 2022, 2023, 2024 ▸ *Summary of Field Work* (this volume, Article 10) ▸ Field trip guidebook: Easton (2022)
	Proterozoic mafic intrusions of the Sudbury area ▸ Compilation and characterization project	ERGMS Core Program	Ongoing – compilation and database construction ▸ *Summary of Field Work* article published in 2021
	Geology and mineral potential of Scarfe, Cobden, Thomson and Patton townships, Blind River area ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work completed; Preliminary Map and MRD in progress ▸ *Summary of Field Work* articles published in 2019, 2022

Abbreviations: *MRD, Miscellaneous Release—Data; OFR, Open File Report.*

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Proterozoic Initiative, *continued*	Compilation and reconnaissance bedrock geology mapping of the Animikie Basin and Midcontinent Rift southeast of Thunder Bay ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2025, 2024, 2023 and 2022 ▸ *Summary of Field Work* article published in 2022 ▸ *Summary of Field Work* (this volume, Article 8)
	Geology of the Brudenell area, Grenville Province ▸ Multi-year 1:50 000 bedrock geology and compilation mapping project	ERGMS Core Program	Ongoing – field work completed; MRD submitted for publication ▸ *Summary of Field Work* articles published in 2011, 2012, 2013 (2), 2016 ▸ OFR published in 2017
	Geology of Carleton Place area, Grenville Province ▸ Multi-year 1:50 000 scale bedrock geology and compilation mapping	ERGMS Core Program	Ongoing – field work completed; MRD submitted for publication ▸ *Summary of Field Work* articles published in 2012, 2017, 2018, 2019
Geology of Northeastern Ontario Initiative	Timmins and Kirkland Lake geological mapping project, Abitibi greenstone belt ▸ Multi-year 1:50 000 scale bedrock geology and compilation mapping project	ERGMS Core Program	Ongoing – field work in 2025 and 2024 ▸ *Summary of Field Work* article published in 2024
	Southern Swayze area (Abitibi greenstone belt) bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in Greenlaw Township in 2025 ▸ Preliminary Maps and MRDs published in 2017, 2018, 2019, 2020 ▸ *Summary of Field Work* articles published in 2015, 2016, 2017, 2018, 2019, 2022, 2023 ▸ *Summary of Field Work* (this volume, Article 7)
	Swayze area (Abitibi greenstone belt) metavolcanic evolution study ▸ Regional and detailed bedrock geology mapping and detailed geochemistry and volcanology	ERGMS Core Program PhD thesis (T.P. Gemmell) Laurentian University–MERC (Metal Earth)	Ongoing – field work completed in 2021; analyses in progress ▸ *Summary of Field Work* articles published in 2017, 2021
	Northern Swayze area (Abitibi greenstone belt) bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping and 1:50 000 scale bedrock compilation	ERGMS Core Program	Ongoing – field work completed; OFR in progress, compilation map submitted for publication ▸ *Summary of Field Work* articles published in 2018, 2019 ▸ Preliminary Maps and MRDs published in 2020, 2021
	Northeast Michipicoten greenstone belt bedrock geology mapping ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in Riggs and Glasgow townships in 2024 and 2023 ▸ Updated databases for previously released P.Maps P.3787, P.3797, P.3803 and P.3814 released in 2025 ▸ *Summary of Field Work* articles published in 2016, 2017, 2018, 2019, 2021, 2022, 2023, 2024

Abbreviations: *MERC, Mineral Exploration Research Centre; MRD, Miscellaneous Release—Data; OFR, Open File Report; P.Map, Preliminary Map.*

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Geology of Northeastern Ontario Initiative, *continued*	Northeastern Michipicoten greenstone belt geochronological and structural study	ERGMS Core Program PhD thesis (L.E.D. Vice) Laurentian University–MERC (Metal Earth)	Ongoing – field work in 2024, 2023 and 2022 ▸ *Summary of Field Work* articles published in 2022, 2024
	Temagami greenstone belt bedrock mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2025, 2024 and 2023 ▸ *Summary of Field Work* articles published in 2019, 2021, 2023, 2024 ▸ *Summary of Field Work* (this volume, Article 5)
	Bedrock geology mapping of Van Hise, Haultain and Nicol townships, Abitibi greenstone belt ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2025, 2024 and 2023 ▸ *Summary of Field Work* article published in 2023 ▸ *Summary of Field Work* (this volume, Article 6)
	Bedrock geology and compilation of the Ramsey–Algoma intrusive complex and surrounding rocks ▸ Multi-year bedrock geology mapping and compilation at 1:100 000 scale	ERGMS Core Program	Ongoing – field work in 2023, reconnaissance work in 2019 ▸ *Summary of Field Work* articles published in 2019, 2020, 2023
Geology of Northwestern Ontario Initiative	Bedrock geology mapping of Marks and Conmee townships ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work completed; Preliminary Map and MRD in progress ▸ *Summary of Field Work* articles published in 2017, 2018
	Bedrock geology mapping of the Straw Lake–Esox Lake area, Rowan–Kakagi greenstone belt ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2022 ▸ *Summary of Field Work* article published in 2022
	Rowan–Kakagi lakes area bedrock geology mapping ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work completed ▸ *Summary of Field Work* articles published in 2016, 2017
	Geological compilation of the Red Lake greenstone belt, Uchi Subprovince	ERGMS Core Program	Ongoing – field work in 2023 and 2022; compilation in progress ▸ Summary *of Field Work* articles published in 2021, 2023
	Bedrock geology mapping and rare-element potential in the central Quetico Subprovince, Georgia Lake area ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2023 and 2019; Preliminary Map and MRD in progress ▸ *Summary of Field Work* articles published in 2019, 2020, 2023 (2)
	Bedrock geology mapping of the Quetico Subprovince and related Proterozoic rocks ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2025, 2024, 2023 and 2022; Preliminary Map and MRD for southern part in progress ▸ *Summary of Field Work* articles published in 2019, 2020, 2021, 2022, 2023, 2024
	Petrology and geochemistry of mafic to ultramafic rocks of the Nakina area, English River Subprovince	MSc thesis (S. Killins) Lakehead University	Ongoing – sampling in fall 2020

Abbreviations: *MERC, Mineral Exploration Research Centre; MRD, Miscellaneous Release—Data.*

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
2-D and 3-D Surficial Sediment Groundwater Mapping Initiative	Three-dimensional (3-D) mapping of Quaternary deposits in the Mount Forest–Elmira area	ERGMS Core Program	New project – drilling in 2025 ▸ *Summary of Field Work* (this volume, Article 19)
	Three-dimensional (3-D) mapping of Quaternary geology in the Guelph area ▸ Multi-year project to generate geologic model for groundwater assessment; Quaternary mapping and drilling	ERGMS Core Program	Ongoing – drilling in 2025; field work in 2025, 2024, 2022 ▸ *Summary of Field Work* article published in 2022, 2023, 2024 ▸ *Summary of Field Work* (this volume, Article 20) ▸ OGS geophysical survey conducted in 2023, GDS and Map published in 2025
	Three-dimensional (3-D) mapping of Quaternary geology in central Simcoe County ▸ Multi-year project to generate geologic model for groundwater assessment; Quaternary mapping and drilling	ERGMS Core Program PhD thesis (R.P.M. Mulligan) McMaster University	Ongoing – drilling in 2018, 2017, 2016 and 2015 ▸ Preliminary Maps published in 2017; other Preliminary Maps, MRD and GRS in progress ▸ PhD completed in 2019; 4 external papers published; 2 external papers in progress ▸ *Summary of Field Work* articles published in 2016, 2017, 2018, 2019
	Three-dimensional (3-D) mapping of Quaternary deposits in the Niagara Peninsula ▸ Multi-year project to generate geologic model for groundwater assessment; Quaternary mapping and drilling	ERGMS Core Program	Ongoing – field work completed; GRS in progress ▸ *Summary of Field Work* articles published in 2013, 2014, 2015 (2), 2016, 2017 ▸ MRDs published in 2017, 2020 ▸ Geophysical survey with GSC (published in 2019)
	Lower Grand River Hydrogeological Characterization ▸ GSC Collaborative Study	ERGMS Core Program in collaboration with GSC	New project – field work in 2025
	Region of Waterloo core logging	ERGMS Core Program	New project – logging of donated core in 2025 ▸ *Summary of Field Work* (this volume, Article 21)
	Norfolk County core logging	ERGMS Core Program	New project – logging of donated core in 2025 ▸ *Summary of Field Work* (this volume, Article 22)
	Regional groundwater systems mapping in the County of Simcoe, southern Ontario	ERGMS Core Program	Ongoing – groundwater sampling in 2019 and 2018 ▸ *Summary of Field Work* articles published in 2018, 2019
	Surficial and subsurface sediment mapping in the City of Ottawa, eastern Ontario	ERGMS Core Program	Ongoing – field work in 2025 ▸ *Summary of Field Work* articles published in 2019, 2022 ▸ *Summary of Field Work* (this volume, Article 15)

Abbreviations: *GDS, Geophysical Data Set; GSC, Geological Survey of Canada; GRS, Groundwater Resources Study; MRD, Miscellaneous Release—Data.*

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Aggregate Resources Initiative	District of North Bay Aggregate Resources Inventory	ERGMS Core Program	Ongoing – field work in 2024 and 2023 ▸ *Summary of Field Work* articles published in 2023, 2024
	Renfrew County Aggregate Resources Inventory	ERGMS Core Program	Ongoing – sand and gravel and selected bedrock areas mapping have been published in the ARO online database ▸ ARIP in progress
	Elgin County Aggregate Resources Inventory	ERGMS Core Program	Ongoing – field work completed ▸ ARIP in progress
	Regional Municipality of Niagara Aggregate Resources Inventory	ERGMS Core Program	Ongoing – field work completed ▸ ARIP in progress
	Haldimand County Aggregate Resources Inventory	ERGMS Core Program	Ongoing – field work completed in 2019 ▸ *Summary of Field Work* article published in 2019
	Identification and mapping of alkali–carbonate reactive layers in the Gull River Formation, near Kingston, Ontario (pilot project)	ERGMS Core Program	Ongoing – field work completed, OFR in progress ▸ *Summary of Field Work* article published in 2018
2-D and 3-D Paleozoic Bedrock Geology Groundwater Mapping Initiative	Upper Ordovician stratigraphy, sedimentology and isotope geochemistry of Upper Trenton Group Cobourg Formation (Collingwood Member) and basal Blue Mountain Formation (Rouge River Member) strata, southwestern Ontario	ERGMS Core Program and collaboration with OGSRL and Mitacs (University of Western Ontario), MSc thesis (D. Atasiei), University of Western Ontario	Completed – thesis defended in June 2025 (Atasiei 2025) ▸ *Summary of Field Work* articles published in 2021, 2022, 2023 ▸ Journal publication: Atasiei et al. (2025)
	Cambrian mapping initiative ▸ Phase 1 involves update of stratigraphy and sedimentology of basal mixed siliciclastic and carbonate strata across southern Ontario	ERGMS Core Program and collaboration with MNR, OGSRL and University of Western Ontario researchers	Ongoing – data gathering in 2023 and 2022; data analysis in progress ▸ *Summary of Field Work* articles published in 2022, 2023
Paleozoic Initiative	Paleozoic geology of eastern Ontario ▸ 1:50 000 bedrock geology mapping; establish stratigraphic framework for the area	ERGMS Core Program	Ongoing – field work in 2023 ▸ *Summary of Field Work* articles published in 2017, 2018, 2019, 2022, 2023
	South Niagara Peninsula bedrock geology mapping project	ERGMS Core Program	Ongoing – field work completed, Preliminary Map in progress
	Paleozoic geology of eastern south-central Ontario ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2024, 2023 and 2022 ▸ *Summary of Field Work* articles published in 2022, 2023, 2024

Abbreviations: *ARIP, Aggregate Resources Inventory Paper; ARO, Aggregate Resources of Ontario; MNR, Ministry of Natural Resources; OFR, Open File Report; OGSRL, Oil, Gas and Salt Resources Library.*

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Paleozoic Initiative, *continued*	3-D Leapfrog® – updating Paleozoic digital map legend and lexicon for southern Ontario ▸ Phase 1: updates to Cambrian and Ordovician succession of eastern and south-central Ontario	ERGMS Core Program	Ongoing – desktop study: work in progress ▸ *Summary of Field Work* article published in 2021
Ambient Groundwater Geochemistry Mapping Initiative	Ambient Groundwater Geochemistry project, eastern Ontario ▸ Bancroft and Madawaska Highlands	ERGMS Core Program	New project – field work completed in 2025 ▸ *Summary of Field Work* (this volume, Article 18)
	Ambient Groundwater Geochemistry project, southwestern Ontario ▸ Groundwater sampling as part of a study by MNR	ERGMS Core Program and collaboration with MNR	Ongoing – groundwater sampling completed in 2024; analysis completed 2025, data compilation in progress
	Ambient Groundwater Geochemistry projects, southern Ontario ▸ Data interpretation	ERGMS Core Program	Ongoing ▸ Updated data published as MRD 283—Revision 2 in 2021
	Ambient Groundwater Geochemistry project, southwestern Ontario ▸ Six Nations First Nation	ERGMS Core Program	Ongoing – field work completed; analyses in progress ▸ *Summary of Field Work* article published in 2023
	Ambient Groundwater Geochemistry project, northwestern Ontario ▸ Thunder Bay	ERGMS Core Program	Ongoing – field work completed in 2024 ▸ *Summary of Field Work* article published in 2024
	Ambient Groundwater Geochemistry project, eastern Ontario ▸ Ottawa Valley	ERGMS Core Program	Ongoing – field work completed in 2024 ▸ *Summary of Field Work* article published in 2024
	Ambient Groundwater Geochemistry project, northeastern Ontario	ERGMS Core Program	Completed ▸ Northern Ontario ambient groundwater geochemistry MRD published in 2024

Abbreviations: *MNR, Ministry of Natural Resources; MRD, Miscellaneous Release—Data.*

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Provincial-Scale Compilation Initiative	Geochronology Inventory of Ontario (GeochrON) ▸ Update current geochronology database	ERGMS Core Program	Ongoing – inaugural publication (beta version) released in 2019; update planned for 2026
	Aggregate Resources of Ontario (ARO) compilation	ERGMS Core Program	Ongoing – inaugural publication released in 2015, with updates published in 2019, 2020 and 2021
	Lake Geochemistry of Ontario (LakeGeochemON) compilation	ERGMS Core Program	Inaugural publication (beta version) released in March 2020
	Improving the records in the Ontario Water Well Information System (WWIS) database	ERGMS Core Program, Ministry of Environment, Conservation and Parks, collaboration with industry	Ongoing – phase 1 nearing completion, industry consultation ongoing ▸ *Summary of Field Work* articles published in 2021, 2023, 2024
	Unified stratigraphic framework for the Provincial Groundwater Monitoring Network (PGMN)	ERGMS Core Program, Ministry of Environment, Conservation and Parks	Ongoing – overview completed in 2023, multi-year study ▸ *Summary of Field Work* article published in 2023
	Determination of indicator minerals in the archived fine-fraction non-magnetic heavy mineral concentrate (HMC) samples	ERGMS Core Program	Ongoing – third year of multi-year study ▸ *Summary of Field Work* articles published in 2023, 2024
	Gold Fingerprinting: Major and trace elements associated with native gold ▸ Working toward an open-source database	ERGMS Core Program Metal Earth, MERC–Laurentian University, Royal Ontario Museum	Ongoing – laboratory and desktop study; additional data acquisition and analysis in progress ▸ *Summary of Field Work* articles published in 2020, 2021, 2022 ▸ MSc thesis by J.D. Melo-Gómez defended in 2023 ▸ Journal publication: Melo-Gómez et al. (2025)
	Critical Minerals in Gold Deposits	ERGMS Core Program; collaboration with industry. MSc theses (J. Cann and H. Eaton-Tessier), University of Toronto	Ongoing – sampling began in 2023; data acquisition and analysis in progress ▸ *Summary of Field Wo*rk article published in 2023 ▸ Two MSc theses (University of Toronto) started in September 2024 and January 2025
	Field structure measurement database	ERGMS Core Program	Ongoing – compilation of field structure measurements collected since 2000 ▸ Compilation completed; database is currently in review (QA/QC)
	Till sample location database	ERGMS Core Program	Ongoing – compilation of indicator mineral and till matrix geochemistry data in progress

Abbreviations: *MERC, Mineral Exploration Research Centre; QA/QC, quality assurance and quality control.*

OVERVIEW OF CURRENT COLLABORATIVE INITIATIVES AND PROJECTS

The ERGMS participates in several collaborative initiatives and projects (*see* Table 4.1). These collaborations are critical to maximizing individual organization resources and delivering the highest quality geoscience to all ERGMS clients and stakeholders.

Collaborations with Mineral Exploration Research Centre (MERC), Harquail School of Earth Sciences, Laurentian University

In the fall of 2016, Laurentian University was awarded $104 million for "Metal Earth" by the Canada First Research Excellence Fund (CFREF). The Fund's objective is to help Canadian postsecondary institutions excel globally in research areas that create long-term economic advantages for Canada. The premise of the Metal Earth project is to explain why some Archean greenstone terranes are rich in mineral deposits, whereas other, similar terranes are much less endowed despite broadly similar geology at surface. The multi-year Metal Earth project is beginning to wind down and details on these activities can be found on the Metal Earth Web site at https://merc.laurentian.ca/research/metal-earth [last accessed November 3, 2025].

Collaborations with the Geological Survey of Canada

In 2021, the federal government launched phase 6 of the Targeted Geoscience Initiative (TGI-6). The Targeted Geoscience Initiative (TGI) is a Government of Canada led, collaborative geoscience research program directed toward providing next generation knowledge and methods that will facilitate more effective targeting of buried mineral deposits. Several TGI-6 projects in Ontario are being led by GSC geoscientists and ERGMS geoscientists have supported this program by sharing information and knowledge over the last year.

The ERGMS is also collaborating with the GSC as part of the Lands and Minerals Sector (LMS) of Natural Resources Canada (NRCan) Canada–3D digital geological map of Canada project. The Canada–3D project is a national collaboration involving the provincial and territorial geological surveys and the Geological Survey of Canada, operating under the auspices of the National Geological Surveys Committee (NGSC). The goal of this project is to develop the next generation of products to enhance the representation of Canada's subsurface geology.

Other Collaborative Projects

As mentioned previously, the ERGMS is involved with numerous governmental and academic partnerships to maximize geoscience resources and to augment the depth of geoscience projects in Ontario. In addition to partnerships with the GSC, the ERGMS also supported and/or participated in several collaborative projects with academic partners and other governmental organizations in 2025 (*see* Table 4.1).

INTERJURISDICTIONAL AND COMMITTEE REPRESENTATION

Staff of the ERGMS represented the Ministry of Energy and Mines, the OGS and other geoscience organizations on several interjurisdictional committees, internal committees and associations during the 2025–2026 fiscal year, which are summarized as follows:

- Commission on Stratigraphic Nomenclature of the Americas (formerly the North American Commission on Stratigraphic Nomenclature)
- National Geological Surveys Committee (NGSC)
- Great Lakes Geologic Mapping Coalition
- Geoscience Laboratories (Geo Labs)–ERGMS Working Group
- Willet Green Miller Centre (WGMC) Joint Health and Safety Committee
- thesis committees and adjunct professorships at universities (Laurentian University, Carleton University, University of Western Ontario, University of Toronto, University of New Brunswick, University of Saskatchewan, University of Brasilia)
- Mineralogical Association of Canada, Council Member
- Canadian Exploration Geophysical Society (KEGS)
- Society of Exploration Geophysicists (SEG)
- Subsurface Gas Management Working Group
- National Dialogue on Groundwater
- Great Lakes Water Quality Agreement (GLWQA) Groundwater Annex committee
- Subsurface Gas Management
- Michigan Quaternary Research Group
- National Drilling Association
- Prospectors and Developers Association of Canada (PDAC) Student–Industry Mineral Exploration Workshop (S-IMEW)

STAFFING CHANGES IN THE SECTION

Sonia Préfontaine accepted the Acting Manager, Geoscience Mapping position within the Sedimentary and Environmental Geoscience Section of ERGMS in May 2025. Two new staff have accepted positions in ERGMS: Rhiannon James, Quaternary Intern; and Nathan Carter, Precambrian Geoscientist. Michael Easton, Senior Geoscience Leader, retired in March 2025 after 43 years of service, and recently accepted a contract position as a Senior Geoscience Leader.

LIST OF PUBLICATIONS[1]

Beckett-Brown, C.E. and Handley, L.A. 2024. Restarting the lake sediment and water geochemistry program: Batchawana greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.19-1 to 19-6.

Beckett-Brown, C.E., Malegus, P.M. and MacDonald, P.J. 2024. Top-to-bottom surficial geochemical characterization of the Great Bear gold project, Red Lake, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.18-1 to 18-8.

Biswas, S. and Evangelatos, J. 2024. Summary of geophysical projects and activities; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.12-1 to 12-4.

Brunton, F.R. 2024a. Overview of Paleozoic bedrock and karst mapping initiatives and the new OGS lithostratigraphic chart for southern Ontario; Ontario Geological Survey Virtual Showcase 2024, November 26–28, 2024, presentation SHOWCASE-24-303.

——— 2024b. The Niagara Geopark – Celebrating the confluence of geology and culture; Ontario Geological Survey Virtual Showcase 2024, November 26–28, 2024, presentation SHOWCASE-24-306.

Brunton, L.E. and Burt, A.K. 2024. Glimpsing gorgeous glacial geology in Guelph; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.24-1 to 24-6.

Burnham, O.M. and MacDonald, C.A. 2024. Production and characterization of an alkali-carbonate reactive reference material: MTO RM ACR XRF; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.27-1 to 27-10.

Burt, A.K. and Brunton, L. 2024. From the top down - Updates from the Guelph 3D sediment mapping project; Ontario Geological Survey Virtual Showcase 2024, November 26–28, 2024, presentation SHOWCASE-24-304.

Burt, A.K. and Galvao, J. 2024. Geological information on new water well records: Internal test results; Ontario Geological Survey Virtual Showcase 2024, November 26–28, 2024, presentation SHOWCASE-24-312.

Burt, A.K., Colgrove, L.M., Kalmo, K.J.J., Ford, D., Holysh, S. and Rivard, C. compilers. 2025. Ontario Groundwater Geoscience 2025 Open House; Ontario Geological Survey, Open File Report 6414, 48p.

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5. Project NE-25-003. Geology of Briggs Township, Temagami Greenstone Belt, Northeastern Ontario



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INTRODUCTION

The Earth Resources and Geoscience Mapping Section of the Ontario Geological Survey started the multi-year Temagami greenstone belt mapping project in 2019 (*see* MacDonald 2019; MacDonald and Kamo 2021; MacDonald 2023, 2024). Project objectives are to 1) update township bedrock geology maps, 2) examine the geological architecture of the greenstone belt, 3) correlate volcanic formations with the chronostratigraphic episodes of the Abitibi greenstone belt, and 4) study geological controls on mineralization.

Bedrock geology mapping of Briggs Township at 1:20 000 scale was the focus of field work during the summer of 2025 (Figure 5.1). A brief summary of the main rock types observed in the Briggs Township is presented in the text below.

ROCK TYPES IN BRIGGS TOWNSHIP

The Temagami greenstone belt is a Neoarchean granite-greenstone inlier surrounded by metasedimentary rocks of the Paleoproterozoic Huronian Supergroup (Bennett, Dressler and Robertson 1991; Ayer et al. 2006). This section summarizes features observed in Briggs Township for the Archean supracrustal and intrusive rocks, as well as Proterozoic intrusive rocks.

Archean Supracrustal Rocks

Archean supracrustal rocks in Briggs Township, include 4 metavolcanic rock units and 1 metasedimentary rock package. Mafic metavolcanic rocks observed along the southern edge of Briggs Township (*see* Figure 5.1) occur as massive, fine-grained flows. Primary features of the metabasalts are obscured as a result of amphibolite-facies metamorphism related to the emplacement of the Iceland Batholith (historically referred to as Iceland Lake pluton and, more recently, as Ingall Lake Batholith) at *circa* 2736 Ma (*see* "Archean Intrusive Rocks").

Immediately north of the metabasalts, felsic to intermediate metavolcanic rocks are most easily observed along the southern shore of Lake Temagami (*see* Figure 5.1). These felsic to intermediate metavolcanic rocks are predominantly composed of thickly bedded polymictic block-rich tuff breccia and lapillistones (Photo 5.1A). Intermediate metavolcanic rocks are generally more prevalent to the south, whereas more felsic units are dominant to the north. Where exposed on islands within Lake Temagami, these felsic to intermediate metavolcanic rocks are strongly deformed by the Northeast Arm deformation zone (*see* Figure 5.1). Along strike to the east, in Strathcona Township, the age of these felsic to

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Ontario Geological Survey, Open File Report 6421, p.5-1 to 5-5.

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intermediate metavolcanic rocks was determined to be 2736 $^{+3}/_{-1}$ Ma (Bowins and Heaman 1991; *see* Figure 5.1).

A second package of mafic metavolcanic rocks occurs directly north of Lake Temagami, as well as in the northwest corner of Briggs Township (*see* Figure 5.1). These mafic metavolcanic rocks occur as massive (Photo 5.1B), pillowed and brecciated flows. Individual flow thicknesses were not observed. Pillowed flows are characterized by thin-selvage, small-size (<50 cm in length) elongate pillows. Locally, flows are strongly magnetic and are spatially associated along strike with interflow oxide-facies ironstone. The mafic metavolcanic rocks are generally weakly deformed, with a faintly visible foliation. Metamorphism of the mafic metavolcanic rocks is greenschist facies, except for along the margin of the Spawning Pluton, where the metamorphic facies is locally higher as a result of contact metamorphism. No age has been determined for this unit.

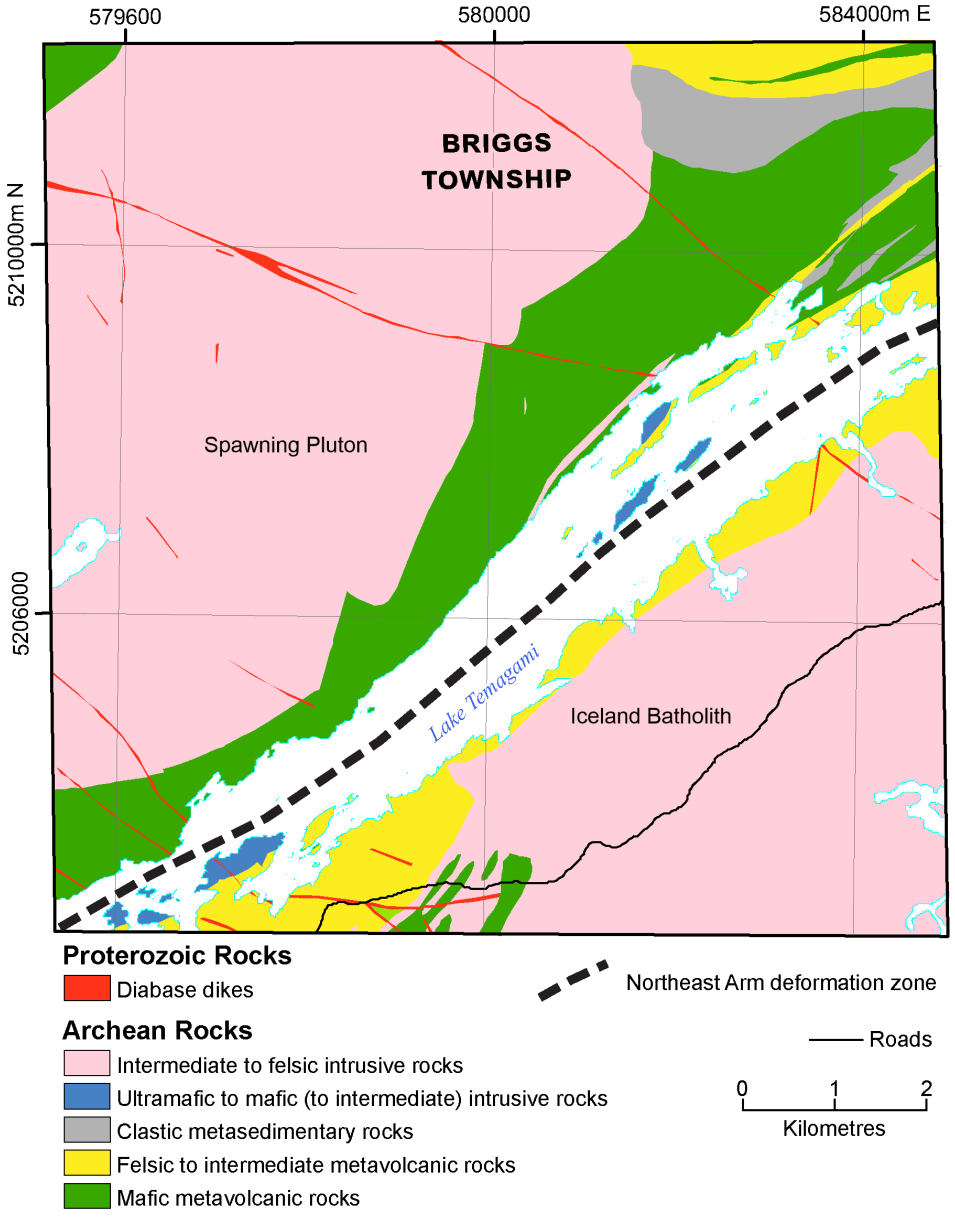


Figure 5.1. Simplified geological map of Briggs Township. Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 17 (geology *modified from* Bennett 1976; Ayer et al. 2006).

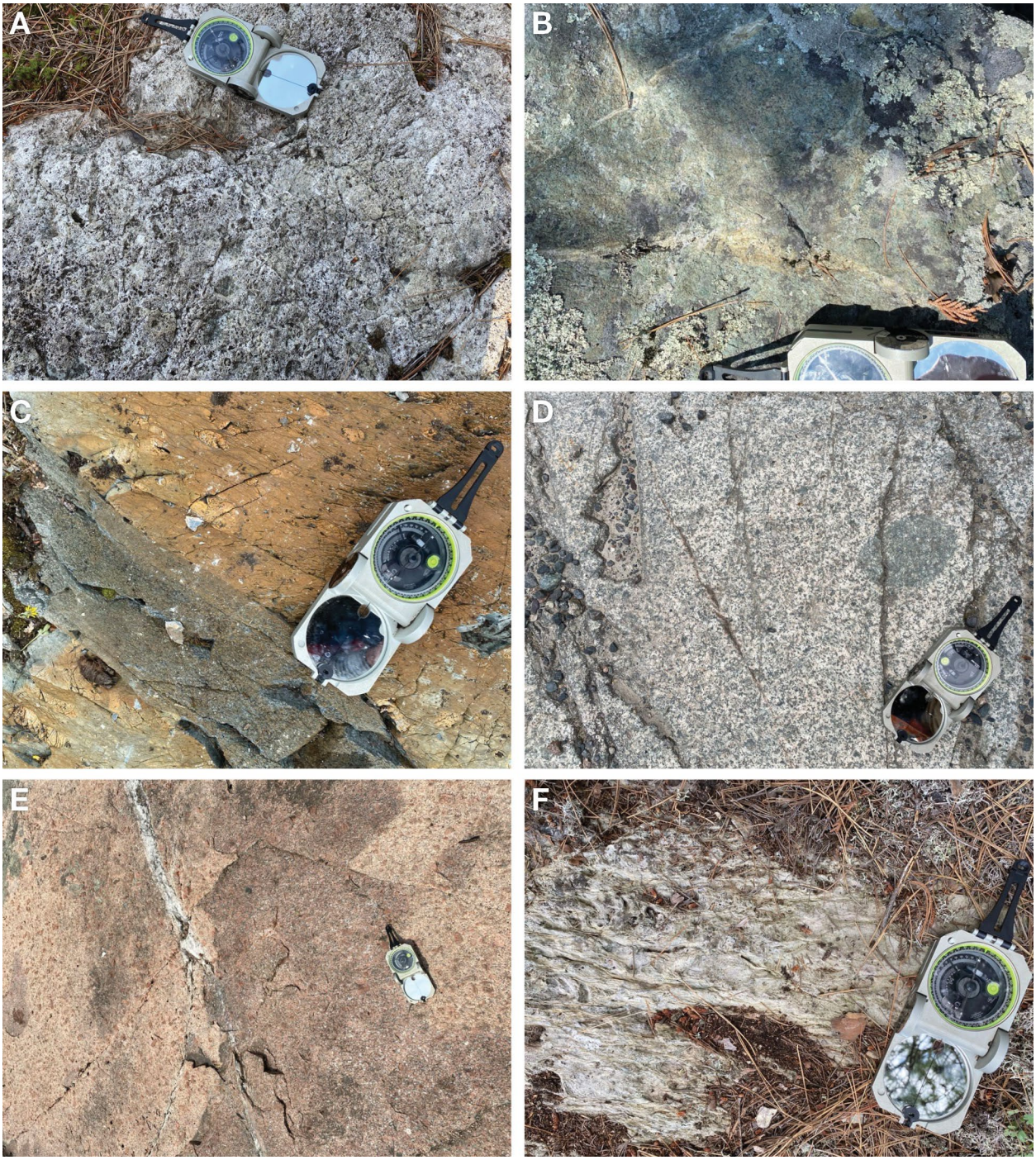


Photo 5.1. Selected photographs of geological features from Briggs Township. **A**) Angular felsic lapillistone metavolcanic rock (station 2PMT059: UTM 578969E 5204077N). **B**) Massive magnetic mafic metavolcanic rock (substation 25PMT031: UTM 581053E 5207757N). **C**) Intermediate block-dominant tuff breccia crosscut by lamprophyre dike (station 25PMT010: UTM 584339E 5210626N). **D**) Iceland Batholith hornblende trondhjemite with diorite xenolith (station 25PMT048: UTM 584514E 5206055N). **E**) Spawning Pluton megacrystic alkali-feldspar granite crosscut by quartz vein (station 25PMT075: UTM 572999E 5205664N. **F**) Sheared felsic volcanic rock displaying sinistral movement within Northeastern Arm deformation zone (station 25PMT053: UTM 576570E 5203351N). Compass for scale is 22 cm long and points north. Location information provided as UTM co-ordinates using NAD83 in Zone 17.

The third metavolcanic rock package of felsic to intermediate rocks is located in northeastern Briggs Township (*see* Figure 5.1). Although poorly exposed, where outcrops exist, this metavolcanic rock unit is composed predominantly of massive intermediate metavolcanic flows, with minor tuff breccias (Photo 5.1C). The unit is moderately to strongly deformed, with a well-developed foliation, and underwent greenschist-facies metamorphism. Along strike in Strathy Township, the age of a sample from this unit was *circa* 2717 Ma (Ayer et al. 2006).

In northeastern Briggs Township, siliciclastic metasedimentary rocks are interbedded with felsic and intermediate metavolcanic rocks near and or at the top of the sequences (*see* Figure 5.1). Siliciclastic metasedimentary rocks are composed of thinly bedded (<10 cm) siltstones, with minor argillites, sandstones and matrix-supported sandy-pebble conglomerates. The metasedimentary rocks are generally weakly deformed. Along strike to the northeast, a maximum age of deposition of 2721.5±1.1 Ma has been reported for this metasedimentary package (Ayer et al. 2006).

Archean Intrusive Rocks

The Iceland Batholith, in southeast Briggs Township (*see* Figure 5.1), is composed mainly of a massive, medium-grained, hornblende-rich trondhjemite. Earlier phases of the pluton include diorite, which occurs as isolated outcrops and as xenoliths within the trondhjemite (Photo 5.1D). Granitic aplite and pegmatite dikes up to 15 cm thick are locally present. The age of the pluton has been determined to be 2736±2 Ma (Bowins and Heaman 1991).

Another major intrusion, the Spawning Pluton, occurs in northwestern Briggs Township (*see* Figure 5.1). The Spawning Pluton is a uniform megacrystic alkali-feldspar granite (Photo 5.1E). The age of the pluton has been determined to be posttectonic at 2676±1.2 Ma (MacDonald and Kamo 2021).

Smaller bodies of Archean intrusive rocks within the map area include both gabbro and porphyritic tonalites. Small gabbro intrusions are exposed on islands and along the south shore of Lake Temagami in southwestern Briggs Township (*see* Figure 5.1). The gabbros are medium grained, with interlocking plagioclase and amphibole grains, with locally significant amounts of disseminated pyrite, pyrrhotite and chalcopyrite. To the southwest in Phyllis Township, emplacement ages for the gabbros were determined at 2732±2 Ma and 2732.7±1.5 Ma (Ayer et al. 2006). Porphyritic tonalite intrusions occur throughout the map area, with the largest occurring near the north shore of Lake Temagami in Briggs Township. The porphyry intrusions contain varying amounts of medium-grained plagioclase, quartz and hornblende phenocrysts in a fine-grained quartz-feldspathic matrix.

Proterozoic Rocks

Proterozoic mafic intrusions include Sudbury swarm diabase dikes, diabase dikes of unknown affinity and lamprophyre dikes (*see* Figure 5.1). Sudbury diabase dikes are composed of medium- to coarse-grained olivine-bearing gabbro. The Sudbury diabase dike swarm has an age of 1238.5±4 Ma (Krogh et al. 1987). Numerous smaller non-magnetic, fine-grained chloritized diabase dikes occur throughout the area. To which swarm these diabase dikes are associated with is unknown, however they intruded subparallel to the Sudbury swam so they may be a phase of that magmatic event. Narrow biotite-rich lamprophyre dikes (*see* Photo 5.1C) observed along the north shore of Lake Temagami intruded into felsic to intermediate metavolcanic rocks and, based on a lack of deformation, are interpreted as Proterozoic in age.

NORTHEAST ARM DEFORMATION ZONE

The Northeast Arm deformation zone trends from southwest to east-central Briggs Township, approximately following the trend of Lake Temagami (*see* Figure 5.1). This deformation zone is approximately 1.5 km wide and is composed of multiple east-northeast–trending high-strain zones, that individually can exceed 100 m in thickness. Lateral shear sense indicators, including C-S fabric, shear bands and drag folds observed within the Archean rocks indicate predominantly sinistral movement (Photo 5.1F). Vertical movement shear indicators, including C-S fabric associated with downdip stretching lineations indicate north-side-up movement. No overprinting relationships between lateral and vertical movement were observed in the field. It is unclear whether they are related to separate deformation events or are the expression of strain partitioning of a single event under a transpressive regime. Horizontal and vertical displacement distances have not been determined.

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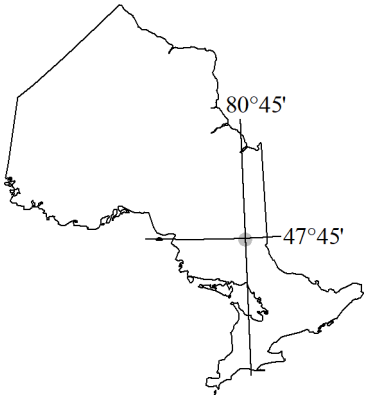
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6. Project NE-23-003. Geology of Haultain, Van Hise and Nicol Townships, Abitibi Greenstone Belt, Northeastern Ontario



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INTRODUCTION

The Gowganda silver camp came to be developed as a result of the more widespread prospecting that followed the silver discoveries in Cobalt in 1903. The region subsequently grew into a large producer of silver from 1910 to 1989 (Sergiades 1968; Ontario Geological Survey 2023). The present surge in interest in critical minerals, such as cobalt, combined with the ongoing discoveries of gold in the project area, has sparked renewed interest in the Gowganda camp. In 2025, geological mapping of Haultain, Van Hise and Nicol townships was conducted at 1:20 000 scale and is part of a multi-year project to update the geological knowledge of the Gowganda area (Figure 6.1). The objectives of this project are the following: 1) to update the geological mapping in Van Hise, Haultain and Nicol townships which were last mapped in 1968 (McIlwaine 1978); 2) to characterize the major lithological units and stratigraphy; and 3) to evaluate the mineral potential of the project area.

REGIONAL GEOLOGY

The project area is located in the Archean Abitibi greenstone belt (*see* Figure 6.1). The Abitibi greenstone belt is most recently subdivided by Thurston et al. (2008, and references therein) and Monecke et al. (2017, and references therein) into the following chronostratigraphic units: pre-2750 Ma episode, 2750–2735 Ma (Pacaud) episode, 2734–2724 Ma (Deloro) episode, 2723–2720 Ma (Stoughton–Roquemaure) episode, 2720–2710 Ma (Kidd–Munro) episode, 2710–2704 Ma (Tisdale) episode and the 2704–2695 Ma (Blake River) episode. Stratigraphically overlying the volcanic episodes in Ontario are 2 dominantly sedimentary episodes referred to as the Porcupine-type (2690–2682 Ma) and the Timiskaming-type (2676–2670 Ma) sedimentary basins. Intruded into the greenstone belt are a variety of ultramafic to felsic Archean intrusions, including the Round Lake batholith (2696.9–2734.6 Ma: Ketchum, Kamo and Davis 2003; Ketchum et al. 2008; Mortensen 1993). Proterozoic mafic dikes of the Matachewan dike swarm crosscut the Archean rocks. Overlying the southern portion of the Abitibi greenstone belt, including the Proterozoic Matachewan dikes, are the sedimentary rocks of the Proterozoic Cobalt Group of the Huronian Supergroup. In the project area, the Huronian Supergroup rocks were deposited in what is known as the Cobalt Basin. Intruded into the Huronian Supergroup and older rocks are mafic intrusions of the Nipissing intrusive suite. Finally, all rocks in the project area are crosscut by the Proterozoic dikes of the Biscotasing and Sudbury swarms.

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GEOLOGY OF HAULTAIN, VAN HISE AND NICOL TOWNSHIPS

Archean Metavolcanic Rocks

The metavolcanic rocks in the project area are restricted to southern Van Hise Township, central to southern Haultain Township, and central to northern Nicol Township (Figure 6.2), and include ultramafic, mafic, intermediate and felsic composition rocks.

Ultramafic metavolcanic rocks have been observed in southern Van Hise Township, southwestern Haultain Township and northern Nicol Township (*see* Figure 6.2), where they are dark grey, weakly to strongly foliated, and very fine grained. They are sporadically fragmental, with centimetre-scale fragments

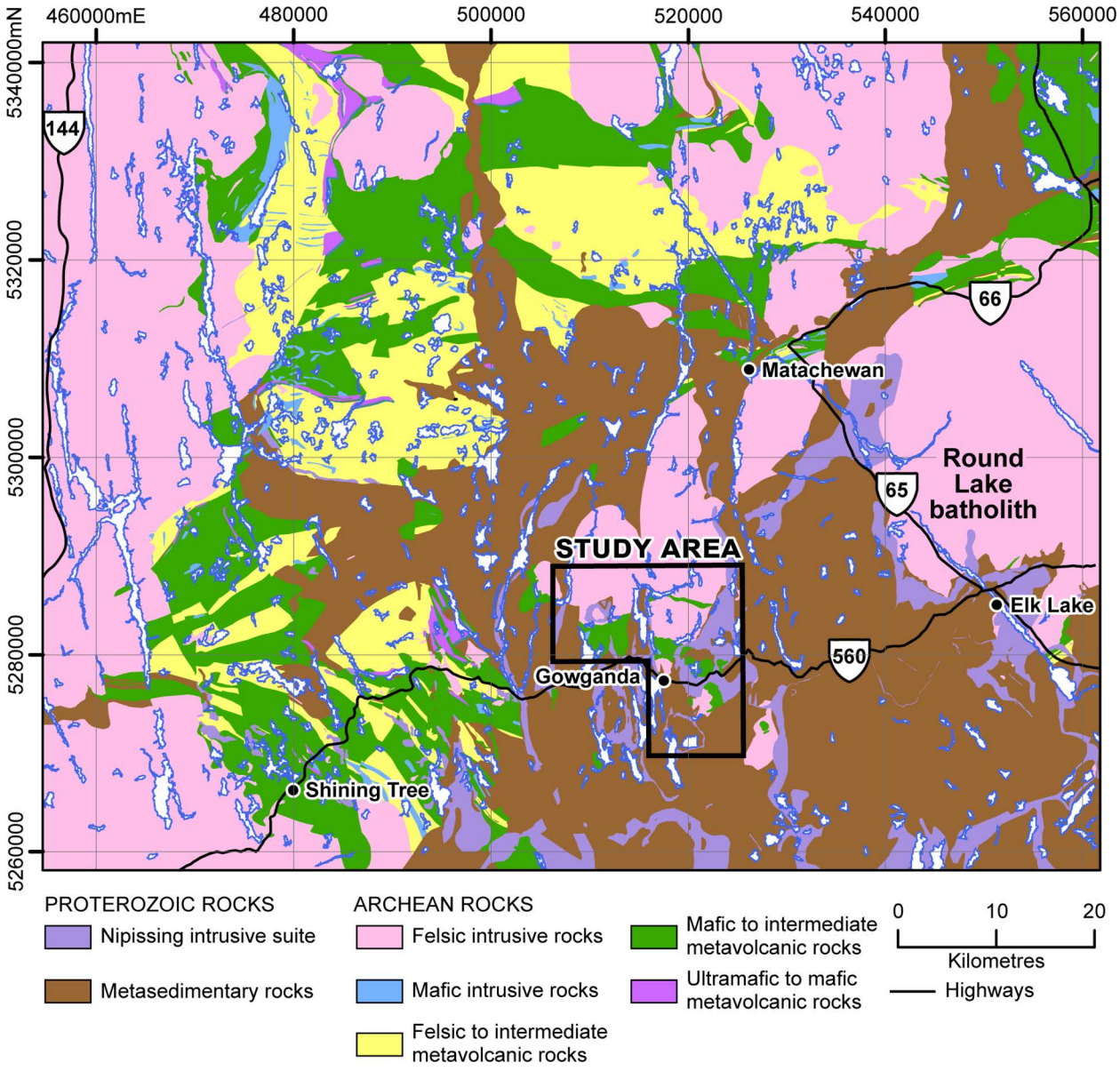


Figure 6.1. Simplified geological map of the Cobalt Basin and Shining Tree area of the Abitibi greenstone belt showing the location of the study area (outlined with a black line) (*modified from* Ontario Geological Survey 2011). Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 17.

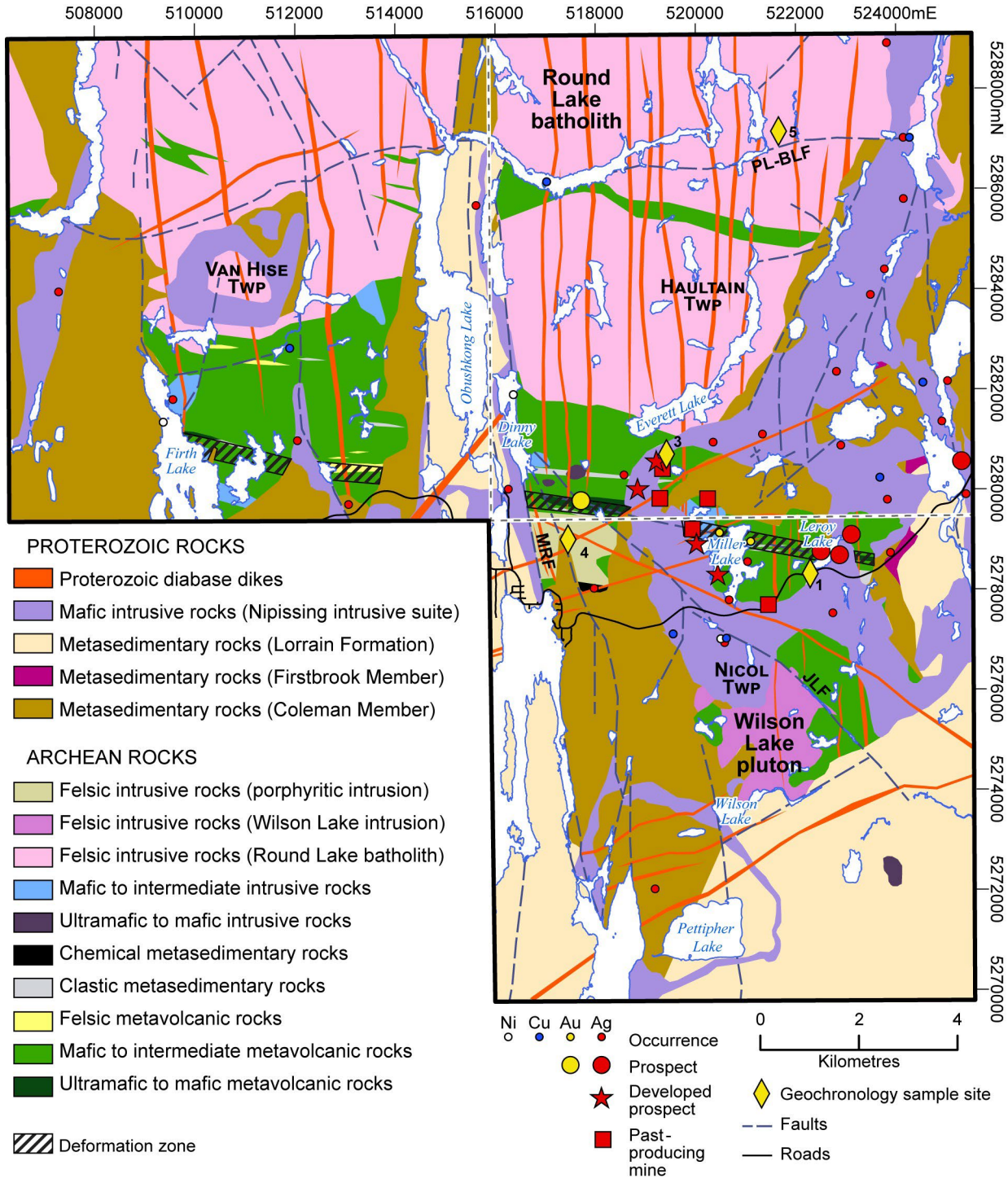


Figure 6.2. Simplified lithological map of the project area (UTM co-ordinates provided in NAD83, Zone 17). Geochronology sample locations 1, 3, 4 and 5 are shown; *see* Table 6.1 for additional information. The locations of Ontario Mineral Inventory (OMI) occurrences, prospects and past-producing mines (Ontario Geological Survey 2023) show the primary commodities. Abbreviations: Ag, silver; Au, gold; Cu, copper; Ni, nickel; JLF, Jacobs Lake fault; MRF, Montreal River fault; PL-BLF, Penassi Lake–Bloom Lake fault.

Table 6.1. Summary of U/Pb ages for samples collected in Haultain and Nicol townships. Sample locations for ages 1, 3, 4 and 5 are shown in Figure 6.2; age 2 is not shown on Figure 6.2 because it is not an emplacement age.

Sample	Mineral	Age (in Ma)	Method	Interpretation	Rock Type	Easting (m)	Northing (m)	Source
1	Zircon	2719.1±1.1	ID-TIMS	Youngest detrital grains (n=3)	Sandstone	522299	5278304	Ketchum (2002)
2	Zircon	2703.7±2.3	ID-TIMS	Inheritance	Syenite dike	517545	5279760	Ayer et al. (2013)
3	Baddeleyite	2217.5±1.6	ID-TIMS	Emplacement	Gabbro	519425	5280689	Corfu and Andrews (1986)
4	Zircon	2698.4±1.6	ID-TIMS	Emplacement	QFP	517524	5279026	Kamo and Nilsson (2025)
5	Zircon	2710.5±1.1	ID-TIMS	Emplacement	Quartz diorite	521827	5287140	Kamo and Nilsson (2025)

Abbreviations: *ID-TIMS = isotope dilution thermal ionization mass spectrometry; QFP = quartz feldspar porphyry.*
Note: *Locations are provided as UTM co-ordinates in NAD83, Zone 17.*

being angular to subangular, monolithic and many are interlocking. Rare spinifex–textured komatiites have been observed, with spinifex laths up to 3 cm long.

Mafic to intermediate metavolcanic rocks within Haultain, Nicol and Van Hise townships are typically dark to medium grey, strongly foliated and very fine grained, although locally, they are medium grained. Pillows and pyroclastic flows have been observed.

Felsic to intermediate metavolcanic rocks occur as narrow and discontinuous flows within the Archean metavolcanic rocks of the project area. They are largely light to medium grey, weakly foliated, and very fine grained.

Archean Metasedimentary Rocks

Archean metasedimentary rocks comprise clastic metasedimentary rocks and chemical metasedimentary rocks.

Clastic metasedimentary rocks occur as narrow interflow units within the mafic to intermediate metavolcanic rocks in Haultain, Van Hise and Nicol townships. They are commonly well-sorted, very thinly bedded siltstones and sandstones. A U/Pb analysis of zircon from a sandstone in Nicol Township using isotope dilution thermal ionization mass spectrometry (ID-TIMS) yielded an age of 2719.1±1.1 Ma, based on 3 concordant grains (Ketchum 2002) (*see* Figure 6.2; Table 6.1: sample 1). This age was interpreted to belong to the Kidd–Munro episode (2720–2710 Ma) (Ketchum 2002); however, it could also be interpreted as part of the 2723–2720 Ma episode (Stoughton–Roquemaure) because the age lies within error of the boundary between the 2 episodes (i.e., 2720 Ma).

Chemical metasedimentary rocks occur as discrete and seemingly discontinuous units in Haultain and Van Hise townships (*see* Figure 6.1). This rock type was observed during 2025 field work, but was not encountered in previous field seasons. Iron-oxide iron formation and sulphide iron formation were observed in northwestern Nicol Township, are very thinly to thinly non-parallel to discontinuously bedded and generally appeared sheared.

Archean Intrusive Rocks

Archean intrusive rocks within the project area include ultramafic intrusions, small gabbroic intrusions, and felsic to intermediate bodies, such as the Round Lake batholith, the Wilson Lake pluton (*see* Figure 6.2), a stock of quartz-feldspar porphyry and smaller felsic intrusive rocks.

Ultramafic intrusive rocks occur in southern and eastern Van Hise Township, and southwestern Haultain Township and northern Nicol Township. They are dark greenish-grey, fine-grained, massive peridotites to dunites with serpentine and talc alteration. The outcrops are generally a distinctive rusty brown, rounded and display cooling fractures. In most cases, mafic intrusive rocks that are spatially associated with the ultramafic intrusive rocks are medium to dark grey, massive to locally foliated, medium-grained gabbros.

The Round Lake batholith can be subdivided spatially into 2 distinct compositional phases (McIlwaine 1978): quartz diorite and tonalite. In northern Haultain Township, the rocks observed tend to be light grey to pink, medium-grained, massive to locally foliated hornblende ± biotite quartz diorite. In central to western Haultain Township and within Van Hise Township, the rocks observed are light pink, massive, medium-grained hornblende tonalite. Uranium–lead analysis of zircon from a quartz diorite rock in Haultain Township using ID-TIMS yielded an age of 2710.5±1.1 Ma (Kamo and Nilsson 2025) (*see* Figure 6.2; *see* Table 6.1: sample 5).

An area of felsic to intermediate rocks in northwestern Nicol Township (*see* Figure 6.2) is now being interpreted largely as an intrusion, which is in line with the thinking of previous workers Collins (1913) and Burrows (1926). Intrusive contacts were identified during the 2025 field work (Photo 6.1A), as well as U/Pb analysis of zircon from a quartz-feldspar porphyritic rock in Nicol Township using ID-TIMS yielded an age of 2698.4±1.6 Ma (Kamo and Nilsson 2025) (*see* Figure 6.2; *see* Table 6.1: sample 4).

The pluton near Wilson Lake, in central Nicol Township (*see* Figure 6.2), has been referred to as the Wilson Lake area granitic rocks (McIlwaine 1978). It has less than 4 km^2 of exposed surface and is commonly porphyritic with euhedral, locally concentrically zoned, plagioclase phenocrysts. It commonly contains abundant xenoliths near its margins.

In the project area, small feldspar-quartz porphyry and hornblende-feldspar porphyry dikes intruded the metavolcanic rocks. They range in thickness from a few centimetres to several metres. The feldspar-quartz porphyry dikes are foliated to massive, pink to beige, with millimetre- to centimetre-scale euhedral to anhedral plagioclase and quartz phenocrysts with the abundance of quartz phenocrysts varying from 1% up to 30%. The hornblende-feldspar porphyry dikes are massive, reddish brown to pink, with millimetre- to centimetre-scale euhedral to subhedral plagioclase and hornblende phenocrysts of roughly equal proportions.

Syenitic dikes have been observed sporadically in Haultain, Van Hise and Nicol townships. Those observed are reddish pink, medium grained and massive, and locally contain coarse phenocrysts of biotite. They are commonly spatially associated with structures but are not deformed, suggesting a late- to post-tectonic relationship. Ayer et al. (2013, p.11, p.130) attempted to obtain an age from a syenite dike from the Haultain Township, but the age of 2703 Ma they obtained was interpreted to be the result of inheritance, and not the age of dike emplacement (*see* Table 6.1: sample 2). Lamprophyre dikes are uncommon in the project area, only having been observed occurring spatially associated with the syenitic dikes in southwestern Haultain Township. They are dark grey, fine to medium grained, massive and biotite rich. More investigation is needed to better understand the composition and overall relationships of these 2 types of dikes.

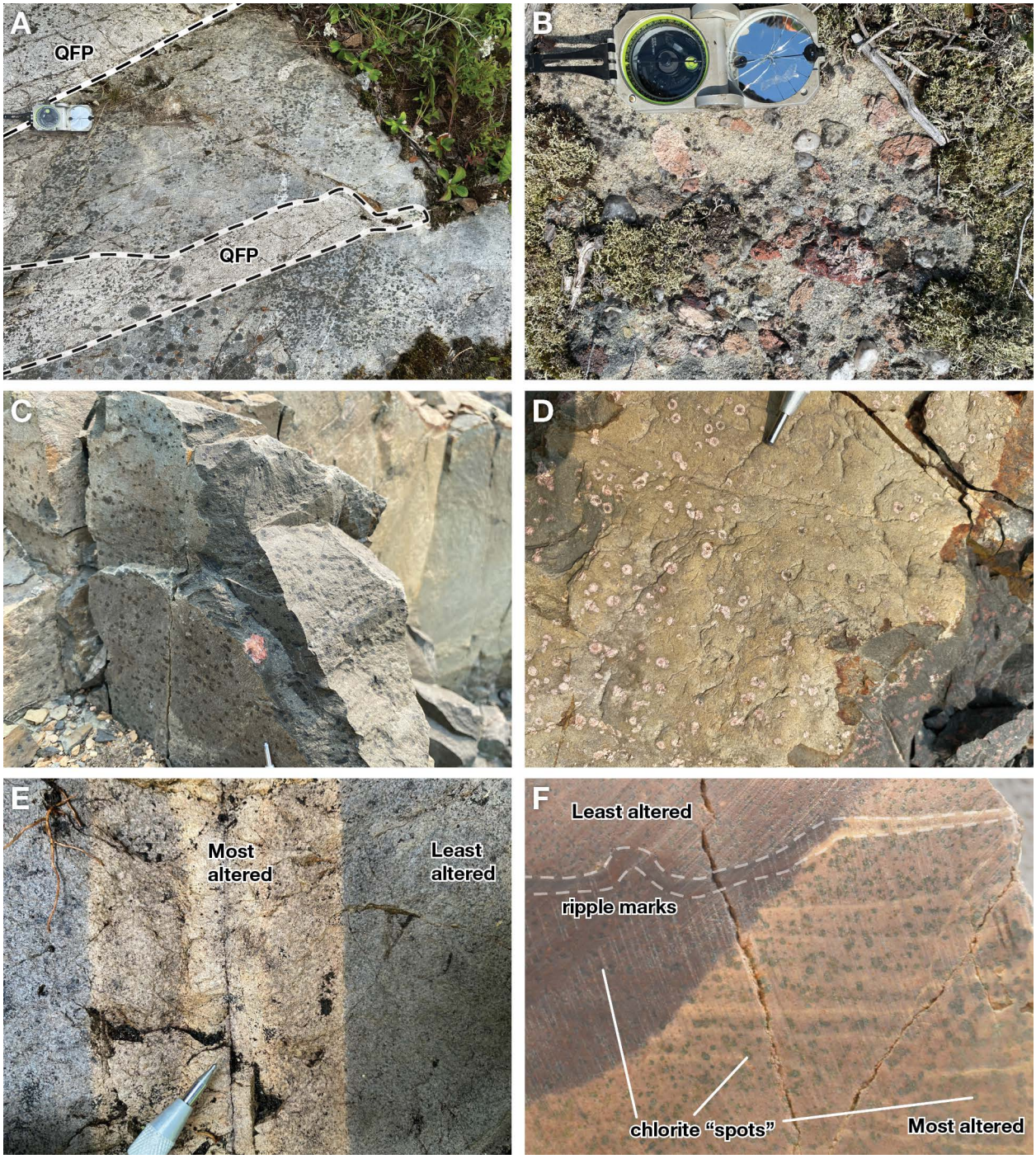


Photo 6.1. Photographs of rock units located Van Hise, Haultain and Nicol townships. **A)** Intrusive contacts of quartz feldspar porphyry (QFP) (UTM 517260E 5279299N). **B)** Pebble beds in Lorrain Sandstone (UTM 515041E 5280527N). **C)** Chlorite "spots" in siltstone of Coleman Member, Gowganda Formation (UTM 514102E 5279891N). **D)** Pink "spots", some seemingly cored with chlorite "spots", in siltstone of Coleman Member, Gowganda Formation (UTM 514102E 5279891N). **E)** Intense, zoned, fracture-controlled albitization in siltstone of Firstbrook Member, Gowganda Formation (UTM 514552E 5279990N). **F)** Cut sample showing intense albitization transecting rippled beds in siltstone of Firstbrook Member, Gowganda Formation. The siltstone and chlorite "spots" become increasingly overprinted in the bottom right of the photo (UTM 514552E 5279990N). All UTM co-ordinates provided using NAD83 in Zone 17. Compass for scale in Photos 6.1A and 6.1B is 6.9 cm wide and sighting arm points north. The magnetic pen tip for scale in Photos 6.1C, 6.1D and 6.1E is 0.3 cm wide. In Photo 6.1F, the uppermost rippled bed is approximately 0.5 cm thick.

Proterozoic Sedimentary Rocks (Cobalt Group)

The Huronian Supergroup comprises 4 stratigraphic groups; from oldest to youngest, these are the Elliot Lake Group, Hough Lake Group, Quirke Lake Group and Cobalt Group (Robertson, Card and Frarey 1969). The Cobalt Group is the only group observed in the area and is subdivided into 4 formations: Gowganda, Lorrain, Gordon Lake and Bar River (Robertson, Card and Frarey 1969). Only the Gowganda Formation, with the Coleman Member and the Firstbrook Member (Robertson, Card and Frarey 1969), and the Lorrain Formation are observed in the map area.

The Coleman Member is observed in western, southern, eastern and central Van Hise Township, eastern Haultain Township, and central to southern Nicol Township. In the project area, the diamictites only form a minority of the exposure of Coleman Member. This member shows a great amount of lithological variety, including mudstones, siltstones, sandstones and clast-supported conglomerates, and include a variety of sedimentary structures, including ripple marks, cross-bedding, and soft-sediment deformation features, such as rip-up clasts and flame structures. The mudstones and siltstones commonly contain pink beds, which can superficially appear sheared and are likely a form of soft-sediment deformation. Locally, the Coleman Member contains rare reddish beds that will be further investigated to determine the source of the colouration.

The Firstbrook Member is observed in southeastern Van Hise Township and northeastern Nicol Township; the rocks are thickly laminated to thinly bedded reddish-grey, purplish and grey mudstones and siltstones and commonly display ripple marks.

The Lorrain Formation is observed on the boundary of Van Hise and Haultain townships, and the eastern, southern and western parts of Nicol Township. It occurred mainly as massive, thinly to thickly parallel planar and cross-bedded sandstones with colours ranging from light grey, light green, pink and purple. Locally, the sandstones contained pebble beds, which are informally known as “puddingstone” if the pebbles contrast strongly in colour with the matrix (Photo 6.1B).

Proterozoic Intrusive Rocks

Proterozoic intrusive rocks in the project area consist of variably differentiated Nipissing intrusions and mafic intrusive rocks of the Matachewan, Biscotasing and Sudbury dike swarms. For more information on the dike swarms, *see* previous descriptions in Walker (2023). In southeastern Nicol Township, a few small outcrops of ultramafic intrusive rock occur in a tight cluster, although the absence of exposed contact with the surrounding Lorrain Formation precludes determining whether it intrudes the Lorrain Formation or is an erosional inlier.

NIPISSING INTRUSIVE SUITE

The Nipissing intrusive suite (2217.5±1.6 Ma: Corfu and Andrews 1986; *see* Table 6.1: sample 3) in the project area occurs as gabbroic sills and dikes, with the sills locally having a saucer-shape form, that primarily intruded the rocks of the Huronian Supergroup and, to a lesser degree, Archean supracrustal and intrusive rocks.

Nipissing intrusions are typically only slightly differentiated, consisting of a basal quartz diabase overlain by gabbro, with the occurrence of more strongly differentiated facies, such as granophyric gabbro, being rare (Lightfoot and Naldrett 1996). The following rock types were observed in the field: quartz diabase, orthopyroxene-phyric gabbronorite, equigranular gabbro, vari-textured gabbro and granophyric gabbro. Where the contacts between the Nipissing intrusions and the country rock were exposed and not structurally or hydrothermally overprinted, the intrusive rocks were dark grey and

aphanitic, interpreted as chill margins. The quartz diabase is a fine-grained diabase-textured quartz gabbro that resembles the various Proterozoic diabase dikes when they lack plagioclase phenocrysts. The orthopyroxene-phyric gabbronorite is readily identified by characteristic equant, medium-grained orthopyroxene phenocrysts which tend to weather to brown. Equigranular gabbro was observed, but appears to be a minor constituent of the Nipissing intrusions in the project area. Vari-textured gabbro, defined by rapid changes in grain size, forms a major part of the Nipissing intrusions in the area and shows variability in the intensity of the texture, the colour of the feldspar, and the modal abundance of minerals. The most evolved phases associated with the Nipissing intrusions in the Gowganda area are referred to as granophyre and aplites, both of which the senior author (JW) found to be poorly defined in historical writings regarding the area. Jambor (1971a) defines granophyre as rocks of the Nipissing intrusion that have a pink granitic appearance and have reduced mafic content, whereas Le Maitre and co-authors (2002, p.86) describe the general definition for a granophyre as a "porphyritic rock of granite composition in which the groundmass alkali feldspar and quartz are in micrographic intergrowth". Based on the latter definition, no true granophyre was confirmed during field work, as the evolved phases in the area are not porphyritic and were not interpreted as granitic in composition. The other rock interpreted to represent an evolved phase of the Nipissing intrusion are the aplitic dikes. Various styles of pink, fine-grained felsic dikes within the Nipissing intrusions were observed and will be further investigated.

STRUCTURAL GEOLOGY

The Gowganda area has undergone extensive ductile and brittle deformation. A major deformation zone has been mapped in the Archean supracrustal rocks from east of Leeroy Lake to Firth Lake (*see* Figure 6.2) with a general west-northwest trend. It shows both brittle and ductile deformation, appearing mylonitized in some sections and brecciated and faulted in others, and will require further investigation. Additionally, several smaller structures of a similar brittle-ductile character that share the orientation of the main deformation zone were observed during field work. Conversely to the main west-northwest shear zone mentioned previously, the regional foliation in Van Hise and Haultain townships measured away from the deformation zone displays, on average, a west-trending orientation. Northwest-trending structures, such as the Jacob's Lake fault (JLF, *see* Figure 6.2), are younger than the regional foliation, but its age relative to the major deformation zone is uncertain. Late, north-trending structures crosscut the deformation zone and, in some cases, have considerable vertical movement (MRF, *see* Figure 6.2), resulting in unconformable contacts. Their relationship with the Nipissing intrusions is complex and likely were active before their intrusion and, in some cases, after they were emplaced.

ALTERATION AND METAMORPHISM

In the Archean supracrustal rocks, pervasive ankerite-albite-pyrite, calcite-magnetite and fuchsite alteration appear to be spatially associated with gold mineralization. Serpentine and talc alteration were associated with the ultramafic rocks. Albite-chlorite-carbonate alteration is associated with the Proterozoic five-element (silver-cobalt-nickel-arsenic ± bismuth) veins in the project area that are spatially associated with the Nipissing intrusions.

In the project area, Archean supracrustal rocks were metamorphosed under greenschist-facies conditions during ductile deformation. Mineral assemblages in the mafic metavolcanic rocks are dominated by chlorite. However, the narrow belt of mafic metavolcanic rocks within the Round Lake batholith in northern Haultain Township displays abundant garnets suggesting that the metamorphic grade reached the amphibolite-facies conditions in that area.

A narrow contact aureole, possibly up to 200 m wide, occurs adjacent to the Nipissing sills. One likely contact metamorphic effect is what is referred to as "chlorite spotting" (Jambor 1971b; McIlwaine 1978) and was observed in the field (Photo 6.1C). The chlorite spots have been reported to occur in Huronian Supergroup metasedimentary rocks, Archean metavolcanic rocks, lamprophyric rocks, and it is contested whether it occurs within the Nipissing sill itself (Jambor 1971b; Appleyard 1981). Jambor (1971b) describes it as bleached halos surrounding cores of 25 to 50% fine-grained chlorite aggregates with the remaining mineralogy being dominantly quartz with minor albite and titanite; however, Appleyard (1981) notes that chalcopyrite and sphalerite can be present. Jambor (1971b) further mentions that most rocks do not contain chlorite spotting. The bleached halos are likely depletion halos, and the occurrence or absence of the chlorite spotting could be dependent on the composition of the host rocks. In addition to the chlorite spotting, a type of "pink spotting" (Photo 6.1D) was observed locally in Coleman Member metasedimentary rocks, but its composition is presently unknown. In the sandstones of the Lorrain Formation, a "red spotting" was observed locally, which superficially resembles jasper pebbles, but the red spots lack sharp clast boundaries, commonly show faint depletion halos, do not appear to change size through graded beds, have texturally the same matrix as the host, and sandstones can contain both red pebbles and "red spots". They may represent the equivalent of chlorite spotting in the Lorrain Formation which Jambor (1971b) noted was rare to absent.

Locally, the Huronian Supergroup metasedimentary rocks near a Nipissing intrusion have undergone complete metasomatism, referred to as "adinoles" by previous workers (Bowen 1910; Moore 1956), which, in some cases, takes on a bleached appearance (Photo 6.1E), typically with rhombic carbonate-porphyroblasts and, in other instances, has apparently turned the metasedimentary rock red and granoblastic. In many cases, the rock transitions subtly from adinole to granophyre and finally into diabase (Bowen 1910; Moore 1956). The albite metasomatism overprints the chlorite spotting (Photo 6.1F) and the redness of the rock, which, in some cases, is primary (i.e., Firstbrook Member), but, in other cases, may be secondary.

MINERALIZATION

Mineralization in the project area is dominated by five-element vein-style mineralization associated with the Nipissing intrusive suite and gold mineralization associated with Archean rocks in the major deformation zone. Notable mineral occurrences within the project area are shown on Figure 6.2. For more information on these mineralization styles, refer to Walker (2023).

Potential advancements into the understanding of the five-element silver-cobalt-nickel-arsenic ± bismuth mineralization include a possible spatial relationship between the major deformation zone and the historically largest producing silver-cobalt-nickel mines (Sergiades 1968) of the Gowganda camp. The implication being that the major deformation zone, which also hosts the known gold occurrences in the area, may have influenced the formation of the more prospective areas of five-element vein mineralization. Smaller but similar trending structures to the main deformation zone were noted in the project area, but their relationship to the mineralization, if any, is presently unknown.

Another noteworthy result of field work is that the surface above the historically most productive silver ± cobalt ± nickel mine (Sergiades 1968) was previously mapped as largely mafic metavolcanic rocks (McIlwaine 1978), but it appears to actually be one or more ultramafic to mafic intrusions. Given that ultramafic intrusions can contain elevated abundances of nickel and cobalt and, depending on the ore-forming model the reader subscribes to, this could have contributed metals to the system. Additionally, the intrusion lacks the foliation present in the Archean supracrustal rocks which results in a lower permeability that could have played a part in the favourability of the area to host mineralization.

ACKNOWLEDGMENTS

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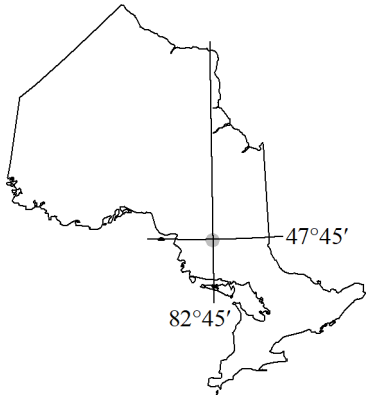
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7. Project NE-25-001. Geology of the Ridout Lake Area, Greenlaw Township, Swayze Area, Abitibi Greenstone Belt, Northeastern Ontario



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INTRODUCTION

The Swayze area of the Abitibi greenstone belt has long been considered the "poor cousin" to the neighbouring Timmins, Matachewan and Kirkland Lake areas of the Abitibi greenstone belt and, therefore, has not received as much exploration attention. A regional-scale compilation mapping project in the mid-1990s (Heather 2001), which included widespread geochronological sampling, demonstrated that the Swayze area has the same episodic metavolcanic units and major faults as those found within the Abitibi greenstone belt east of the Kenogamissi Batholith (Figure 7.1; Heather 2001). The Swayze area, therefore, should represent a westward continuation of the fertile Abitibi greenstone belt and should have the potential to host the same types of precious and base metal mineral deposits.

This mapping project is part of a multi-year project that started in 2014 to update the geology and assess the mineral potential of the Swayze area (related project numbers: Project Unit 14-008, and Projects NE-17-001, NE-17-002, NE-18-002, NE-19-003, NE-22-003, NE-23-002 and NE-25-001). Field work, this year, focussed on parts of Cunningham and Greenlaw townships (*see* Figures 7.1 and 7.2).

REGIONAL GEOLOGY

The Abitibi greenstone belt is located in the eastern part of the Wawa–Abitibi terrane of the southern Superior Province (Percival et al. 2006). It is composed predominantly of mafic to felsic metavolcanic rocks with minor ultramafic metavolcanic rocks, as well as clastic and chemical metasedimentary deposits. The volcanic and sedimentary episodes in the Abitibi greenstone belt were most recently defined by Thurston et al. (2008, and references therein) and Dubé and Mercier-Langevin (2020, and references therein). The volcanic episodes, with lithostratigraphic groups defined by Heather (2001) for the Swayze area in brackets (where applicable), are as follows: pre-2750 Ma (pre-Pacaud) episode, 2750–2735 Ma (Pacaud) episode [Chester group], 2734–2724 Ma (Deloro) episode [Marion group], 2723–2720 Ma (Stoughton–Roquemaure) episode, 2719–2711 Ma (Kidd–Munro) episode [Biscotasing group], 2710–2704 Ma (Tisdale) episode [Trailbreaker group] and 2704–2695 Ma (Blake River) episode [Swayze group]. In Ontario, rocks deposited during the volcanic episodes are overlain by rocks deposited during 2 dominantly sedimentary episodes referred to as the Porcupine-type (2690–2682 Ma) and the Timiskaming-type (2676–2670 Ma) [Ridout group] sedimentary basins.

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Ontario Geological Survey, Open File Report 6421, p.7-1 to 7-7.

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The Swayze area (*see* Figure 7.1) of the Abitibi greenstone belt is mainly composed of mafic, intermediate and felsic metavolcanic rocks, with local ultramafic metavolcanic rocks, clastic and chemical metasedimentary rocks, and synvolcanic to syntectonic felsic to ultramafic intrusive rocks. It is bounded (*see* Figure 7.1) by the Kenogamissi Batholith (locally known as the Rice Lake batholith in the study area: *see* Becker and Benn (2003)) to the east, the Ramsey–Algoma granitoid complex to the south, the Kapuskasing Structural Zone to the west and the Nat River complex to the north (not shown on Figure 7.1).

ARCHEAN LITHOSTRATIGRAPHY OF THE RIDOUT LAKE AREA

The supracrustal rocks of the Ridout Lake area are composed primarily of metavolcanic rocks with local units of metasedimentary rocks (Figure 7.2). These rocks are intruded and crosscut by smaller bodies of felsic to intermediate intrusive rocks.

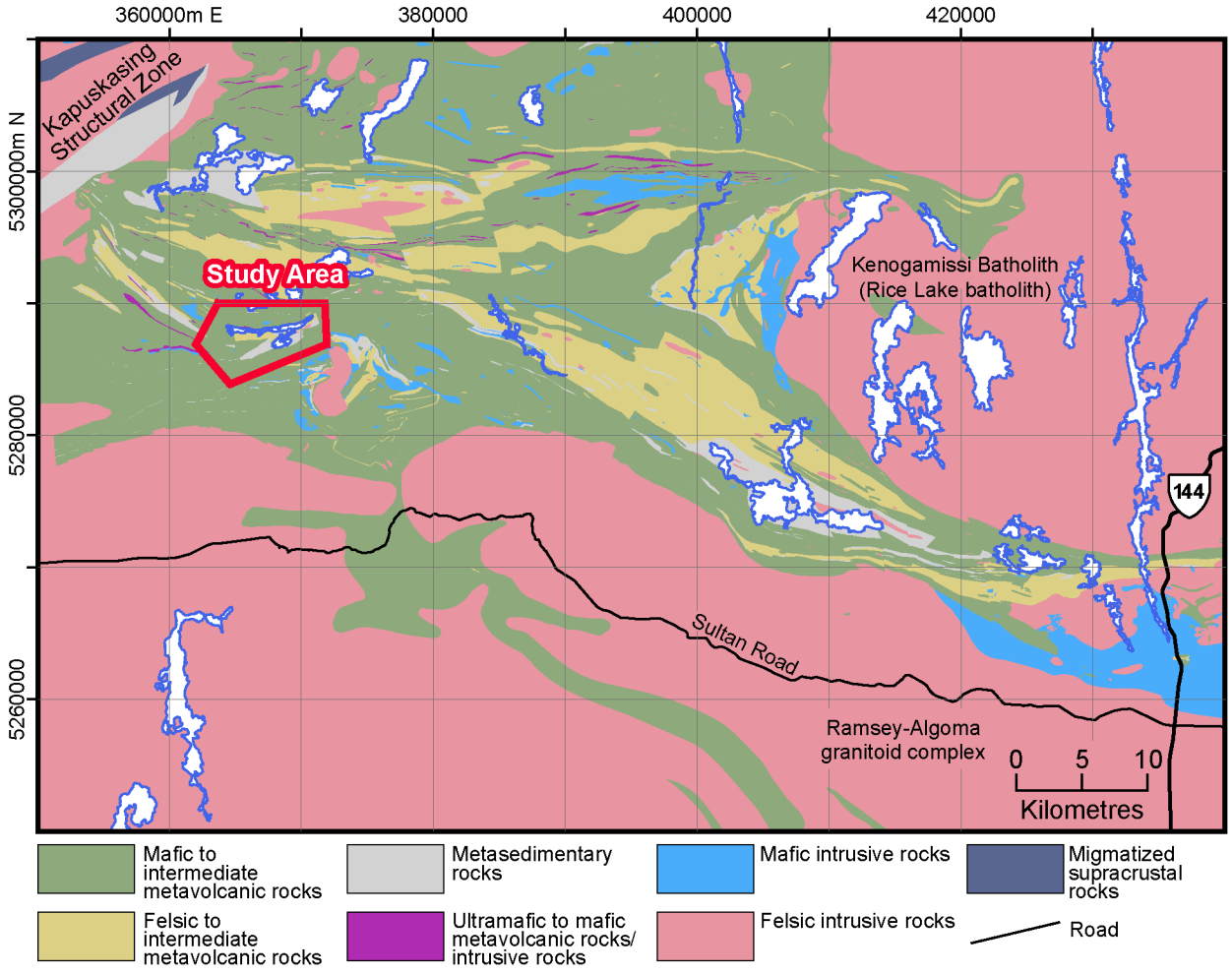


Figure 7.1. Simplified geological map of the southern Swayze area of the Abitibi greenstone belt displaying the study area (outlined by red box). Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 17. Geology *modified from* Ontario Geological Survey (2011).

Archean Metavolcanic Rocks

Within the study area, the metavolcanic rocks include abundant mafic to intermediate massive to pillowed flows interlayered with minor ultramafic to mafic flows and felsic to intermediate volcaniclastic rocks.

Mafic to intermediate and intermediate metavolcanic rocks constitute the dominant rock types within the Ridout Lake area (*see* Figure 7.2). These rocks vary in colour from dark green to light green and are typically cryptocrystalline to fine-grained, massive and pillowed lava flows (Photo 7.1A). Pillows are typically ameboid shaped, range in size from 50 to 100 cm wide and thick, and are separated by thin 1 to 3 cm thick interpillow materials that locally contains pyrite or pyrrhotite. Massive, fine-grained ultramafic to mafic metavolcanic flows occur locally on the north shore of Ridout Lake and on the western shore of Hotstone Lake (*see* Figure 7.2). These flows vary from medium to dark green to an altered brown with fuchsite defining the foliation.

Felsic to intermediate metavolcanic rocks mainly occur as volcaniclastic deposits that have preferentially taken up most of the deformation across the lakes of the area. The felsic to intermediate volcaniclastic rocks are dominantly white to light greyish green thinly bedded tuffs (Photo 7.1B) with lesser lapilli tuffs and tuff breccias. One of these units, from an outcrop in Ridout Lake, yielded an age of 2730±3 Ma (van Breemen, Heather and Ayer 2006) (Table 7.1; *see* Figure 7.2, location 1). A second unit, located along Little Ridout Lake, yielded an age of 2695±2 Ma (van Breemen, Heather and Ayer 2006) (*see* Table 7.1; *see* Figure 7.2, location 2).

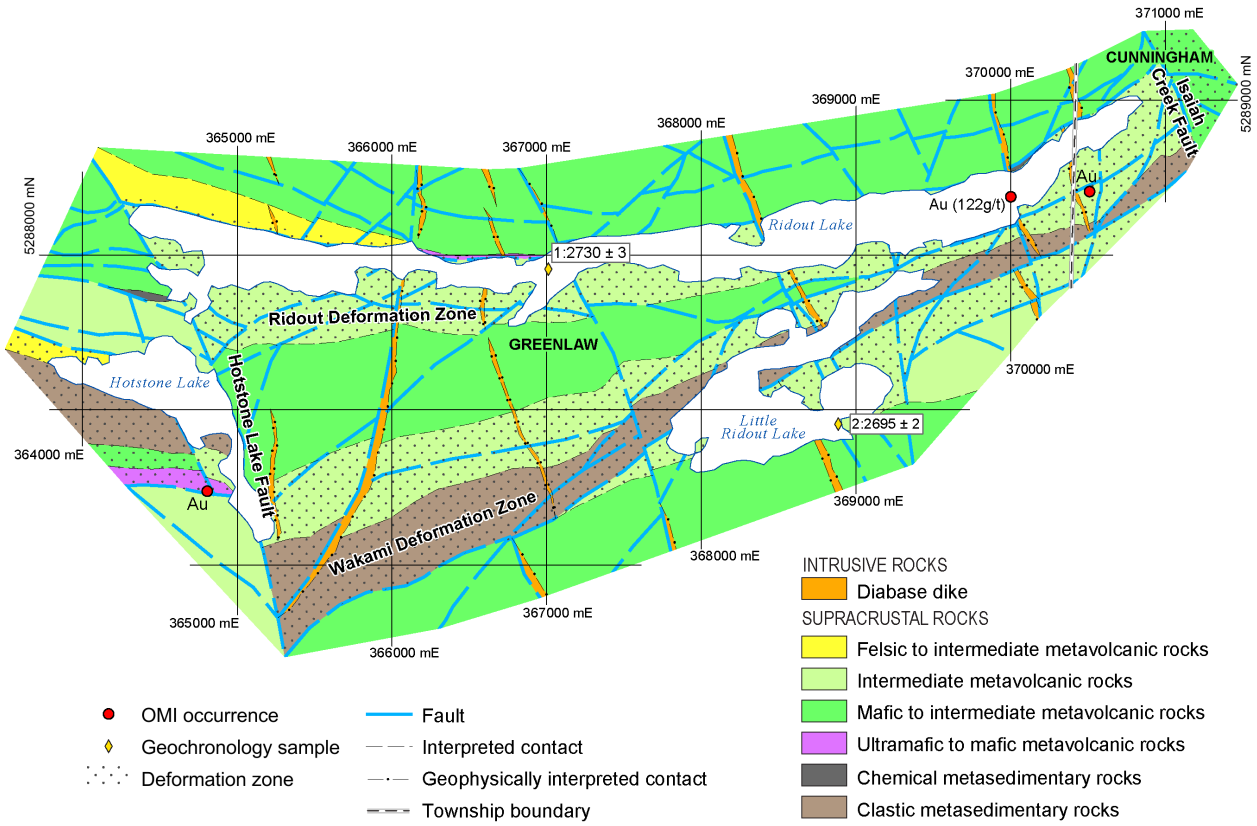


Figure 7.2. Preliminary geological map of the Ridout Lake area. Geochronology data are presented in million years (Ma); *see* Table 7.1 for additional information. Ontario Mineral Inventory (OMI) (Ontario Geological Survey 2025) indicate documented primary commodities and OMI category. Abbreviation used: Au, gold. Location information provided as UTM co-ordinates using NAD83 in Zone 17.

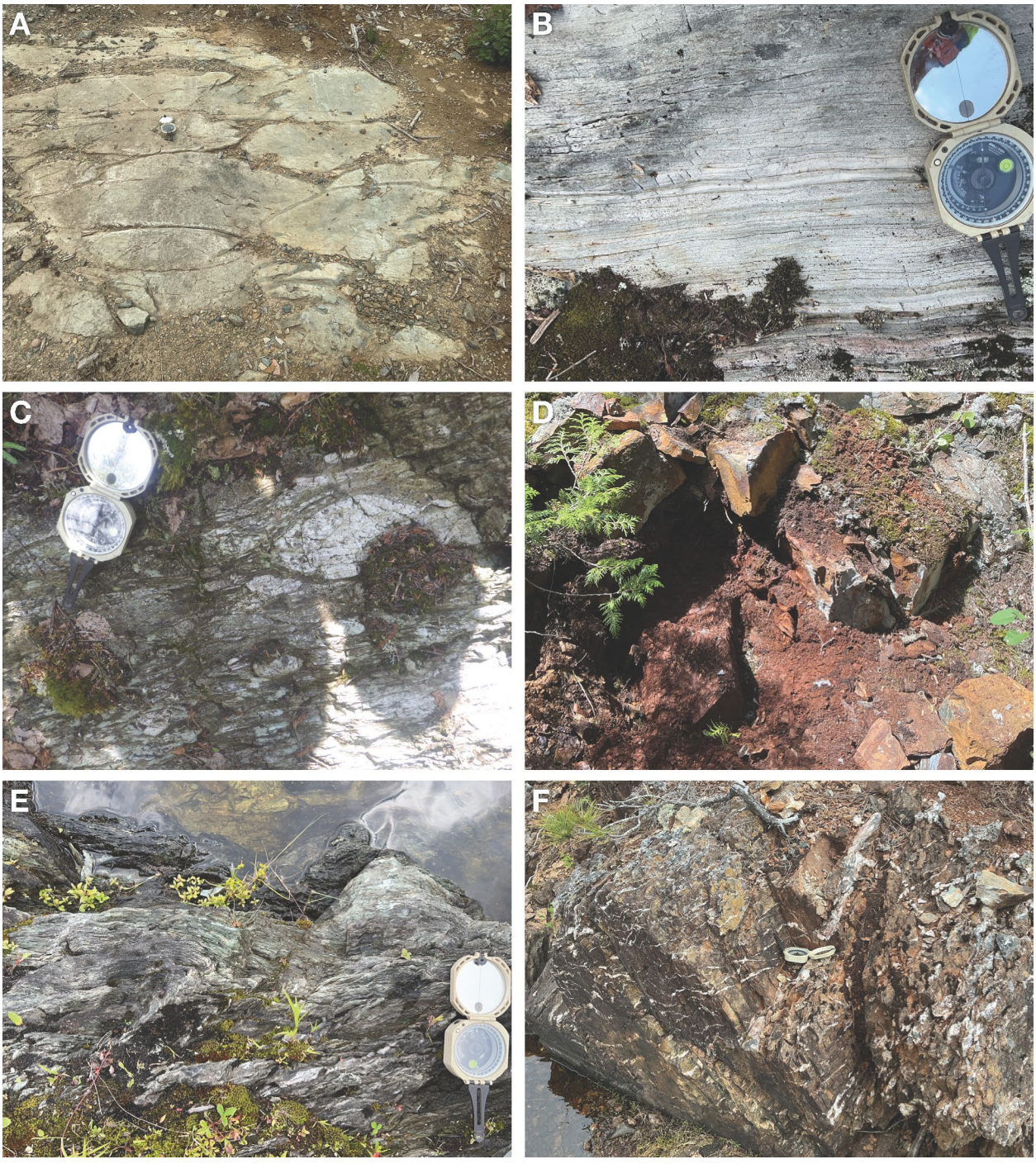


Photo 7.1. Selected photographs of lithological units. **A)** Fine-grained mafic pillowed flow with younging to the south in Greenlaw Township (substation 25TG0015SS: UTM 369281E 5286790N). **B**) Thinly bedded, fine-grained felsic tuff (or sandstone) in Greenlaw Township (substation 25TG0353SS: UTM 364128E 5287286N). **C**) Polymictic conglomerate with volcanic, intrusive and sedimentary clasts in Cunningham Township (station 23TG050: UTM 371131E 5288631N). **D**) Banded ironstone in Greenlaw Township (station 25LP016: UTM 370050E 5288556N). **E**) Deformed mafic metavolcanic rocks exhibiting Z folding in Greenlaw Township (substation 25TG0354SS: 3 UTM 64484E 5287456N). **F**) Deformed intermediate tuff with pervasive iron-carbonate alteration, fuchsite defining the foliation and crosscutting quartz-carbonate veins in Greenlaw Township (station 25TG013: UTM 367008E 5287963N). Compass for scale is 22 cm long, with sighting arm pointing north. Hammer for scale is 42 cm long. All location information provided as UTM co-ordinates using NAD83 in Zone 17.

Table 7.1. Geochronological data referred to in the text; locations and ages are shown on Figure 7.2.

No. on Figure 7.2	U/Pb Method on Zircon [a]	Age (Ma)	Interpretation	Rock Type	Easting [b] (m)	Northing [b] (m)	Source
1	TIMS	2730±3	Volcanism	Felsic crystal tuff	367013	5287904	van Breemen, Heather and Ayer (2006)
2	TIMS	2695±2	Volcanism	Felsic crystal tuff	368881	5286906	van Breemen, Heather and Ayer (2006)

[a] *Methods abbreviations: TIMS, U/Pb thermal ionization mass spectrometry.*
[b] *Locations provided as UTM co-ordinates in NAD83, Zone 17.*

Archean Metasedimentary Rocks

The study area hosts both clastic and chemical metasedimentary rocks. Clastic metasedimentary rocks are present along Little Ridout and Hotstone lakes (*see* Figure 7.2). The clastic metasedimentary rock units comprise up to approximately 250 m thick, southwest-trending, Timiskaming-style polymictic conglomerate lenses exposed along the Wakami deformation zone (*see* Figure 7.2). The conglomerates are primarily matrix supported and are composed of pebble-sized clasts with lesser cobbles and boulders and are intercalated with local silty to sandy beds (Photo 7.1C). The conglomerates are polymictic with clasts, in decreasing order of abundance, of felsic to intermediate metavolcanic rocks, felsic to intermediate intrusive rocks, mafic metavolcanic rocks, massive pyrite and locally sparse chert and hematized chert.

The chemical metasedimentary rocks were only observed in narrow, approximately 10 m, near-vertical, west-trending horizons on the western and northeastern shore of Ridout Lake (*see* Figure 7.2). The ironstones are primarily oxide or carbonate facies with lesser sulphide facies. They are predominantly composed of chert with lean alternating bands of magnetite, carbonate or sulphide beds (Photo 7.1D).

Archean Intrusive Rocks

In the Ridout Lake area, Archean intrusive rocks are locally present. These intrusive rocks are felsic to intermediate porphyritic intrusions (not represented on Figure 7.2) that are small (metre scale), are typically white to light grey, and have 1 to 5 mm feldspar and/or quartz phenocrysts.

PROTEROZOIC INTRUSIVE ROCKS

All Archean rocks in the field area are crosscut by a single Proterozoic dike swarm. Gabbro dikes of the Matachewan dike swarm (*circa* 2460 Ma: Bleeker et al. 2015), which are generally north to northwest trending, were observed in the map area (*see* Figure 7.2). These dikes can range from a few centimetres to several metres wide, and typically exhibit well-developed chilled margins. These dikes are amphibole and pyroxene rich, magnetic and locally contain euhedral to anhedral plagioclase phenocrysts.

STRUCTURAL GEOLOGY

The dominant fabric in the Ridout Lake area is a penetrative tectonometamorphic foliation defined by sericite and chlorite that trends approximately west and is steeply dipping. It is parallel to the dominant regional foliation observed in northwestern Cunningham Township to the east (Gemmell and Creppin 2023).

Two dominant high-strain zones occur across the study area: 1) the Ridout deformation zone to the north and 2) the Wakami deformation zone to the south (*see* Figure 7.2). Both deformation zones are characterized by the destruction of primary textures and commonly contain abundant iron-carbonate alteration. The Ridout deformation zone follows the east-west trend of Ridout Lake. To the east, the

Ridout deformation zone branches off onto the Wakami deformation zone that trends to the southwest along Little Ridout Lake (*see* Figure 7.2). The Ridout deformation zone has been traced over tens of kilometres across the southern Swayze area (Heather 2001) and has generally been known as the most significant deformation zone in this area. In the Ridout Lake area, the Wakami deformation zone clearly offsets the Ridout deformation zone; when plotted on a map, the offset of the Wakami deformation zone is sinistral to the Ridout deformation zone. The Wakami deformation zone can be followed along strike to the southwest all the way to the Ramsey–Algoma granitoid complex (*see* Figure 7.1). However, its northeastern extension into the Swayze area is still a matter of debate and its relationship with the Rundle deformation zone remains enigmatic. Locally, these high-strain zones exhibit both sinistral and dextral kinematic indicators. The sinistral shearing was observed predominantly in the Timiskaming-type conglomerates along the Wakami deformation zone, which suggests that this deformation event is a younger one.

Late phases of the ductile deformation are characterized on the outcrop scale by local crenulation cleavage (*see* Photo 7.1E).

Late east-northeast– and later north-northwest–trending brittle faults that exhibit both strike–slip and dip–slip components crosscut all supracrustal rocks in the study area. The Hotstone Lake fault, located on the west side of the Ridout Lake area, has a north-northwest strike and may have a dextral displacement of approximately a little more than 1 km. The Hotstone Lake fault is similar in trend to the Isaiah Creek fault, located in northwestern Cunningham Township. However, on a map, the Isaiah Creek fault displays a pattern indicating an apparent sinistral offset of approximately 1.4 km. It is unclear whether or not these 2 faults were active during the Archean, but they are parallel to many other similar northwest-trending faults or fractures in the area along which the Matachewan dikes emplaced. This suggests that these structures were somewhat active (i.e., the expression of the regional stress field) during the intrusion of the Matachewan dike swarm in the Paleoproterozoic.

ALTERATION AND METAMORPHISM

The earliest observed alteration (syn- to post-metamorphism) is widespread fracture-controlled replacement of amphiboles and feldspars by chlorite and sericite, respectively, in mafic to felsic metavolcanic rocks. Later phases of alteration overprint the supracrustal rocks within high-strain zones and include iron carbonate, sericite, chlorite, quartz and fuchsite alteration (*see* Photo 7.2F). The later overprinting alteration is interpreted to be related to hydrothermal fluids.

Archean rocks in the study area have undergone regional lower greenschist-facies metamorphism, with local areas of upper greenschist-facies metamorphism. Lower greenschist-facies assemblages are characterized by chlorite ± actinolite in the mafic metavolcanic rocks, chlorite + muscovite in the felsic metavolcanic, metasedimentary and intrusive rocks; the upper greenschist facies is characterized by the increased amphibole content (actinolite) over chlorite.

MINERALIZATION

There are 2 known occurrences and 1 discretionary occurrence of gold mineralization in the Ridout Lake area, all of which are hosted within high-strain zones and are associated with iron-carbonate and quartz-carbonate veining (Ontario Geological Survey 2025; *see* Figure 7.2). The Garvey vein (Gold Island) is ranked as a discretionary occurrence; some work performed in the Garvey vein reported gold values up to 122 g/t Au (Sexton, Goodwin and Collins 1996). Although only 3 occurrences are reported (Ontario Geological Survey 2025) in the map area, it is important to highlight that there are numerous assessment files from the area that report gold grades above the Ontario Mineral Inventory minimum requirement of 0.5 g/t Au for an “occurrence” (Ontario Geological Survey 2023).

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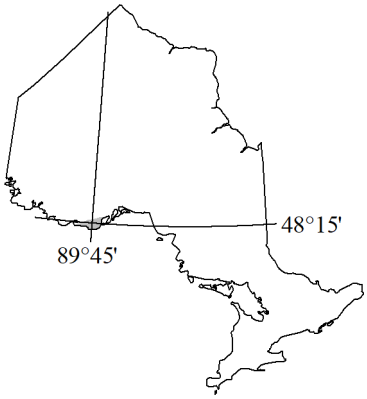
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8. Project NW-22-002. Toward a Refined Lithostratigraphic Nomenclature for the Animikie Group in Ontario



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INTRODUCTION

Bedrock mapping of the Paleoproterozoic rocks of the Animikie Group has not been carried out in Ontario for several decades and existing mapping does not cover the bulk of its known spatial extent at a scale more detailed than 1:250 000. Consequently, the lithostratigraphic nomenclature for the Animikie Group in Ontario has seen limited critical review or revision since the 1950s and 1960s when the OGS carried out mapping of part of the Gunflint Formation. Goodwin completed a doctoral thesis on the stratigraphy of the Gunflint Formation (e.g., Goodwin 1953, 1956, 1960; Moorhouse 1960) and the Rove Formation was examined in a doctoral thesis study by Morey (1967, 1969). Although lithostratigraphic nomenclature has not been significantly modified, numerous important advances have been made in understanding the geology of the Animikie Group (among others, *see* for example, Fralick, Davis and Kissin 2002; Addison et al. 2005).

Re-examining the lithostratigraphy of the Animikie Group, particularly with the goal of developing a nomenclature suitable for 1:50 000 scale mapping, has been one aim of field work related to an ongoing project that includes compilation, geophysical and lidar data interpretation, and bedrock geology mapping, which was initiated in the Animikie Basin in 2022 (Metsaranta and Kurcinka 2022). The overall goal of this project is to produce new digital bedrock geology maps of the Animikie Basin and spatially associated rocks of the Midcontinent Rift, in the area stretching from the City of Thunder Bay southward to the Canada–United States border and westward to the Gunflint Lake area (Metsaranta and Kurcinka 2022, 2024).

In this article, we attempt to summarize existing lithostratigraphic stratigraphic nomenclature for the Gunflint and Rove formations based mainly on work by Gill (1926), Goodwin (1953, 1960), Moorhouse (1960) and Morey (1967) and propose tentative revisions for the purpose of regional bedrock mapping, based on new outcrop and drill-core observations. Tanton (1931) also described the stratigraphy of the Animikie Group, but description of that data are not compiled herein for brevity. The primary goal of these revisions is to move toward the development of descriptive, mappable units that convey the essential characteristics of rocks comprising Animikie Group in Ontario and their stratigraphic and spatial relationships. The location of the project is shown in Metsaranta and Kurcinka (2022).

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GENERAL LITHOSTRATIGRAPHY OF THE ANIMIKIE GROUP IN ONTARIO

A more-or-less formalized lithostratigraphic nomenclature for the Animikie Group in Ontario at the "Formation" level has been established and used since the early part of the 20th century (e.g., Gill 1926; Tanton 1931). The lower part of the Animikie Group consists of the Gunflint Formation comprising mainly iron-rich chemical sedimentary rocks (mineralogically varied grainstone and mudstone) with minor conglomerate, shale, volcaniclastic rocks and basalt. The Gunflint Formation rests unconformably on Archean basement (continental crust) without intervening older Proterozoic strata. Estimates of the thickness of the Gunflint Formation indicate that it is approximately 200 m thick (e.g., Metsaranta and Kurcinka 2022; Pufahl 1996). The upper Animikie Group consists of the Rove Formation that disconformably overlies the Gunflint Formation. The Rove Formation consists of a coarsening thickening upward sequence of primarily siliciclastic rocks (siltstone, pyritic shale, greywacke). Morey (1967) estimated that the Rove Formation is approximately 975 m thick. An angular unconformity separates the overlying Mesoproterozoic rocks of the Sibley Group from the Animikie Group.

Gunflint Formation Subdivisions

A two-fold informal lithostratigraphic subdivision into lower and upper units (lower Gunflint, upper Gunflint) has been employed since the work of Gill (1926), Goodwin (1953, 1960) and Moorhouse (1960). This general subdivision largely follows the longstanding traditional subdivision of the Biwabik Iron Formation ("Mesabi Iron Range") primarily into lower and upper members with lower cherty and lower slaty, and upper cherty and upper slaty submembers, respectively, that overlie the siliciclastic Pokegama Formation (*see* stratigraphy reviews in Ojakangas, Morey and Southwick 2001; Severson, Heine and Patelke 2009, and references in both). In the Mesabi Iron Range, these divisions are well established and based on correlation of rock units exposed during mining operations that have continued for longer than a century. Broderick (1920) also applied such terminology to the Gunflint Formation of northern Minnesota.

Despite a general agreement on correlation of the Gunflint Formation with similar rocks of the Biwabik Iron Formation, important differences exist. Chemical sedimentary rocks dominate both areas and are clearly similar; however, the Gunflint Formation includes a higher proportion of volcanic rocks and fine-grained siliciclastic material (Tanton 1931; Gill 1926; Goodwin 1960; Moorhouse 1960), whereas, according to detailed work described in Severson, Heine and Patelke (2009), siliciclastic material is an exceedingly rare occurrence (restricted to the Lower Cherty, and only debatably in parts of the Lower Slaty, i.e., the "intermediate slate") and volcanic rocks are entirely absent.

More detailed descriptive lithostratigraphic subdivisions of the Gunflint Formation in Ontario compiled from Gill (1926) and Goodwin (1953) are shown in Tables 8.1a and 8.1b. For more detailed descriptive reviews, readers are encouraged to refer to the original literature. Non-standard rock terminology used in this older literature is somewhat difficult to follow (for descriptions, *see* Gill (1926) and Moorhouse (1960)); "taconite" refers to chemical sedimentary rocks with visible granular texture (likely analogous to grainstone, or packstone in the carbonate classification scheme of Dunham (1962), but with a mainly non-carbonate intraclast composition); shale or tuffaceous shale refers to fine-grained siliciclastic (interpreted to be volcaniclastic) rocks; and "banded" refers to thinly bedded, mainly chemical sedimentary rocks. "Algal chert" corresponds to the more conventionally used terms stromatolite or microbialite and "basic flow" is equivalent to basalt or mafic lava or basalt.

Subdivisions established by Gill (1926) differ to some extent from those of Goodwin (1953, 1960) (*see* Tables 8.1a and 8.1b). However, similarities are clear. Both nomenclature schemes, in addition to similar descriptions of iron-rich chemical sedimentary rocks, recognize a lower conglomerate unit,

Table 8.1a. Lithostratigraphic subdivisions of the Gunflint Formation based on Goodwin (1953, 1960).

Goodwin (1953, 1960) Informal formation or member-rank subdivisions	**Goodwin (1953, 1960) Informal member- or submember-rank subdivisions**	**Maximum thickness (nearest metre, converted from feet)**
Upper Limestone	None	6
Upper Gunflint	Upper taconite facies, Upper banded chert carbonate facies	55
	Upper tuffaceous shale facies	5
	Upper jasper facies	20
	Upper algal-chert facies, includes basic flow rock up to 40 feet locally	7 (excluding basic lavas)
Lower Gunflint	Lower west taconite facies, Lower east taconite facies, Lower banded chert-carbonate facies	64
	Lower tuffaceous shale facies	5
	Lower algal-chert facies	5
Basal Conglomerate	None	1 (rounded up artificially typically thinner)
		168 total thickness (maximum)

a lower shale unit (siliciclastic and/or volcaniclastic origin interpreted), the existence of a basaltic lava flow unit of apparently limited areal extent, an upper tuffaceous unit of volcaniclastic origin and an upper carbonate-rich unit. Similarly, both schemes recognize lower and upper "algal chert" units, and volumetrically dominant chemical sedimentary rock units appear to comprise broadly similar granular textured and more thinly laminated iron-rich rocks of varying mineralogy (greenalite, siderite, chert, jasper, hematite, magnetite).

Only Goodwin (1960) and Moorhouse (1960) and maps therein, have attempted to apply internal subdivisions of the Gunflint Formation to geological mapping. Small bedrock maps contained in Gill (1926) and mapping by Tanton (1931) do not portray internal subdivisions of the Gunflint Formation, although Tanton (1931) does include lower and upper iron formations as codes in his legend. Curiously, bedrock geology maps in Goodwin (1960) and Moorhouse (1960) did not precisely employ their detailed lithostratigraphic subdivisions (*see* Table 8.1a) as contacts displayed on their maps. These maps **do** attempt to portray the "upper and "lower" Gunflint formations, However, the contact is typically marked by an "argillite-tuff" unit. The "argillite tuff" unit appears to match the description of the "upper tuffaceous shale facies" (Goodwin 1953, 1960); however, this does not correspond to their subdivision of "lower Gunflint" and "upper Gunflint" formations (*see* information compiled in Table 8.1a). The reason for this discrepancy is unclear but may relate to the fact the maps (early 1950s) were completed prior to the geological reports. This may also be the result of it being difficult to precisely apply detailed stratigraphic subdivisions in this relatively poorly exposed flat-lying basin.

An alternative nomenclature for the Gunflint Formation in northern Minnesota and Ontario, based on a sedimentologic and sequence stratigraphic approach, is described by Jirsa (2011) and Jirsa et al. (2011), based to some extent on work by Pufahl (1996) and Pufahl and Fralick (2000). This work presented the stratigraphy of the Gunflint Formation in the context of sea level transgression–regression events and placed the "divide" between the lower Gunflint and upper Gunflint at a maximum regressive surface interpreted to coincide with a unit of stromatolites, intraformational conglomerates and alteration interpreted to represent an interval of shallow water deposition or subaerial exposure. These stromatolites likely correspond with the upper algal chert facies of Goodwin (1953, 1960) and the algal cherts in "Division 4" of Gill (1926). In this subdivision, the contact between the lower sequence and upper sequence is coincident with the upper contact of the "upper cherty" submember (Jirsa 2011).

Table 8.1b. Lithostratigraphic subdivisions of the Gunflint Formation based on Gill (1926).

Gill (1926) Informal formation- or member-rank subdivisions	Gill (1926) Informal member- or submember-rank subdivisions	Maximum thickness (nearest metre)
Division 5 (upper slaty)	Ferruginous limestone and dolomite with interbedded magnetic and amphibolitic cherty taconite	37
	Massive thick beds of greenalite and cherty taconite with magnetite and carbonate-rich partings	46
	Thin siderite-greenalite and magnetite-rich beds with fissile, ferruginous, in some cases tuffaceous, partings; lenticular beds of nearly pure chert, and a few of greenalite taconite. All show more or less alteration to amphibolitic and magnetitic types near sill contacts	22
	Tuffaceous taconite	1
	Hematite-magnetite taconite, with ferruginous, slaty, in part tuffaceous, interbeds	18
	Conglomeratic hematite and cherty taconite	2
Division 4 (upper cherty)	Chert with algal structures	3
	Cherty taconite, in part oolitic, associated with algal chert and intraformational conglomerate, locally 0 to 50 feet of lava	3
	Massive cherty taconite, locally magnetic, with jasper seams and locally intraformational conglomerate	6
Division 3 (upper cherty and part of lower slaty)	Magnetic greenalite and cherty taconite	15
	Magnetic chert with magnetite nodules and interbeds of greenalite taconite; grading horizontally into greenalite taconite with carbonate nodules and cherty-carbonate beds	37
	Greenalite taconite with small carbonate nodules locally; siderite-greenalite slate; cherty taconite at the bottom	23
Division 2 (intermediate slate)	Ferruginous slate including some fragmental, probably pyroclastic material, and locally carbonaceous matter	5
Division 1 (lower cherty)	Cherty and (or) greenalite taconite with variable amounts of carbonates	5
	Chert with algal structures and small amounts of cherty taconite, in part oolitic	3
Basal conglomerate		1
		227 total thickness (maximum)

Problems exist with the application of this two-sequence nomenclature for mapping the Gunflint Formation in Ontario. It does not include some volcanic, volcaniclastic and siliciclastic units known to be present in the Animikie Basin in Ontario (and thus no provisions for mapping their distribution). Also, the interpretation of the upper sequence as a continuous transgressive tract (Jirsa 2011) is problematic because the intraformational breccias interpreted as Sudbury impact ejecta near the top of the Gunflint Formation directly overlie stromatolites (e.g., Addison et al. 2010) implying a sea level regression occurred toward the end of Gunflint Formation deposition. Further, thesis work by Arts (2015) indicated the presence of an additional stromatolitic interval within the upper Gunflint sequence suggesting that the upper sequence of the Gunflint may in fact represent several cycles of sea level change, rather than a single cycle.

Rove Formation Subdivisions

Although much of the outcrop belt of the Rove Formation in Ontario was mapped by the OGS in the 1970s and 1980s (Geul 1970; Smith and Sutcliffe 1989), previous work on lithostratigraphic subdivisions

of the Rove Formation was carried out mainly by Morey (1967), who divided the Rove Formation into 3 subunits:

- a lower argillite unit 400 feet (approximately 122 m) thick
- a transitional unit of greywacke and silty argillite 70 to 100 feet (approximately 21 to 30 m) thick
- an upper unit of greywacke and argillaceous siltstone 2700 feet (approximately 823 m) thick with local quartzite beds toward the top

Bedrock geology maps depicting internal subdivisions of the Rove Formation do not exist as far as we know. Additional complexities in Rove Formation stratigraphy not captured in this nomenclature scheme include the presence of thin tuffaceous horizons in lower part of the Rove Formation (e.g., Addison et al. 2005). Also, Tanton (1936) mapped a succession of mafic to intermediate flows apparently concordant with Rove Formation strata (*see also* Cundari 2010).

PROVISIONAL LITHOSTRATIGRAPHIC UNITS MAPPABLE AT 1:50 000 SCALE

Provisional "mappable" revised subdivisions of the Gunflint Formation, based on compilation, preliminary bedrock mapping and drill-core logging (mainly drill core ST-22-01), are shown in Figure 8.1 with comparisons to subdivisions of Jirsa (2011), Gill (1926) and Goodwin (1953, 1960). The applicability of these map units to 1:50 000 scale mapping in the Animikie Basin in Ontario remains to be fully tested. Herein, we provide brief descriptions of provisional member-rank subdivisions of the Gunflint Formation, which we group informally into lower, middle and upper parts of the Gunflint Formation to facilitate comparison to older informal nomenclature. The informal (lower, middle, upper) divisions approximate "Formation" rank units and there may be utility in defining them as such in the future. Such a change would also require revising Gunflint Formation (and Rove Formation) to "Group" level. However, prior to proposing such major changes to the current stratigraphic lexicon, more work is required and this may not serve a significant purpose. The provisional member-rank units will need to be further defined in a subsequent publication in order to be compliant with the North American Stratigraphic Code (North American Commission on Stratigraphic Nomenclature 2021). It is expected that the proposed member-rank subdivisions in this article will change because of additional mapping and drill-core logging. This provisional subdivision uses a lithostratigraphic approach, instead of focussing on a "sequence" correlation approach. This approach may, in fact, help to clarify correlation of stratigraphic sequences by emphasizing boundaries of more rapidly deposited volcanic rock units rather than sea-level-change linked facies variations which may help others to support contemporaneity of shallower and deeper water facies.

Lower Part of the Gunflint Formation

The lower part of the Gunflint Formation includes the provisional Kakabeka member, Schreiber Beach member, North Lake member and Little Gull Lake member and encompasses rocks occurring between the Archean basement and the base of basaltic flows of the Mink Mountain member.

KAKABEKA MEMBER

The Kakabeka member refers to a thin basal conglomerate present discontinuously throughout the Animikie Basin. It is typically a massive, siliciclastic, polymictic pebble to cobble conglomerate less than 1 m thick. It is typically poorly sorted, clast to locally matrix supported and includes a variety of clast

types, usually reflecting local basement rock geology. Photo 8.1A shows a representative photo of the basal conglomerate along Highway 102 west of Thunder Bay. The Kakabeka member is sharply overlain by cherty stromatolites or grainstones of the Schreiber Beach member.

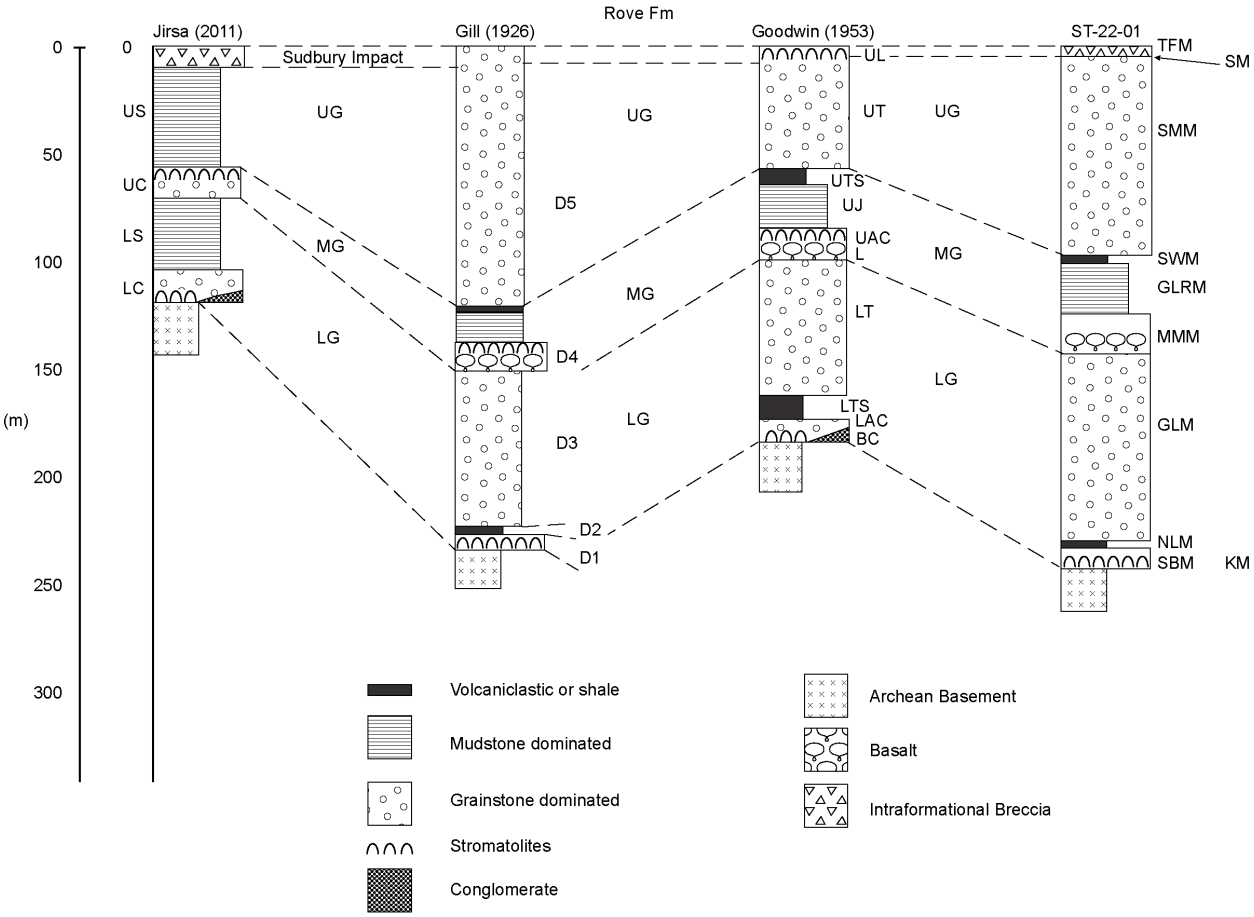


Figure 8.1. A comparison of simplified stratigraphic columns for the Gunflint Formation *adapted from* Jirsa (2011), Gill (1926) and Goodwin (1953, 1960) to provisional lithostratigraphic member-rank subdivisions of the Gunflint Formation in drill core ST-22-01 (this study). Drill hole ST-22-01 (UTM 283702E 5335114N, Zone 16) cored a section through most of the Rove Formation and all the Gunflint Formation nearly perpendicular to bedding in the central part of the Ontario portion of the Animikie Basin providing an ideal model of Animikie Group stratigraphy. The column of Jirsa (2011) was derived from work carried out in northern Minnesota; the column of Gill (1926) is mainly based on work in the southwestern part of the Animikie Basin in Ontario; and the column of Goodwin (1953) is based mainly on mapping in the northeastern and central parts of the Animikie Basin in Ontario. Abbreviations related to Jirsa (2011) idealized stratigraphic column: US is upper slaty, UC is upper cherty, LS is lower slaty, and LC is lower cherty. Abbreviations related to Gill (1926) idealized stratigraphic column: D5 is Division 5, D4 is Division 4, D3 is Division 3, D2 is Division 2 and D1 is Division 1. Abbreviations related to Goodwin (1953, 1960) idealized stratigraphic column: UL is upper limestone, UT is upper taconite, UTS is upper tuffaceous shale, UJ is upper jasper, UAC is upper algal chert, L is lava, LT is lower taconite, LTS is lower tuffaceous shale, LAC is lower algal chert, and BC is basal conglomerate. Abbreviations related to simplified stratigraphic column for drill core ST-22-01 (this study) as follows: TFM is Terry Fox Lookout member, SM is Stanley member, SMM is Shuniah Mines member, SWM is Spillway member, GLRM is Gravel Lakes Road member, MMM is Mink Mountain member, GLM is Little Gull Lake member, NLM is North Lake member, SBM is Schreiber Beach member, and KM is Kakabeka member. The SM and KM are not present in ST-22-01, but their typical stratigraphic positions based on outcrop observations are indicated. For correlations between columns, LG is lower part of the Gunflint Formation, MG is middle part of the Gunflint Formation, and UG is upper part of the Gunflint Formation: these are informal descriptive divisions of the Gunflint Formation described in the body of the article. Note that sills of Midcontinent Rift–related diabase are removed from idealized Gunflint Formation section derived from drill core ST-22-01. Thicknesses of some thinner units exaggerated to make them more visible, more accurate thicknesses should be taken from descriptions in the text of the article.

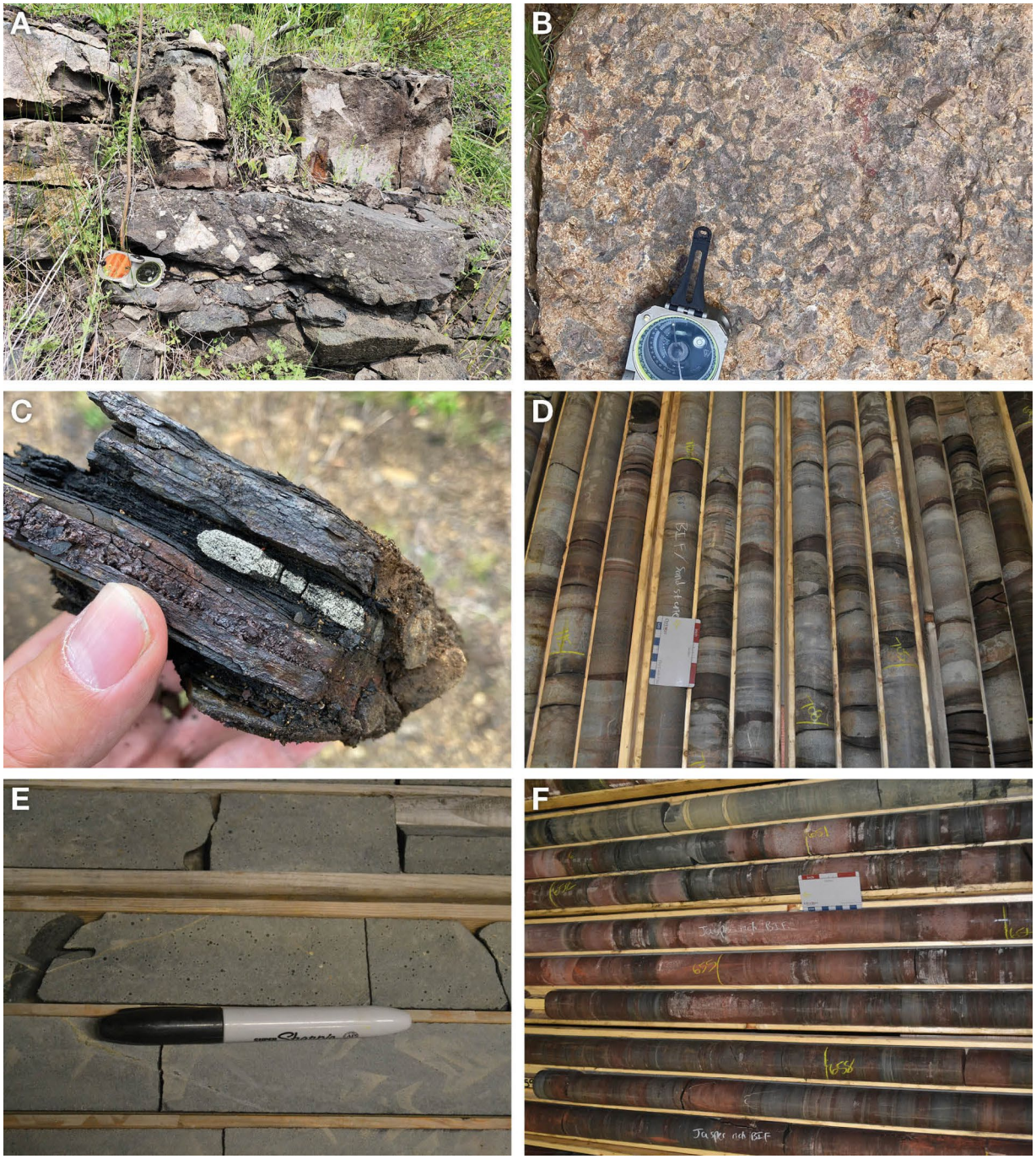


Photo 8.1. Representative photos of provisional subdivisions of the Gunflint Formation. **A**) Quartz pebble–rich conglomerate of the Kakabeka member overlain by cherty grainstones and overlying chloritized Archean granitoid rocks, Highway 102. Station 25RTM851: UTM 330816E 5370654N, Zone 16. Compass is 22 cm long. **B**) Bedding plane view of digitate cherty stromatolites (Schreiber Beach member) resting directly on Archean granitoid rocks (not visible in photo), Jean Township. Station 23CEK002: UTM 710215E 5347749N, Zone 15. Compass sighting arm is 7 cm long. **C**) Thinly bedded pyritic shale of the North Lake member. Station 22RTM014: UTM 687237E 5335852N, Zone 15. Thumbnail is 1.5 cm wide. **D**) Medium- to thick-bedded pale cherty grainstone beds and red chemical mudstone beds of the Little Gull Lake member. Drill core ST-22-01: UTM 283702E 5335114N, Zone 16; NQ core, approximate depths 700 to 716 m. Scale card smaller gradations in centimetres; way-up is toward the right. **E**) Vesicular basalt of the Mink Mountain member, Hartington Township. Drill core ST-22-01: UTM 283702E 5335114N, Zone 16; approximate depth 680 m. Marker is 15 cm long. **F**) Interbedded red chemical mudstones, pale red cherty grainstones and thin grey volcaniclastic to siliciclastic horizons of the Gravel Lakes Road member. Drill core ST-22-01: UTM 283702E 5335114N, Zone 16; approximate depths 650 to 660 m. Smaller scale card divisions in centimetres.

SCHREIBER BEACH MEMBER

Provisionally, the Schreiber Beach member contains stromatolites (Photo 8.1B) and coarse-grained, medium-bedded, locally conglomeratic (intraformational), locally trough cross-stratified, cherty grainstones occurring between Archean basement and/or the Kakabeka member but below the base of the North Lake member. Typical thicknesses of this member are undetermined; however, in drill core ST-22-01, cherty stromatolites and grainstones between Archean basement and the base of a thin black shale representing the North Lake member amount to a thickness of 1.8 m. In outcrop, greater minimum thicknesses (at least 3–4 m) have been observed. At a more detailed scale, this unit could be divided further into stromatolitic and grainstone submembers.

NORTH LAKE MEMBER

The provisional North Lake member comprises a thin, black, fissile, pyrite-nodule–bearing shale (Photo 8.1C), locally containing micaceous material on shaly parting surfaces. Gill (1926) described the unit (his "Division 2") as follows: "This division, though thin, is one of the most uniform and persistent in the iron formation, and is, therefore, of great value for purposes of correlation". In drill core ST-22-01, this member is only 0.8 m thick. Gill (1926) provided its thickness as between 8 and 15 feet (2.5 to 4.5 m) thick and Goodwin (1953, 1960) measured a thickness of 4 to 22 feet (1.2 to 6.7 m). Goodwin (1953) reported that this unit is only present in the southwestern portion of the basin. However, our field observations and maps in Moorhouse (1960) and Goodwin (1960) show many outcrops comprising his unit 3e (i.e., Gunflint Formation, argillite) within the lower Gunflint formation, near the basal unconformity in the northern part of the City of Thunder Bay, suggesting that this unit extends farther to the northeast than suggested by Goodwin (1953).

LITTLE GULL LAKE MEMBER

The Little Gull Lake member (Photo 8.1D) comprises the bulk of the lower part of the Gunflint formation. In drill core ST-22-01, it is 49.6 m thick and is in sharp contact with the underlying shale and the overlying basaltic lava flows. This unit is inferred to correspond to the "lower taconite facies" ("lower west" and "lower east" taconites and "lower banded chert-carbonate") of Goodwin (1953) and "Division 3" of Gill (1926). This member is heterogenous, comprising mainly chert-cemented grainstones of various mineralogies (chert, greenalite, iron carbonate, iron oxide; presently, we do not have petrographic data to support a robust characterization of mineralogy or primary versus secondary phases). Thin- to medium-bedding thicknesses are predominant and grainstones are on average medium grained. In drill core ST-22-01, the unit contains varying proportions of laminated or thin-bedded reddish chemical mudstone. Locally, thin intraformational conglomerates are present, as are 1 to 2 cm diameter round calcite nodules, resembling pisoliths.

Middle Part of the Gunflint Formation

The middle part of the Gunflint Formation includes strata that occur between the base of the basaltic rocks of the Mink Mountain member and the top of the volcaniclastic rocks of the Spillway member and includes the Gravel Lakes Road member that is a mixed, mainly chemical sedimentary rock, but with minor, thin siliciclastic rock beds.

MINK MOUNTAIN MEMBER

The Mink Mountain member comprises mafic volcanic rocks, including a thin lower unit of mafic tuff and possibly pillowed flows with hyaloclastic breccias and an upper unit of metres-thick massive mafic flows characterized by millimetre-size round vesicles (Photo 8.1E) and with flow contacts marked

by thin pinkish-red alteration zones. This unit crops out in Jean Township and appears in drill core ST-22-01 approximately 20 km to the southeast in Hartington Township, indicating that it is not an aerially restricted unit as previously presumed. In drill core ST-22-01, the Mink Mountain member is 20.9 m thick; Goodwin (1953, 1960) estimated its thickness to be 40 feet (12 m) from outcrop exposures and Gill (1926) suggested a thickness of up to 50 feet (15 m).

GRAVEL LAKES ROAD MEMBER

A distinctive unit of thin- to medium-bedded red, hematite-rich (jasper) chemical mudstone, fine-, medium- and coarse-grained grainstone with laminae and thin beds of siliciclastic (possibly volcaniclastic) siltstone–mudstone occurs between the Mink Mountain member and observably tuffaceous rocks of the Spillway member. In outcrop, it locally contains a stromatolitic chert unit at its base sharply overlying the Mink Mountain member. The Gravel Lakes Road member appears to correspond to the "upper jasper facies" of Goodwin (1953, 1960) and Gill (1926) describes an approximately 18 m thick unit of similar rocks in the lower part of his "Division 5". It is probable that this unit corresponds to the base of the upper Gunflint sequence of Jirsa (2011) and Jirsa et al. (2011). In drill core ST-22-01, the Gravel Lakes Road member is 21.5 m thick; Goodwin (1953) has the "upper jasper facies" as 40 to 64 feet (12.2 to 19.5 m) thick. Photo 8.1F shows an example of the appearance of this unit in drill core ST-22-01. More detailed submember-rank divisions (e.g., the stromatolitic portion) may be needed to fully describe this unit.

SPILLWAY MEMBER

The Spillway member comprises thin- to medium-bedded, locally normally graded, locally small-scale trough cross-stratified (rippled), accretionary lapilli-bearing, tuffaceous siltstone to sandstone that is likely reworked. The basal contact of this unit is sharp, and the upper contact is gradational. In drill core ST-22-01, this unit is approximately 1.5 m thick, and likely corresponds to the 5 to 16 feet (1.5 to 4.9 m) thick "upper tuffaceous shale facies" of Goodwin (1953, 1960) and a "tuffaceous taconite" 1.5 to 2 feet (0.5 to 0.6 m) thick in "Division 5" of Gill (1926). Photo 8.2A shows the lower contact of a distinctive, normally graded, accretionary lapilli-bearing tuffaceous bed in drill core ST-22-01.

Upper Part of the Gunflint Formation

The upper part of the Gunflint formation includes rocks occurring between the top of the volcaniclastic rocks of the Spillway member and the base of the Rove Formation. The upper part of the Gunflint Formation consists of 3 members: the chemical grainstone- and mudstone-dominated Shuniah Mines member, the thin chert–limestone stromatolitic rock–dominated Stanley member and the intraformational breccia and other fragmental rock–dominated Terry Fox Lookout member.

SHUNIAH MINES MEMBER

The provisional Shuniah Mines member is the thickest unit of the upper part of the Gunflint formation. It is defined by its gradational lower contact with the Spillway member and a sharp upper contact with the Stanley member or the Terry Fox Lookout member. This member should likely be subdivided at submember level in the future. In drill core ST-22-01, the unit comprises 68.1 m of mainly medium- to thick-bedded, on average coarse-grained, grainstones of varying mineralogy (more oxide-rich lower, more chert-rich and iron-carbonate–rich higher) with minor thin beds of chemical mudstone. Bed thicknesses and grainsize increase upward. The unit appears to contain siliciclastic (likely volcaniclastic) laminae sporadically throughout, although visually they seem to be most apparent lower in the unit. Addison et al. (2010) inferred that volcaniclastic laminations persist to the top of the Gunflint Formation.

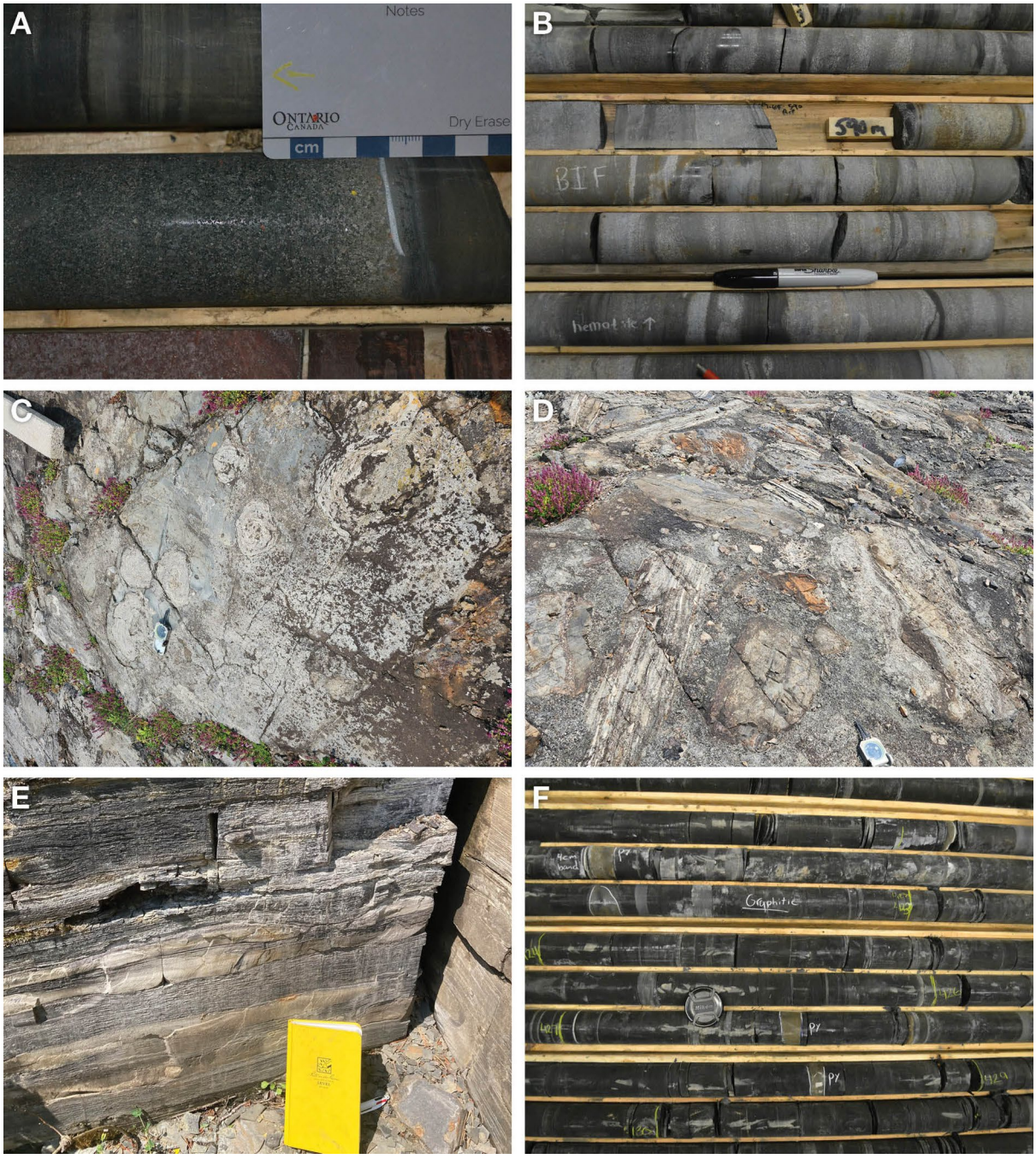


Photo 8.2. Representative photos of some provisional member-rank subdivisions of the Gunflint and Rove formations. **A**) A bed of reworked lapilli tuff of the Spillway member, showing normally graded bedding, top is to the left. Drill core ST-22-01: UTM 283702E 5335114N, Zone 16; 650 m depth, NQ core. Scale card gradations in centimetres. **B**) Medium-bedded coarse-grained grainstones and oxide-rich chemical mudstone interbeds (Shuniah Mines member). Drill core ST-22-01: UTM 283702E 5335114N, Zone 16. Marker 15 cm long and points up hole, 590 m wooden metre marker shows depth. **C**) Bedding plane view of cabbage-like stromatolite mounds of the Stanley member at an outcrop on South Hill Street in the City of Thunder Bay. Station 25RTM847: UTM 334171E 5366304N Zone 16. Compass is 22 cm long. **D**) Intraformational breccias of the Terry Fox Lookout member (thought to be Sudbury meteorite impact related, e.g., Addison et al. 2005)) at an outcrop on South Hill Street in the City of Thunder Bay. Station 25RTM847: UTM 334171E 5366304N, Zone 16. Compass is 22 cm long. **E**) Thin- to medium-bedded, intercalated siltstone and fine-grained sandstone beds with carbonate concretions, Lower Rove A member (Oliver Creek member). Station 23CEK053: UTM 312242E 5357666N, Zone 16. Notebook is 19 cm tall. **F**) Sulphide layers and nodules in black shale, Lower Rove B member. Drill core ST-22-01: UTM 283702E 5335114N, Zone 16; NQ core diameter, approximate depths 420 to 431 m. Lens cap approximately 7 cm diameter.

This unit corresponds to the 150 to 180 feet (46 to 55 m) thick "upper taconite facies" of Goodwin (1953, 1960) and to the parts of Gill's (1926) "Division 5" above "tuffaceous taconite" (*see* Tables 8.1a and 8.1b). Photo 8.2B shows strongly magnetic grainstones in the lower part of this unit in drill core ST-22-01.

STANLEY MEMBER

The provisional Stanley member comprises thinly bedded and laminated, dark grey to black chert–limestone, locally observed as stromatolite mounds (Photo 8.2C). The limestones sharply overlie the Shuniah Mines member and are sharply overlain, locally erosively (Addison et al. 2010), by rocks of the Terry Fox Lookout member. Locally, the Stanley member is characterized by cabbage-like stromatolitic mounds. No equivalent of this unit occurs in drill core ST-22-01, but, in outcrop, it tends to be less than 1 m thick. At several localities within the City of Thunder Bay, this unit is radioactive, with gamma-ray spectrometer readings ranging from 500 to 2000 counts per second. This unit likely corresponds to the "upper limestone" of Goodwin (1953, 1960).

TERRY FOX LOOKOUT MEMBER

The provisional Terry Fox Lookout member refers to rocks described in detail and interpreted by Addison et al. (2005, 2010) to represent deposition of ejecta created by the Sudbury meteorite impact 1850 million years ago (Davis 2008; Krogh, Davis and Corfu 1984). In drill core ST-22-01, this unit is approximately 4.5 m thick. Typically, it consists of coarse-grained intraformational breccias and locally accretionary lapilli–bearing fragmental rocks. Photo 8.2D shows coarse-grained intraformational breccias at an outcrop on South Hill Street in the City of Thunder Bay.

Rove Formation

The Rove Formation is described only briefly here. The stratigraphy of Morey (1967, 1969) serves as a good basis for bedrock mapping of the Rove Formation. Because previous mapping of lithostratigraphic subdivisions of Rove Formation is not available, at the moment, we lack sufficient confidence to propose geographic names; however, in some cases, tentative geographic names are given in parentheses. For the purposes of 1:50 000 mapping, we propose the following member-rank units for the Rove Formation from base to top:

- Lower Rove A member (Oliver Creek or Riverdale Quarry member) comprising grey to black, thinly bedded siltstone, mudstone, fine-grained sandstone and thin pale green tuff beds, with locally prominent carbonate concretions, an approximate thickness of 72 m in drill core ST-22-01, disconformably overlying the Gunflint Formation and with an indistinct gradational upper contact marked by waning proportion of siltstone, fine-grained sandstone beds and tuff beds (Photo 8.2E).
- Lower Rove B member (clear outcrop analogues not known to authors) comprising black, locally pyritic nodules and beds, organic-rich shale with locally thin pale green tuff beds with an approximate thickness of 88 m (in drill core ST-22-01) and gradational upper and lower contacts (Photo 8.2F).
- Middle Rove member (Middle Falls member), similar to the transitional member of Morey (1967), comprising thin- to medium-bedded siltstone and fine- to medium-grained sandstone (wacke) and having a thickness of approximately 130 m in drill core ST-22-01 and characterized by gradational contacts.

- Devon member (appears to be part of Middle Rove) comprising basalt to basaltic andesite (Cundari 2010) flows that are potentially intercalated with Rove Formation sedimentary rocks in Devon Township (Tanton 1936). Member is of undetermined thickness, but is possibly correlative with a thin, fine-grained and locally vesicular mafic horizon 3.75 m thick in in drill core ST-22-01.
- Upper Rove member (Sturgeon Bay member) comprising grey, medium- to thick-bedded, medium- to coarse-grained sandstones intercalated with thinner siltstone and mudstone and having a minimum thickness of 158 m in drill core ST-22-01. The base of this member would be provisionally marked by the appearance of thickly bedded grey coarse-grained sandstone beds.

Summary

We have found the decades to century-old work of Tanton (e.g., 1931), Goodwin (1953, 1960) Moorhouse (1960), Gill (1926), Morey (1967) and Jirsa (2011) to be excellent descriptions of the detailed lithostratigraphic framework of the Animikie Group in Ontario. These works, combined with many more recent academic studies that have provided new insights into the stratigraphy and age of the Gunflint and Rove formations, have allowed us to piece together a provisional stratigraphic nomenclature that we plan to apply, test and refine with bedrock mapping. We stress that the subdivisions herein are preliminary and, therefore, are subject to future revisions based on more comprehensive bedrock geological mapping planned for coming field seasons and newly acquired geochemical, geochronological and petrographic data. At the completion of the bedrock geology mapping project, we hope to formalize a descriptive lithostratigraphic nomenclature for the Animikie Group in Ontario.

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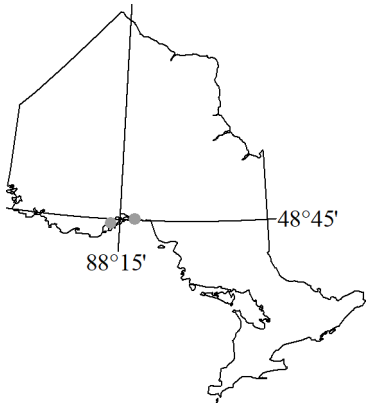
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9. Microfossil Preservation in the Paleoproterozoic Gunflint Formation: Comparative Study of the Pass Lake and the Classic Schreiber Beach Localities, Northern Ontario



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INTRODUCTION

The Paleoproterozoic Gunflint Formation (*circa* 1.88 Ga) continues to be an important stratigraphic unit for understanding the evolution of the Precambrian biosphere (e.g., Fralick, Davis and Kissin 2002; Fralick et al. 2017). In its well-preserved microfossil assemblages and chemical sedimentary rocks, the Gunflint Formation contains a detailed record of the Earth's evolving biological and geochemical systems during the Paleoproterozoic (e.g., Barghoorn and Tyler 1965; Cloud 1965; Awramik and Barghoorn 1977). These microfossils, found within cherty stromatolitic layers in the basal and middle parts of the formation, are among the most diverse and well-preserved Paleoproterozoic microfossils known worldwide (Knoll et al. 2006; Knoll and Nowak 2017; *see also* González-Flores et al. 2022 for a recent summary). Gunflint Formation microfossil assemblages display unicellular morphologies with complex features (e.g., surface tubercles, processes, and scale-like ornaments), but their biological affinities remain uncertain with various interpretations suggesting they could be prokaryotes, early eukaryotes, or even fungi (e.g., Krumbein 1983; Alleon et al. 2016; Wacey, Eiloart and Saunders 2021; González-Flores et al. 2022; Sasaki et al. 2022).

A key limitation in resolving this uncertainty has been the lack of comprehensive, high-resolution imaging studies capable of detailing Gunflint Formation microfossil microstructures (~1–10 μm) and ultrastructures (10–100 nm). Addressing this gap, by finding additional well-preserved microfossils and clearly imaging them to document their structures, is critical for accurately assessing the evolutionary significance of these fossils and for determining whether they represent an early record of eukaryotic life. The focus of this article is to present the preservation state and characteristics of preserved microbiota (i.e., microfossils) associated with Gunflint Formation cherty stromatolites at a newly sampled locality near Pass Lake, Ontario (Pass Lake locality) and compare them to the Schreiber Beach locality from which many of the best-preserved Gunflint Formation microfossils have been previously described (e.g., LaBerge 1967; Awramik and Barghoorn 1977; González-Flores et al. 2022).

This article presents preliminary results of an ongoing Master of Science (MSc) thesis of Sarah Kup at the University of Western Ontario. Stromatolitic chert at the Pass Lake locality was first reported by Metsaranta and Kurcinka (2022), which led to a field visit by the authors in summer 2024. Sampling carried out during this field visit provided materials for the content of this article and the MSc study. Additional sampling of Gunflint Formation stromatolites was carried out in July 2025. The current

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Ontario Geological Survey, Open File Report 6421, p.9-1 to 9-14.

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Precambrian mapping project of Ontario Geological Survey (OGS) (*see* Metsaranta and Kurcinka 2022; *see also* Metsaranta and Kurcinka, this volume, Article 8) provided an excellent opportunity for research collaboration by incorporating OGS expertise in Precambrian geology of the Thunder Bay region and for expanding the search for microfossil-bearing localities in the Gunflint Formation.

GEOLOGY OF THE GUNFLINT FORMATION

The Gunflint Formation stretches from northeastern Minnesota to the Schreiber area along the north shore of Lake Superior (Figure 9.1). The Gunflint Formation and overlying Rove Formation, together with correlative rocks in northern Minnesota, comprise the Animikie Group, which was deposited in the Animikie Basin during the Paleoproterozoic (e.g., Ojakangas, Morey and Southwick 2001). The Animikie Group generally comprises 3 units: a lower unit siliciclastic unit (Pokegama Formation, Kakabeka conglomerate); a middle unit of mainly iron-rich chemical sedimentary rocks (the Biwabik, Cuyuna and Gunflint formations); and an upper unit of turbiditic sandstones and pyritic, carbonaceous shales (Virginia and Rove formations) (e.g., Ojakangas, Morey and Southwick 2001).

The Gunflint Formation is approximately 200 m thick (e.g., Metsaranta and Kurcinka 2022) and consists predominantly of quartz and/or iron-ooidal grainstone, iron carbonates, banded iron formations and cherty stromatolites (Floran and Papike 1975). The middle to upper part of the Gunflint Formation contains a lapilli tuff horizon with an age of 1878±1 Ma (Fralick, Davis and Kissin 2002). Close to the top of the formation, rocks interpreted to represent ejecta from the Sudbury meteorite impact (*circa* 1850 Ma) occur (Krogh, Davis and Corfu 1984; Addison et al. 2005) providing good constraints on the absolute age of the Gunflint Formation microbiota. The Gunflint Formation has been subdivided into lower and upper sequences, each representing a broad transgressive–regressive cycle (e.g., Fralick et al. 2017) that corresponds with lithostratigraphic subdivisions of earlier workers (e.g., Goodwin 1960). Stromatolites

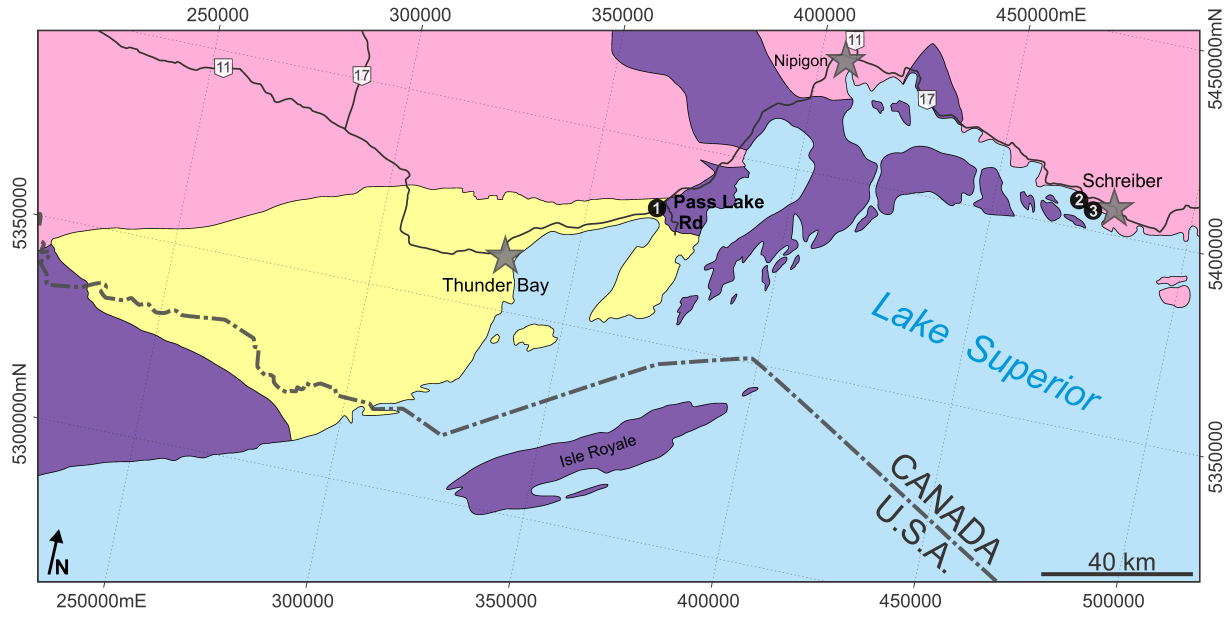


Figure 9.1. Generalized geology of the Thunder Bay region of Ontario, north of Lake Superior, into northeastern Minnesota and northern Michigan, including the approximate locations of the investigated Pass Lake locality (1) and Schreiber Beach locality samples GSC24541 (2) and GSC24380 (3). Archean rocks are shown in pink, younger Proterozoic rocks are shown in purple, and the Animikie Group (Gunflint and Rove formations) is shown in yellow (*modified from* Ishida, Hashizume and Kakegawa 2017; Mueller 2019; and González Flores 2022). Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 16.

are generally considered to occur at 3 distinct horizons within the Gunflint Formation (e.g., Goodwin 1960; Addison et al. 2005) reflecting episodes of shallow-water marine conditions. The lower stromatolites occur either directly on Archean basement rocks, or overlie the basal conglomerate, the middle stromatolites form the base of the upper transgressive sequence, and the upper stromatolites occur immediately beneath rocks of the Sudbury impact layer near the top of the Gunflint Formation.

At the Pass Lake locality, roadcut sections on both the northwest and southeast sides of Highway 17 expose a maximum of 3.5 m of the basal Gunflint Formation (Figure 9.2). Here, the Gunflint Formation non-conformably overlies the Archean basement, which is marked by an undulatory, peneplained surface. The Archean basement consists of dark greenish grey chloritized granitoid, with an exposed thickness of 0 to 3 m along the roadcut section, with local relief up to 2 m. Immediately above the Archean basement is the Kakabeka conglomerate, which comprises a quartzite-pebble conglomerate, with a dark grey to black grainstone matrix. The conglomerate varies from 0 to 30 cm in thickness, usually absent from the local topographic highs (knobs or ridges of the Archean basement), but changes from relatively thin to thick in depressions of various depths. The basal conglomerate lag may contain large, well-rounded boulders, up to 0.5 m in diameter and thus protruding into Unit 1 of the Gunflint Formation. At this outcrop, such large boulders have been observed only on the northwest side of the highway. Black, cherty bands (0.1–1.5 cm) occur locally in parts of the Kakabeka conglomerate.

Unit 1 of the Gunflint Formation is characterized by the common occurrence of cherty, domical to columnar stromatolites within the basal 2 m of the formation. Relatively large stromatolite heads tend to occur preferentially on knobs or ridges of the Archean basement, usually metres apart from one another. Smaller stromatolite heads (5–15 cm in diameter or height) are present locally, even on top of the Kakabeka conglomerate. Tabular, finely undulatory, microbialite-like structures (commonly <10 cm thick) may occur in places, or laterally connected to stromatolite heads. The microbialite-like structures may weather to a reddish colour, similar to some of the weathered stromatolite heads. Overall, the colour of the domical to columnar cherty stromatolites ranges from red, yellow, white, grey and black, depending on the iron content and the nature of weathering. Relatively large (usually fresh) stromatolite heads tend to be jet black near their centre and change to lighter grey and white toward their edges; however, edges themselves are commonly marked by red and/or yellow banding. The stromatolites are most easily seen and accessible toward the southern ends of the outcrop, directly above the road ditch level. The Pass Lake locality stromatolites are interpreted to be at the same stratigraphic horizon as the Schreiber Beach locality stromatolites.

The overlying Unit 2 and Unit 3 consist of metre-size packages of grainstone to sandstone, with large-scale sets of tabular cross-stratification, which are often highlighted by white cherty bands, with minor mudstone partings (*see* Figure 9.2). A hematite-stained, 0.5 to 1 m thick, sandstone with medium planar beds overlies Unit 3.

Units 4 to 7 have a broadly similar lithology as Units 2 and 3, except that the mudstone partings become thicker and more laterally continuous. In Unit 4, a thin band (up to 15 cm thick) of reddish-brown, hematitic-oolitic siltstone to mudstone is present, below the hematite-stained, medium planar-bedded sandstone of Unit 5 (*see* Figure 9.2). The top of the outcrop has a reddish-brown, 10 to 15 cm thick unit of very thinly bedded, hematitic-oolitic mudstone to siltstone (blue arrow in Figure 9.2).

PREVIOUS WORK

Tyler and Barghoorn (1954) were the first to characterize the Gunflint Formation microfossils. Using transmitted light microscopy, they interpreted the preserved structures as fungal hyphae and cyanobacteria. This landmark discovery not only brought attention to the Gunflint Formation but also marked a turning point in Precambrian micropaleontology, as these were the oldest microfossils known at

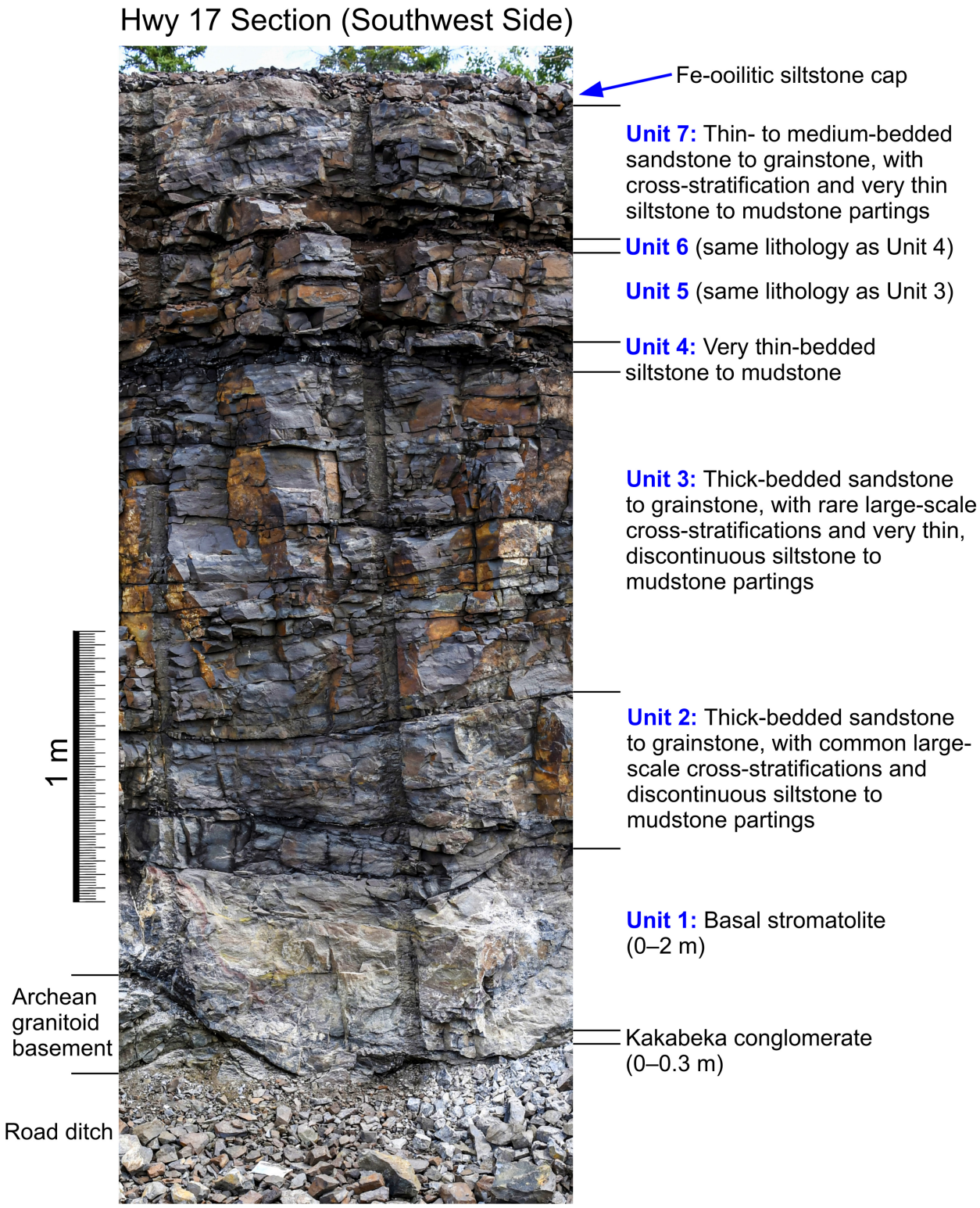


Figure 9.2. Roadcut stratigraphic section on southeastern side of Highway 17 (Pass Lake locality in Figure 9.1). The basal part of the Gunflint Formation is divided into 7 units (refer to the text for detailed description of lithology).

the time. Barghoorn and Tyler (1965) described 12 new morphotypes of Gunflint Formation microfossils in detail; Cloud (1965) emphasized their exceptional preservation and their relevance to reconstructing Precambrian environmental conditions, including atmospheric reduction–oxidation states. LaBerge (1967) observed that diagenetic alteration tended to obscure microfossil features and associated stromatolitic fibres. Hofmann (1969) expanded on this with a broader investigation of stromatolitic structures and their associated microbiotas in Canada. Awramik and Barghoorn (1977) later classified the Gunflint Formation microfossils into categories of budding bacteria, cyanophytes (cyanobacteria) and taxa of unknown affinities. Kaźmierczak (1979) proposed a eukaryotic affinity for some of the unicellular morphotypes.

With advanced microanalytical techniques, the Gunflint Formation microfossils have been characterized in more detail. For example, scanning electron microscopy (SEM) combined with focussed ion beam milling enabled three-dimensional (3-D) tomography to reconstruct ultrastructural data previously unattainable by light microscopy (Wacey et al. 2012). Studies involving biochemical characterizations detected isotopic biosignatures (Williford et al. 2013), as well as preserved molecular functional groups (e.g., amides) using scanning transmission X-ray microscopy (STXM) coupled with X-ray absorption near edge structure (XANES) spectroscopy (Alleon et al. 2016). More recently, "colonial-type" microfossils were discovered in the Gunflint Formation, which were previously only known from the Belcher Group (1.90 Ga). This discovery suggests a potential evolutionary shift from prokaryotic to proto-eukaryotic life to an earlier date as well as diversified metabolic pathways (Sasaki et al. 2022, 2024).

Studies of cherty Proterozoic formations, including the Gunflint, have recently revealed microfossils with clear eukaryotic traits, including cyst-like cellular bodies, complex surface ornamentation, and preserved cytoskeletal walls (Knoll et al. 2006; González-Flores et al. 2022). Recent work by González-Flores et al. (2022), has shown that hydrofluoric acid etching significantly improves the quality of SEM imaging and elemental analysis in chert-hosted microfossils, enabling documentation of ultrastructures, such as complex ornamentations and well-preserved cytoskeletal cell walls, critical for determining biological affinities.

Collectively, these studies highlight both the diversity of interpretations surrounding the Gunflint Formation microbiota and the role of emerging technologies in refining our understanding of these remains. The Gunflint Formation, with its exceptional preservation and morphological diversity, remains central to testing hypotheses about early eukaryotic evolution. Ultra-high-resolution imaging offers a critical tool for elucidating the biological nature of these microfossils and situating them more precisely within the early biosphere's evolutionary history. As such, producing high-resolution optical and SEM images is essential for documenting the Orosirian (i.e., 2050–1800 Ma) microfossil morphologies preserved in the Gunflint Formation and potentially identifying early eukaryotic traits.

OBJECTIVES

The overall goal of this MSc study is to explore the biological affinities of microfossils from the Gunflint Formation by using a high-resolution correlative microscopy approach. The study has 3 primary objectives, each to be achieved with corresponding analytical techniques. These objectives and analytical techniques are as follows:

1. map the distribution of microfossils over a *circa* 30 × 50 mm areas in petrographic thin sections (i.e., microbial film scale) using a Keyence VHX-6000 Digital Microscope with 3-D optical scanning and magnifications up to 2000×.
2. characterize micrometre-scale morphology and ultrastructures of selected microfossils using a high-resolution, Zeiss® Axioskope® optical microscope equipped a 100× oil lens and a 1.6× intermediate lens to yield a total magnification of 160×.

3. characterize the surface of preserved microbial films and individual microfossils using SEM and compare these micrographs to light micrographs obtained from conventional optical methods (*see* objectives 1 and 2).

The objective of this article is to highlight some preliminary results of application of these analytical techniques to characterizing microbiota contained in samples from the Pass Lake locality and samples from the Schreiber Beach locality.

MATERIALS AND METHODS

Sample Acquisition

During field work in the summers of 2024 and 2025, we investigated several Gunflint Formation exposures. Among these, the Pass Lake locality (UTM 367643E 5383270N, Zone 16U) was investigated and sampled in detail by the authors (*see* Figure 9.1) and is the focus of this article. The Pass Lake locality is an extensive roadcut excavated in the early 2010s during the widening of Highway 17, near the junction with the Pass Lake Road (Highway 587). The Pass Lake locality was studied in greater detail because of the extensive lateral exposure of the basal approximately 3.6 m of the Gunflint Formation, the clarity of the basal contact with the Archean basement (chloritized granitoid), and the accessibility to well-developed, dark-coloured, cherty stromatolites.

Over 100 hand samples (0.5–10 kg size) of cherty stromatolites were collected from the Pass Lake locality, from which 6 petrographic thin sections were prepared. Additionally, 14 SEM tablets were extracted from the pitch-black parts of the cherty stromatolites; 4 tablets were etched in hydrofluoric acid for 5 minutes, 4 tablets for 10 minutes, and 6 tablets were left unetched. The Pass Lake samples were collected from domical or columnar stromatolites within the basal 1 to 2 m of the Gunflint Formation, immediately above the unconformity with the underlying Archean basement rock (*see* Figure 9.2).

Two sets of hand samples were loaned from the Geological Survey of Canada (GSC), including the catalogued sample lot GSC24380 from the classic Schreiber Beach locality (GSC Locality No. 78417: 474541E 5404972N, Zone 16U), and lot GSC24541 from Winston Point (GSC Locality No. 78418: 471021E 5406688N, Zone 16U), farther west along the shoreline from the Schreiber Beach locality (*see* Figure 9.1). These samples were originally collected by Hofmann (1971) from coastal outcrops of a small outlier of the Gunflint Formation, about 10 km southwest of the town of Schreiber, within the Schreiber Channel Provincial Reserve, Ontario, Canada. Sample GSC24380 was subdivided into several bulk pieces and labelled separately (e.g., GSC24380d and GSC24380e) from which multiple thin sections were prepared. Several smaller centimetre-size pieces were cut from both GSC24380 and GSC24541 for petrographic thin sections and were prepared for SEM imaging and elemental analysis using the same hydrofluoric acid etching techniques as for the Pass Lake samples.

Light Microscopy

Optical microscopy was performed using 2 different microscopes:

- the Zeiss® Axioskope® with a 100× oil lens and a 1.6× intermediate lens (a combined 160× total optical magnification)
- the Keyence VHX-6000 Digital Microscope with up to 2000× total optical magnification; two-dimensional (2-D) montage and three-dimensional (3-D) depth montage

Various extended depth of focus (EDF) techniques associated with the 2 microscopes listed above were used in this study to maximize the depth of field view in micrographs, which is critical for viewing relatively large areas of a thin section at ultra-high magnifications. The 3-D depth montage setting of the Keyence microscope was particularly effective. This feature digitally composites multiple focal planes from a 30 µm-thick thin section into a single high-quality image, thereby reducing background noise and increasing clarity.

Imaging of surface features can result in loss of detail if the focal depth range is too large. This can be seen when surface features of opposite sides of a spherical subject are both included in the image layers that combine into one image. To achieve the best result of imaging complex 3-D objects, the Zeiss® Axioskope® was paired with a Nikon® DS-F3 digital camera and the Nikon® NIS-Elements imaging software package (version 4.1 and version 5.02). The EDF of NIS was used to combine a series of manually acquired confocal image layers (a Z-series) into a single image. This technique has proven particularly useful for images acquired at 160× objective-lens magnification.

Large areas of the thin sections were scanned using the Keyence VHX-6000 Digital Microscope as 2-D montages at 20 to 200×, allowing efficient identification of microfossil distribution patterns and selection of key areas for higher magnification analysis. Smaller areas were imaged in 3-D depth montages at 2000× from where the upper and lower depth of focus limits for a single cell were manually selected and the automatic EDF function was set at 0.75 µm pitch intervals (i.e., the "confocal" intervals). Subject details were lost if the upper and lower depth of focus limits were too large or if the pitch was too high or low. The images were later edited using Adobe® Photoshop® to enhance contrast.

Scanning Electron Microscopy Energy Dispersive Spectroscopy

Scanning electron microscopy was conducted at 2 facilities at the University of Western Ontario:

1. The LEO (Zeiss) SEM 1530 was used at the Nanofabrication Facility.
2. Both the Hitachi® SU8230 Regulus® ultra-high resolution field emission scanning electron microscope (FE-SEM) with Bruker® X-Flash and the Hitachi® SU3500 variable pressure SEM combined with an Oxford Instruments® X-Max® 50 SDD X-ray detector were used at Surface Science Western.

The SEM was used extensively in this study to produce high-resolution images of surface topography with a good depth of field through a highly focussed electron beam (primary). As this beam scans and interacts with the surface of the sample at 0.5 to 30 kV, multiple low-energy secondary electrons form. The actual sample surface image is formed through measurements of the intensity of these secondary electrons as a function of the scanning primary electron beam's position. To get the highest quality and resolution images, a liquid nitrogen source was added to a special specimen chamber of the FE-SEM to minimize carbon deposition and overcharging during imaging. A 5.0 kV accelerating voltage was used because 3.0 kV and 15.0 kV did not yield sharp images. For SEM imagery, the secondary electron (SE) beam was preferred (rather than the in-lens beam) to produce a better 3-D image and realistic surface topography of microfossils ranging from 1 to 30 µm. The SEM micrographs served as a valuable reference for comparison with optically obtained images of similarly shaped microfossils. During energy dispersive X-ray spectroscopy (EDS), a 6.0 kV accelerating voltage was used for elemental analysis where the concentration of carbon (C), silicon (Si), oxygen (O), iron (Fe) and sulphur (S) were mapped. The EDS micrographs served to compare the carbon and silicon concentrations of the microfossils and the surrounding matrix.

RESULTS

This section presents the microscopy results in 2 parts: 1) a comparison of SEM and optical images classified by morphological type, and 2) comparison of microfossil preservation in samples from the Pass Lake and Schreiber Beach localities.

Scanning Electron Microscopy and Optical Images of Similar Morphological Types

Similar filamentous and coccoid microfossil forms were observed in thin sections and SEM tablets from both the Pass Lake and Schreiber Beach localities. These can each be categorized into 2 distinct types:

- Filamentous type 1: Assigned to *Gunflintia*, these forms are segmented and approximately 2 µm in diameter (Photos 9.1A to 9.1F, 9.2G and 9.2H).
- Filamentous type 2: Comprising unnamed filamentous forms that were >5 µm in diameter, often displaying branches or T-junctions—morphological features commonly associated with fungi (Photos 9.2A to 9.2C).
- Coccoid type 1 (not illustrated): Small, thin-walled spheres <5 µm in diameter, lacking any visible surface ornamentation.
- Coccoid type 2: More complex spherical forms with distinct surface ultrastructures (such as processes and scale-like textures), suggestive of possible eukaryotic affinity (Photos 9.2C to 9.2F; *see also* González Flores 2022).

Varied States of Microfossil Preservation in Pass Lake Section

Optical microscopy of thin sections from the Pass Lake locality revealed a wide range of variation in microfossil preservation states as will be discussed below with comparisons to samples from the Schreiber Beach locality.

Microfossils with Strong Thermal Alteration

As can be seem from the petrographic thin sections, the most common state of preservation in samples from the Pass Lake is characterized by opaque, black to poorly translucent, brownish microbial films with filamentous and coccoid cell structures (Photos 9.3A to 9.3C). In contrast to thin sections from the Pass Lake locality, thin sections from Schreiber Beach are characterized by translucent, brownish microbial films with filamentous and coccoid cell structures and only rare opaque, black clusters of microfossils (Photos 9.3D to 9.3F).

Well-Preserved Microfossils

Optical microscopy of thin sections from the Pass Lake locality revealed localized pockets of translucent, brownish microbial films containing both filamentous and coccoid cell forms (*see* Photos 9.3A to 9.3C). Included in these pockets of well-preserved microfossils are coccoid type 2 cells with surface ornamentation and scale-like surface ultrastructures (*see* González Flores 2022 for detailed descriptions). Ultra-high-resolution SEM images further confirmed the preservation of both filamentous and coccoid types (*see* Photos 9.1D to 9.1F, 9.2A and 9.2G). In general, filamentous cell types tend to be more easily observed using optical microscopy than SEM, possibly as the result of the organic sheaths of filamentous

types being thin and delicate and thus disintegrating more easily than other microfossils during hydrofluoric acid etching (*see* Photo 9.1C and 9.2C). Optical analysis of Schreiber Beach samples revealed a dominance of translucent, brownish structures with only rare black microscopic clusters (*see* Photos 9.3D to 9.3F).

Overall, thin sections from the Pass Lake locality show a generally good preservation of microfossils, albeit with a slightly higher degree of thermal alteration as compared to Schreiber Beach thin sections as demonstrated by the prevailing preservation of semi-opaque organic laminae, with only isolated micro-pockets of translucent, amber-coloured microfossils.

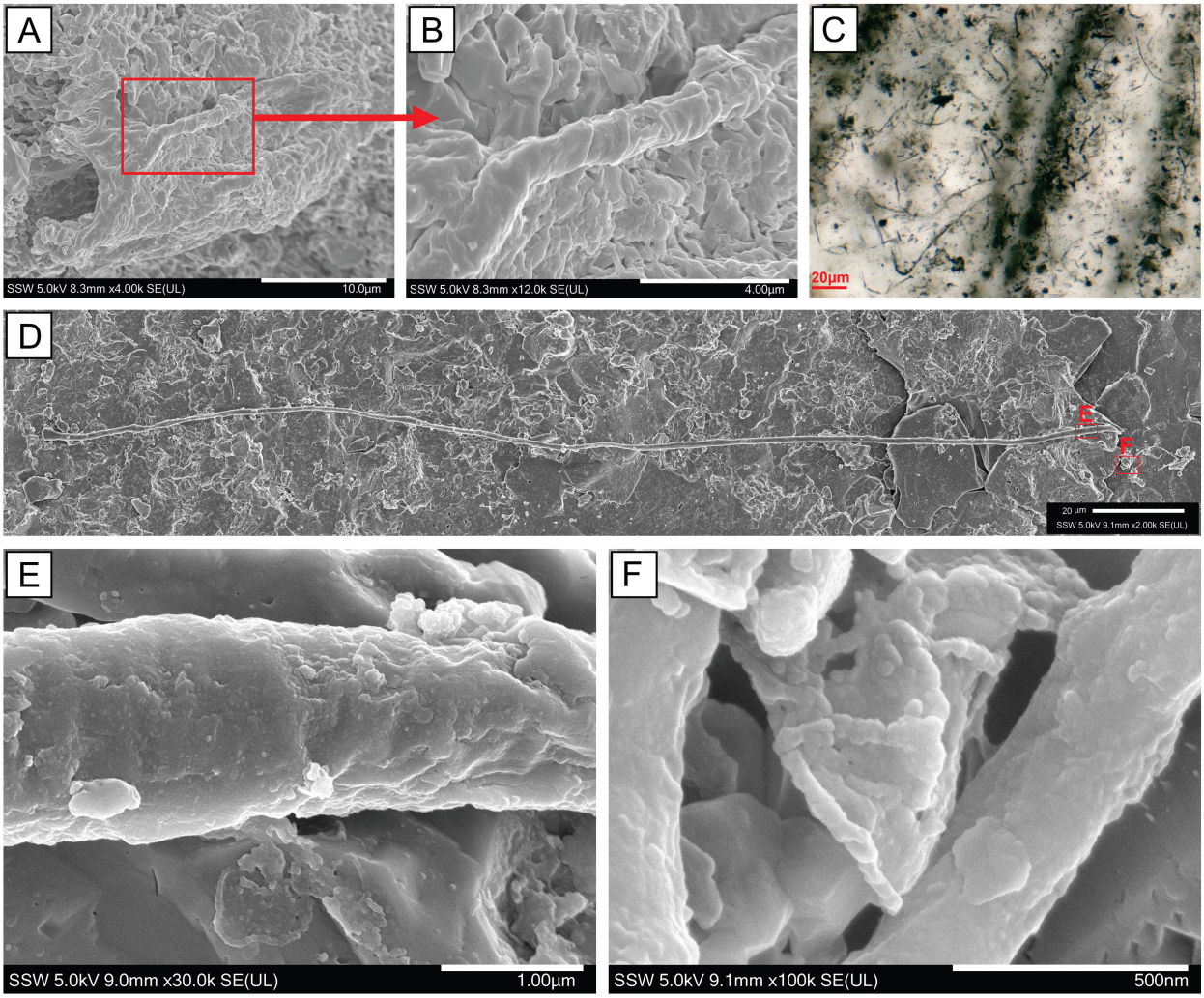


Photo 9.1. Filamentous type 1 microfossils as seen in SEM micrographs (Photos 9.1A, 9.1B, 9.1D, 9.1E and 9.1F) and in an optical image (Photo 9.1C). Photos 9.1A and 9.1B are from the Schreiber Beach locality; Photos 9.1C to 9.1F are from the Pass Lake locality. **A)** Long, segmented filaments, which have been etched out of the surrounding cherty matrix. The red rectangle corresponds to the enlarged image of Photo 9.1B. **B)** Enlarged view of the area within the red rectangle in Photo 9.1A highlighting the segments of a filament. **C)** Dark, stromatolitic laminae and clusters of filamentous and coccoid microfossils. **D)** A ~250 µm long filamentous microfossil and a cluster of smaller diameter (300 nm) filaments on the right side of the micrograph. Red rectangles, marked E and F (in red), correspond to the enlarged images of Photos 9.1E and 9.1F. **E)** Enlarged view of inset E (shown in Photo 9.1D) showing the larger filament covered by nano-granular chert, which is typical of all Gunflint Formation microfossils. **F)** Enlarged view of inset F (shown in Photo 9.1D) showing submicron-sized (50 to 300 nm in diameter) filaments covered by nano-granular chert, which is partly integrated with the rock-matrix chert (*see also* Photo 9.2G). Hydrofluoric acid etching time for samples: 10 minutes (Photos 9.1D to 9.1F); 30 minutes (Photos 9.1A and 9.1B).

COMPARISON OF PRESERVATION STATES BETWEEN PASS LAKE AND SCHREIBER BEACH

Both previous studies and the present investigation demonstrate that the classic Schreiber Beach samples exhibit the best-preserved microfossils and organic matter in general. For example, sample GSC24380 contains the best-preserved microfossils (*see* Photos 9.2B and 9.2F; *see also* González-Flores et al. 2022). Similarly, the columnar to digitate cherty stromatolites in sample GSC24541 preserves the microscopic-scale microbial-rich laminae and individual microfossils (*see* Photos 9.3D to 9.3F). In contrast, the Pass Lake samples display both opaque black and translucent brownish features in the same thin section (*see* Photos 9.3A to 9.3C).

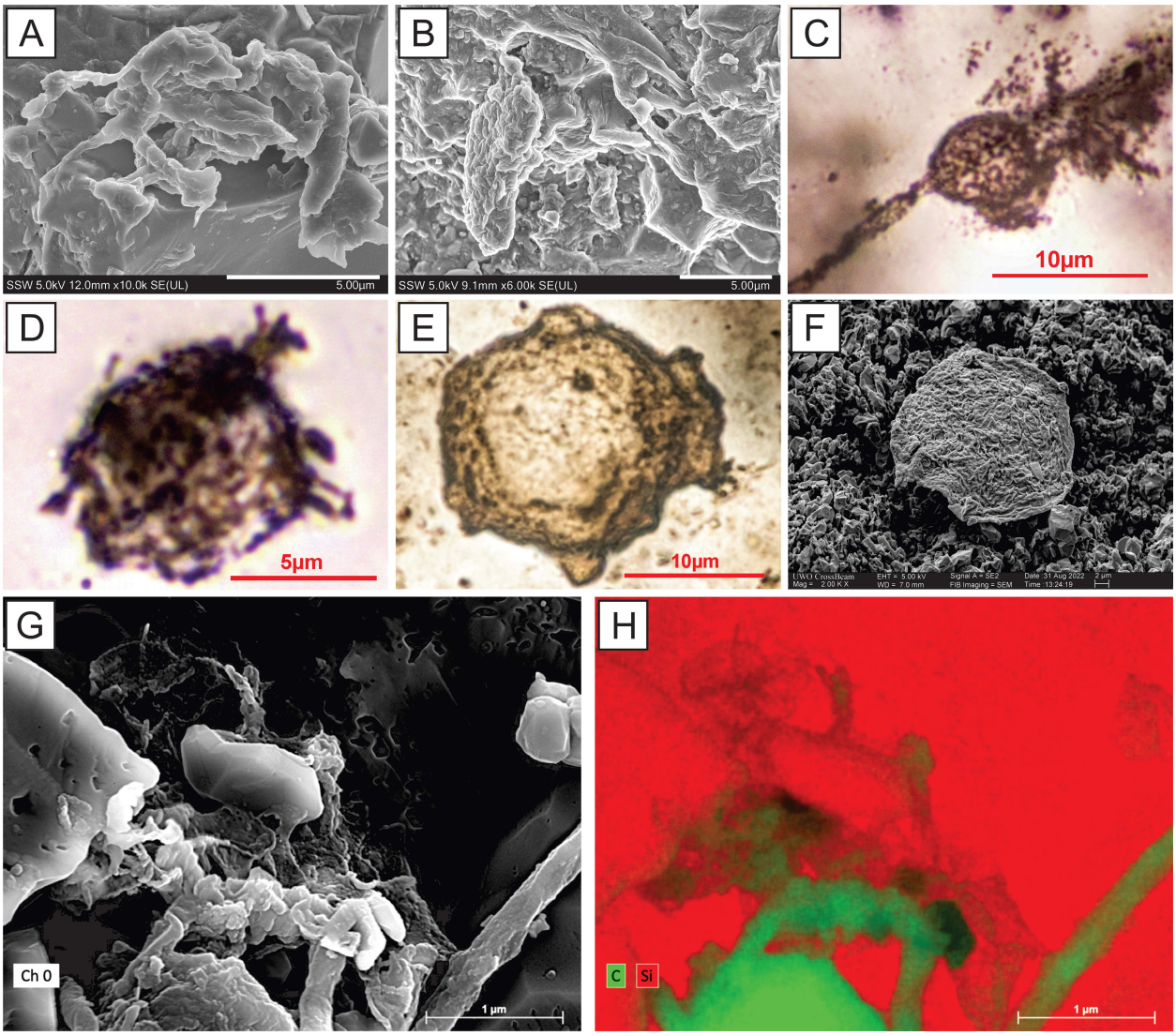


Photo 9.2. Filamentous and coccoid microfossils from Schreiber Beach (Photos 9.2B, 9.2E and 9.2F) and Pass Lake (Photos 9.2A, 9.2C, 9.2D, 9.2G and 9.2H), as seen in SEM micrographs (Photos 9.2A, 9.2B, 9.2F and 9.2G), optical images (Photos 9.2C to 9.2E), and an EDS micrograph (Photo 9.2H). **A, B, C)** Filamentous type 2 microfossils with visible branching or T-junctions. **D, E, F)** Coccoid type 2 microfossils with visible cell processes, pits, wrinkles, and scale-like surface structures. **G, H)** Paired micrographs showing concentration of carbon (C, green) in the microfossil structures in contrast to the concentration of silicon (Si, red) in the surrounding chert matrix. Hydrofluoric acid etching time for samples: non-etched (Photos 9.2A and 9.2B); 10 minutes (Photos 9.2F and 9.2G).

These dark opaque microfossils are characteristic of a relatively high degree of thermal alteration of organic material as described by Alleon et al. (2016) in their comparative study of microfossil preservation across 5 localities (excluding Pass Lake) of the Gunflint Formation, where they documented significant variation in organic matter degradation under diagenetic temperatures of 150 to 170°C.

Samples from both localities show stromatolite laminae made up of organic matter and discrete cellular bodies with microzoning of varying degrees thermal alteration. Schreiber Beach samples are generally better preserved than Pass Lake samples exhibiting fewer thermally altered opaque, black areas and more common well-preserved translucent, brownish structures in the same thin section. Pass Lake samples had pockets of well-preserved translucent, brownish structures. Although the Pass Lake samples contain pockets of well-preserved translucent features, overmature opaque black regions are commonly interspersed throughout thin sections. Despite this, Pass Lake remains a promising area for study because of these well-preserved translucent, brownish structures.

Despite the differences in optical appearance (brown, translucent versus black, opaque), SEM imaging reveals excellent preservation of the microbial films as well as individual microfossils in both localities, particularly their surface textures (micro- and ultrastructures). Microbial films and organic-rich laminae are extensively interwoven with pockets and laminae of nano-scale chert granules and coarser micro-quartz (*see* Photos 9.1A, 9.1B, and 9.1D to 9.1F). As is shown in Photos 9.2G and 9.2H, the microfossil structures retain a high concentration of carbon as opposed to the surrounding cherty matrix, which is largely devoid of carbon.

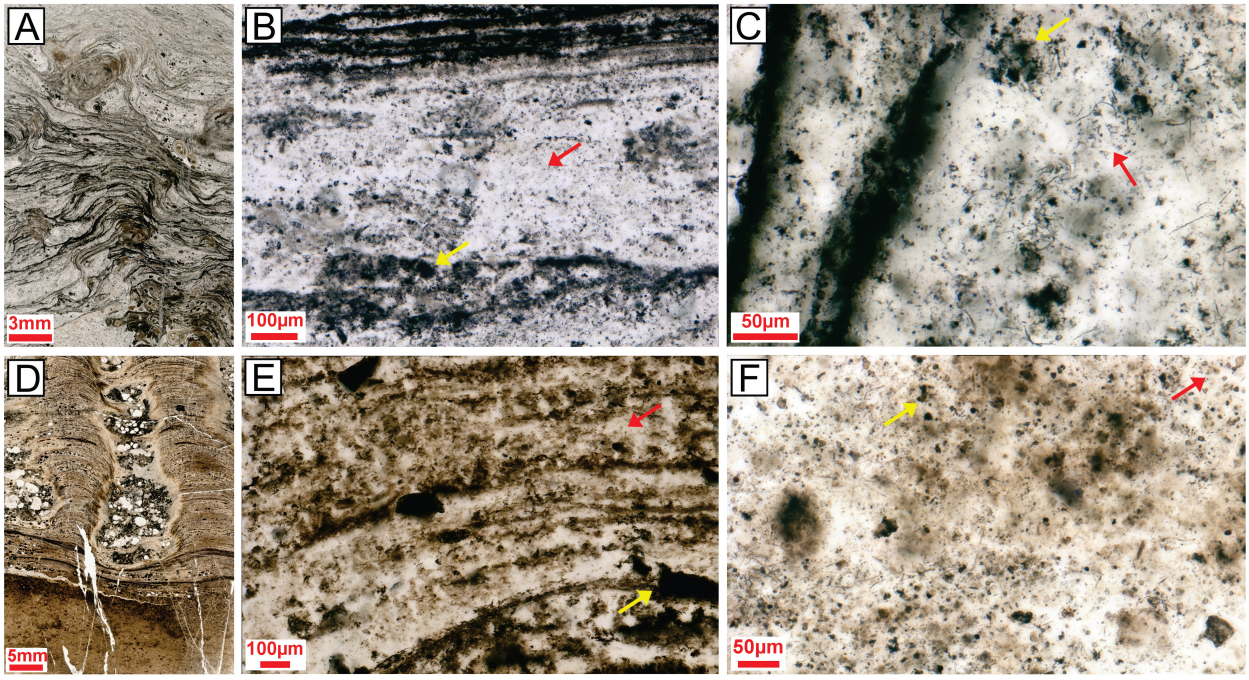


Photo 9.3. Optical image comparison (thin sections) of preservation states between Pass Lake (Photos 9.3A to 9.3C) and Schreiber Beach (Photos 9.3D to 9.3F). **A)** The overall stromatolite structure with ferruginous ooids embedded in stromatolitic laminae, visible to the naked eye. **B, C)** Translucent, brownish microbial films with filamentous and coccoid cell structures (highlighted by red arrow) and opaque, black microbial films with filamentous and coccoid cell structures (highlighted by yellow arrow). Opaque, black microbial laminae are considered to show strong thermal alteration. **D)** Stromatolitic digits with ooids and quartz grains filling spaces in between. **E, F)** Common translucent, brownish microbial films with filamentous and coccoid cell structures (highlighted by red arrow) and rare opaque, black microbial films with filamentous and coccoid cell structures (highlighted by yellow arrow) showing strong thermal alteration.

Samples from both Schreiber Beach and Pass Lake exhibit excellent preservation of coccoid type 2 forms, characterized by pits, wrinkles, and processes on cell walls. Filamentous types, including both small-diameter (<2 μm) and larger (>5 μm) forms occur in samples from both localities. The larger filaments commonly display branches with T-junctions (e.g., *see* Photo 9.2A). Both small and large forms have been observed to associate with coccoid cell bodies (*see* Photos 9.1C, 9.2B and 9.2C).

Thus far, the available optical and SEM imaging data suggest that well-preserved Gunflint-type microfossils (both filamentous and coccoid types) tend to occur in sporadic pockets in samples collected from the Pass Lake locality. This is in contrast to the excellent fossil preservation found much more commonly and uniformly in the samples from Schreiber Beach (especially from the jet black, obsidian-like stromatolitic chert lithotype). However, given the easy accessibility and the large quantity of samples collected in the past 2 field seasons, the Pass Lake locality has proven a significant addition to the material basis of research on the Gunflint Formation microbiota.

ACKNOWLEDGMENTS

We respectfully acknowledge that the area of study is on the traditional lands of the Indigenous Peoples of the Robinson-Superior Treaty territory. We also respectfully acknowledge the Anishinaabek, Haudenosaunee, Lūnaapéewak, and Chonnonton Nations, whose traditional territories are where this publication was drafted and this analytical research was conducted at the University of Western Ontario. We thank our reviewers, Manuel Duguet and Katherine Hahn (OGS), for their insightful suggestions and comments. This study is part of an MSc thesis project at the University of Western Ontario by Sarah Kup. SK acknowledges the undergraduate and graduate assistantships at Western. This study is funded by Natural Sciences and Engineering Research Council of Canada (NSERC) Discovery Grants to JJ and JS. Stephen Wood at Western made petrographic thin sections and polished slabs for this study. Ivan Barker, from Surface Science Western, provided training and guidance on Keyence optical as well as SEM imaging. Todd Simpson and Tim Goldhawk, from the Western Nanofabrication Facility, provided training and guidance on SEM imaging and performed the hydrofluoric acid etching.

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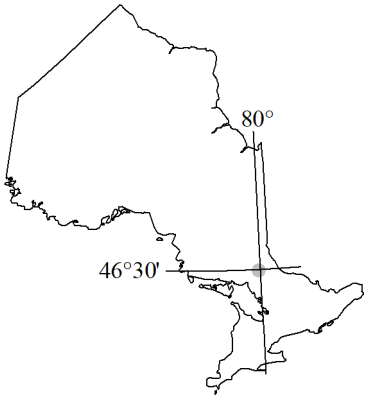
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10. Project SO-22-003. Zirconium and Rare Earth Element Potential of a Grenville Province Gneiss North of Verner, Northeastern Ontario



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INTRODUCTION

Ontario's Critical Minerals list (www.ontario.ca/page/critical-minerals) includes both zirconium and the rare earth elements. This article reports on geochemical results from a sample collected in the summer of 2024 that contains some of the highest zirconium and rare earth element contents recorded for any igneous rock sample from the Grenville Province of Ontario. The sample is from the Badgerow complex, located approximately 8.5 km north of the community of Verner in the Nepewassi domain of the Grenville Province, as described by Easton and Kamo (2024) (Figure 10.1).

GEOLOGY

The Badgerow complex (Lumbers 1975), located in Badgerow and eastern Hugel townships, lies within northern Nepewassi domain of the Grenville Province (Easton 1992) (*see* Figure 10.1). The main part of the complex is roughly circular, approximately 4.5 by 3.5 km in size (Figure 10.2). The circular part of the complex is only weakly deformed, with a narrow gneissic margin and a massive to slightly foliated interior. It consists predominantly of pink weathering, medium-grained monzogranite with less than 5% mafic minerals (Table 10.1: sample 24RME-3047). Near the eastern margin of the complex on Kipling Road, fine-grained monzogranite veins crosscut medium-grained gabbro of the complex containing relict pyroxene cores rimmed by amphibole. The monzogranite was sampled for geochemistry and U/Pb geochronology because of the relatively undeformed nature of the felsic rocks of the Badgerow complex, the fact that it is the only near-circular pluton in northern Nepewassi domain, and its similarity to another body in southern Nepewassi domain, as described in Easton and Kamo (2024) (*see* Table 10.1: sample 24RME-1114).

Approximately 600 m northeast of the near-circular body, Lumbers (1974) included an approximately 6 km long and up to 1 km wide lens of gneissic syenite as part of the Badgerow complex (*see* Figure 10.2). This lens is well exposed along Highway 575, and is a medium-grained, slightly greenish, gneissic amphibole syenite (*see* Table 10.1: sample 24RME-3052). Given its mineralogy, and its much greater degree of deformation, it is likely older than the Badgerow complex, yet it is still younger than its host migmatitic rocks. As such, it is unclear why Lumbers (1974) included it as part of the Badgerow complex, The gneissic syenite has uranium and thorium contents slightly richer than average upper crust (2.7 ppm U and 10.5 ppm Th, respectively: Rudnick and Gao 2014), but there is little difference between the uranium and thorium contents of the gneissic syenite and the undeformed monzogranite of the circular part of the Badgerow complex (*see* Table 10.1). This is reflected in the

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regional gamma spectrometric data for the area, where moderately high anomalies for equivalent U, equivalent U/potassium values, and equivalent U/equivalent Th value occur in association with the Badgerow complex (Carson et al. 2002).

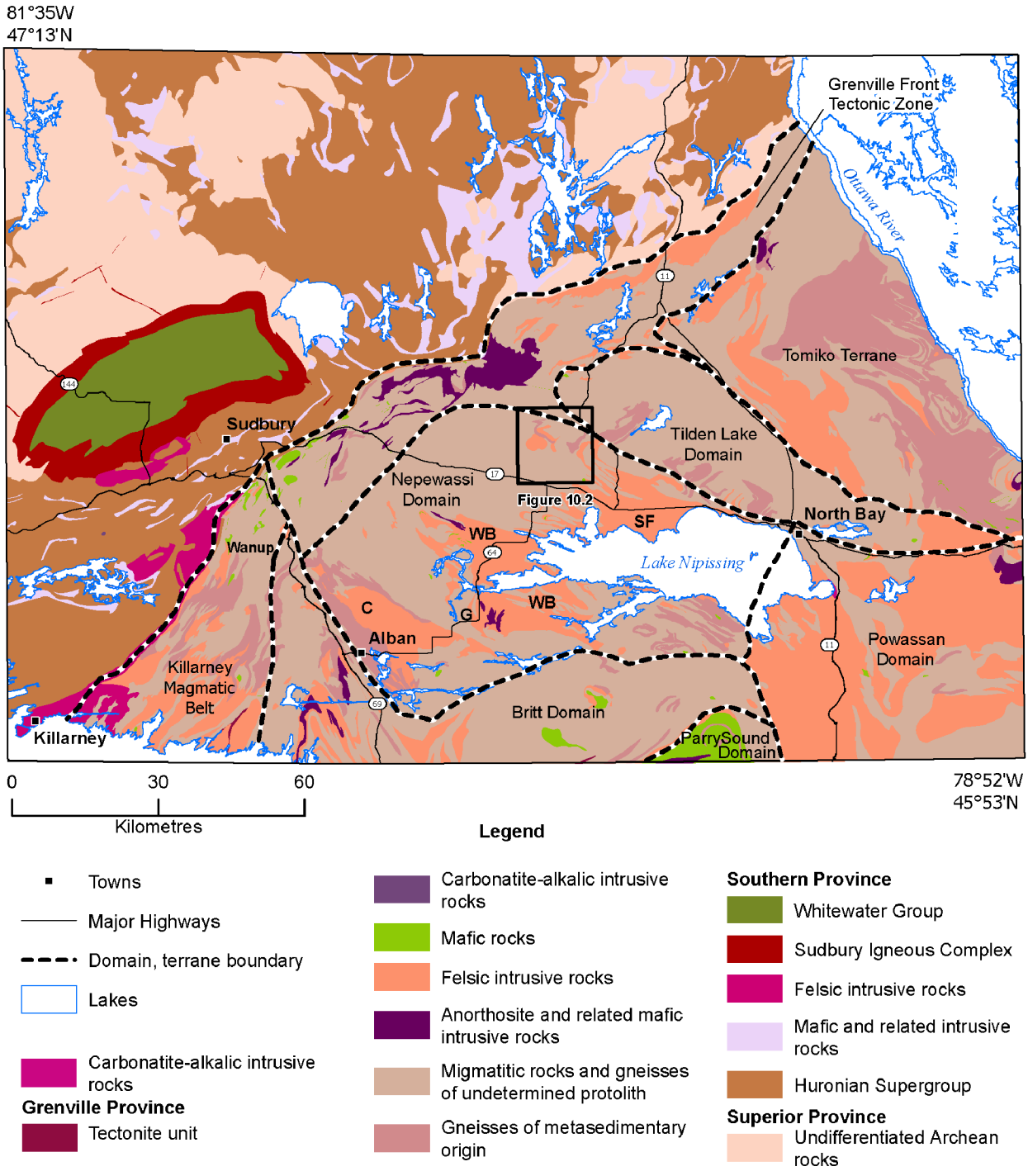


Figure 10.1. Geology of the northern Central Gneiss Belt of the Grenville Province and the Grenville Front region in Ontario. Location of Figure 10.2 is indicated by the solid-line box. Abbreviations: C, Cosby pluton; G, gabbro body on Highway 64; SF, Sturgeon Falls batholith; WB, West Bay batholith. Figure *modified from* Easton (1992, p.755), Easton (2014), Easton and Kamo (2024) and Ontario Geological Survey (2011).

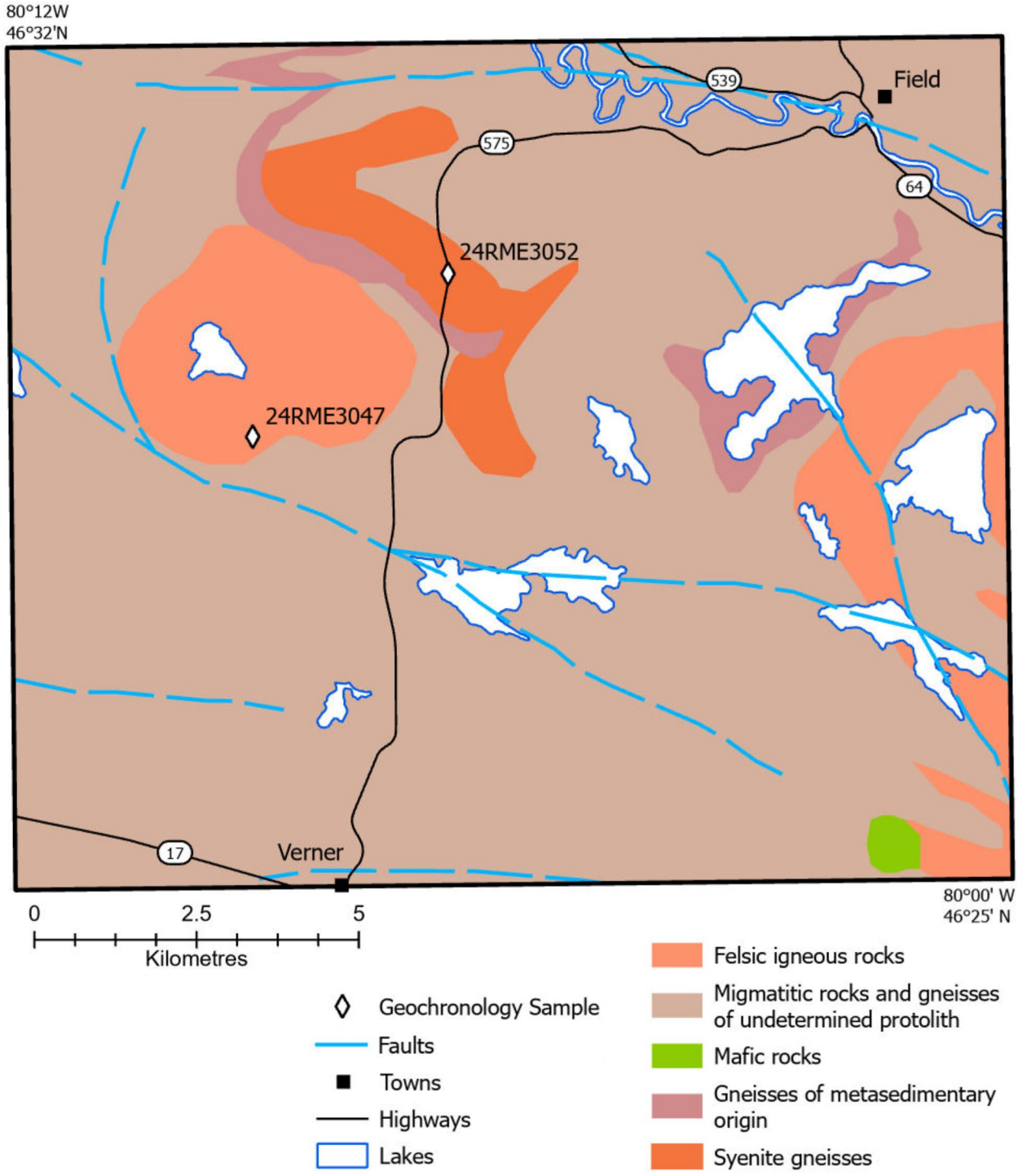


Figure 10.2. Simplified geological map of the Badgerow complex in the Grenville Province north of Verner. Sites sampled for geochemistry and for U/Pb geochronology are indicated. Geology *modified from* Ontario Geological Survey (2011).

GEOCHEMISTRY

Geochemical results are provided in Table 10.1. Geochronology results for samples 24RME-3047 and 24RME-3052 were not available at the time of writing. Note that for some trace elements, results are provided in Table 10.1 for analysis by both X-ray fluorescence spectrometry (XRF) and inductively coupled plasma mass spectrometry (ICP–MS). This is because some refractory phases, such as zircon, may not be completely digested during dissolution for ICP–MS analysis, thereby resulting in lower values for an element, such as zirconium, than that given by the XRF method. This is illustrated in sample 14RME-1073, a West Bay sample with the highest zirconium content, where zirconium by ICP–MS is 668 ppm Zr versus 1008 ppm Zr by XRF. Only the West Bay samples show this effect. In the case of sample 24RME-3052, the difference between zirconium contents by the 2 methods reflects the differences in lower upper detection limit of the 2 methods (detection limit >2400 ppm Zr for XRF versus >17 000 ppm Zr for ICP–MS).

Granitic samples 24RME-1114 and 24RME-3047 are similar in most major and trace element compositions (*see* Table 10.1) and have similar rare earth element patterns even though their total rare earth contents are notably different (Figure 10.3). Sample 24RME-3052 is notably different in being peralkaline and having very high niobium, yttrium, zirconium and total rare earth contents (*see* Table 10.1; *see* Figure 10.3). There are some similarities between sample 24RME-3052 and the West Bay migmatitic monzonite body located to the south of Verner (*see* Table 10.1; *see* Figure 10.1). Key differences are that the West Bay body samples do not show a europium anomaly (*see* Figure 10.3), nor are they peralkaline.

Table 10.1. Representative chemical analyses for samples discussed in the text. All analyses were performed at the OGS Geoscience Laboratories in Sudbury.

	24RME-1114	**24RME-3047**	**24RME-3052**	**West Bay gneiss average (n=10)**	**14RME-1073 West Bay gneiss**
Easting (m)	552423	565131	568146	n/a	553202
Northing (m)	5112392	5147631	5150140	n/a	5122237
Township	Hartland	Badgerow	Badgerow	n/a	Haddo
Rock type	monzogranite	monzogranite	syenite gneiss	monzonite gneiss	monzonite gneiss
Chemical affinity	subalkaline	subalkaline	alkaline	alkaline	alkaline
Shand's Index	on divide	on divide	peralkaline	on divide	metaluminous
Specific gravity (g/cm^3)	2.64	2.63	2.72	n/a	n/a
Major elements (wt %)					
SiO_2	76.01	75.83	64.01	64.76	61.34
TiO_2	0.21	0.13	0.46	0.70	0.62
Al_2O_3	12.19	13.53	14.87	16.12	16.63
$Fe_2O_3^{total}$	2.26	1.10	7.19	5.44	6.59
FeO	0.46	0.31	4.93	1.77	1.42
MnO	0.022	0.011	0.209	0.101	0.157
MgO	0.05	0.15	0.10	0.83	0.38
CaO	0.445	0.745	1.008	2.091	2.412
Na_2O	3.44	5.04	6.50	4.39	5.59
K_2O	5.22	3.81	5.09	4.82	4.80
P_2O_5	0.008	0.022	0.006	0.198	0.123
CO_2	0.057	0.050	0.10o	0.153	0.095
S	<0.001	<0.001	0.005	0.021	0.025
LOI	0.15	0.29	0.08	0.69	0.33
Total	100.03	100.51	99.52	100.35	99.09
Mg number	4.2	21.27	2.68	22.97	10.25
CIA	57.24	59.04	54.14	58.09	56.88

The West Bay body does contain abundant, large zircons (Van de Kerckhove and Easton 2016), but total zirconium contents in the West Bay body still are notably lower than in sample 24RME-3052 (average 638 ppm Zr versus 4800 ppm Zr, respectively, *see* Table 10.1). For comparison, the West Bay sample with the highest zirconium content (*see* Table 10.1: sample 14RME-1073) is still 3 to 4 times lower than in sample 24RME-3052.

Table 10.1, ***continued***.

	24RME-1114	**24RME-3047**	**24RME-3052**	**West Bay gneiss average (n=10)**	**14RME-1073 West Bay gneiss**
Trace elements (ppm)					
Ba [1]	149	432	55	1758	2060
Rb	135	116	201	82	69
Sr	30	118	21	281	295
Nb [1]	23.4	36.1	152.8	36.4	64.0
Nb [2]	24.1	35.8	164.4	35.9	61.18
Ta [2]	0.87	2.66	6.28	1.69	2.624
Th [2]	10.8	33.5	28.2	7.3	6.6
U[2]	1.56	7.03	8.56	1.45	1.26
Y [1]	59	16	145	38	41
Y [2]	61.9	16.4	155.4	38.3	40.19
Zr [1]	394	179	>2400	638	1008
Zr [2]	481	192	4800	502	668
Rare earth elements (ppm)					
La	115.54	22.93	442.28	83.77	75.10
Ce	234.06	43.39	886.77	168.80	152.63
Pr	26.336	4.566	95.528	19.848	18.316
Nd	96.54	15.13	32.983	7.359	6.942
Sm	16.46	2.87	51.19	12.25	12.00
Eu	0.765	0.355	3.682	2.964	3.783
Gd	12.79	2.09	37.45	9.00	9.05
Tb	1.859	0.336	5.290	1.251	1.299
Dy	11.41	2.27	31.96	7.423	7.987
Ho	2.295	0.508	0.497	1.411	1.553
Er	6.77	1.82	20.22	4.059	4.444
Tm	0.974	0.320	3.183	0.585	0.664
Yb	0.542	2.608	24.198	3.809	4.621
Lu	0.971	0.450	3.899	0.595	0.770
Total REE	533.31	99.44	1935.89	389.35	361.60

UTM co-ordinates are provided in NAD 83, Zone 17.

[1] Element determined by X-ray fluorescence.

[2] Element determined by inductively coupled plasma mass spectrometry.

Average of West Bay gneiss samples is from *data found in Van de Kerckhove and Easton (2016), as is sample 14RME-1073.*

Abbreviations: CIA, chemical index of alteration of Nesbitt and Young (1982); g/cm^3, grams per cubic centimetre; LOI, loss on ignition; n/a, not applicable; ppm, parts per million; wt %, weight percent oxide. The term "on divide" indicates samples plot on the dividing line between peraluminous and metaluminous.

DISCUSSION

Further work is needed on the gneissic syenite unit to determine if it was originally an intrusive or a volcanic rock. The fact that it is fine to medium grained and has a strong gneissic texture makes it difficult to determine the original protolith solely on the basis on outcrop observations. Additional sampling and mineralogical study of the gneissic syenite is needed also to better understand the potential economic significance of the geochemical results reported herein.

If a high radiometric signature is a characteristic of the peralkaline gneiss unit of the Badgerow complex, then the regional gamma-ray spectrometric data of Carson et al. (2002) suggests no other similar bodies are present in either the Nepewassi or Tomiko domains of the northern Grenville Province in Ontario.

Sappin, Houlé and Bleeker (2025) have noted that many known Canadian REE-niobium-tantalum deposits are associated with peralkaline intrusions and peralkaline volcanic rocks and that additional deposits may remain unrecognized in metamorphic terrains of the Canadian Shield. The fortuitous nature of the discovery of the peralkaline gneissic syenite described herein illustrates the difficulty in recognizing such rocks in areas that have only received reconnaissance level mapping and geochemical sampling.

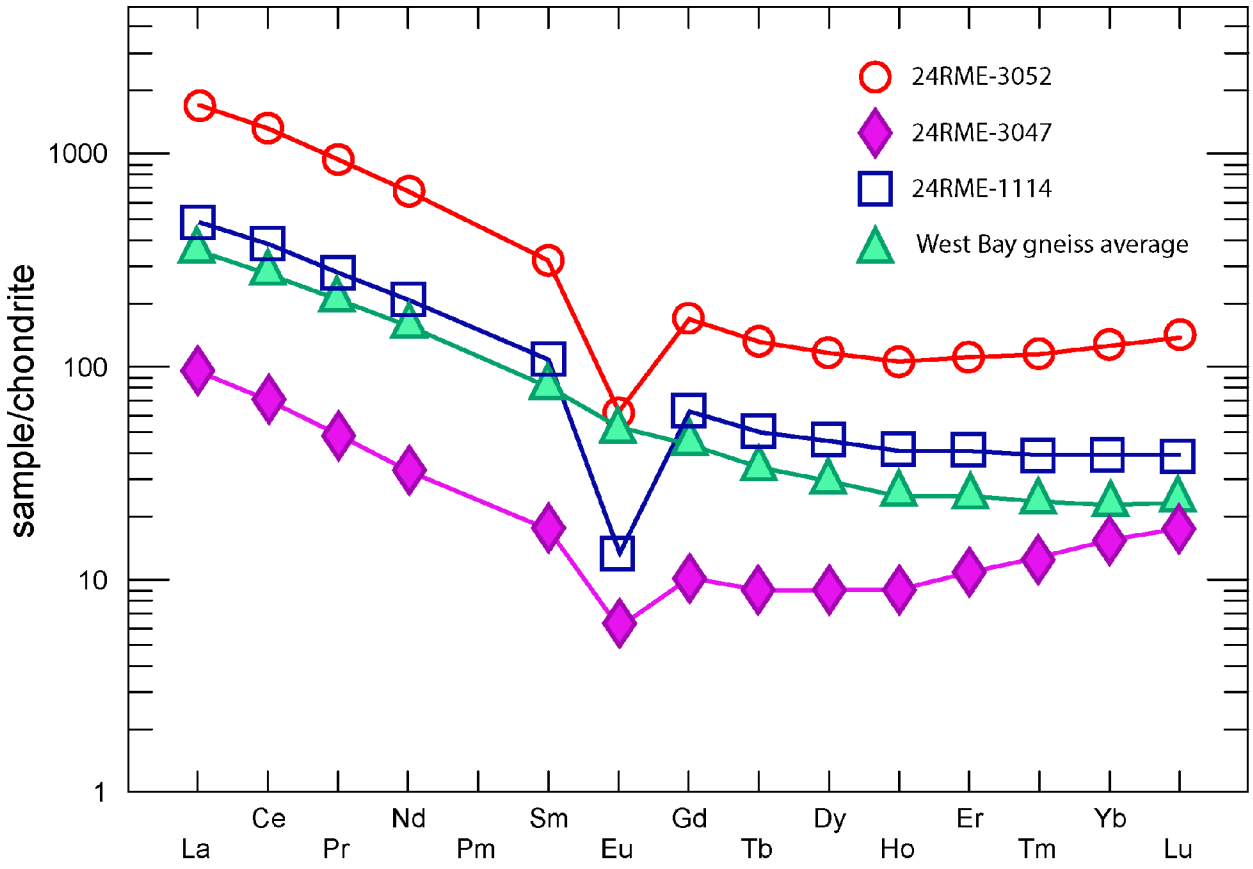


Figure 10.3. Chondrite-normalized rare earth element plot for granitoid samples listed in Table 10.1. See text for discussion. A reminder that the y-axis scale is logarithmic, so the difference between samples 24RME-3047 and 24RME-3052 is larger than it might appear (e.g., La normalized is 97 ppm for sample 24RME-3047, but 1866 ppm for sample 24RME-3052). Normalizing values of Sun and McDonough (1989) were used.

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11. Summary of Geophysical Projects and Activities



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INTRODUCTION

During the past year, the Ontario Geological Survey (OGS) published 1 geophysical data set from the gravity survey conducted in the Guelph area in 2023 (Ontario Geological Survey 2025a, 2025b). This data set comprises 3394 new ground gravity stations and supports the OGS Groundwater Program. In addition, data sets from 2 airborne gravity and magnetic surveys, donated by Nuclear Waste Management Organization (NWMO), were reprocessed in 2024 and 2025 and are currently being prepared for public release. Finally, an airborne magnetic gradiometric and gamma-ray spectrometric survey was flown in the Sault Ste. Marie area from June 15 to July 28, 2025, by Sander Geophysics Limited.

Geophysical services, including imaging, data compilation and interpretation, were provided by OGS geophysicists in support of bedrock mapping, groundwater, and the Resident Geologist programs.

GEOPHYSICAL DATA RELEASES FOR 2025

In April 2025, the ground gravity survey for the Guelph area was published as Geophysical Data Set (GDS) 1090 and is accompanied by the residual Bouguer anomaly Map 80 487 (Ontario Geological Survey 2025a, 2025b). Figure 11.1 shows the location of this survey.

NEW AIRBORNE GEOPHYSICAL DATA

Preparation for the public release of 2 data sets donated by the NWMO is ongoing. These data sets consist of airborne gravity and magnetic surveys flown in 2015 in the Hornepayne and Manitouwadge areas (*see* Figure 11.1). The Hornepayne survey comprises 12 694 line-kilometres and covers 2 separate blocks with a total area of 1238 km^2. The Manitouwadge survey consists of 13 957 line-kilometres over 3 blocks and extends over a total area of 1334 km^2. The donated data were reprocessed to conform with other OGS airborne geophysical data sets in preparation for publication in both map and digital formats. The reports are ready, and the maps are undergoing final review.

New airborne magnetic gradiometric and gamma-ray spectrometric data were acquired in the Sault Ste. Marie area at a nominal line-spacing of 200 m (*see* Figure 11.1). The contract to conduct this survey was awarded to Sander Geophysics Limited. The data were acquired between June 15 and July 28, 2025, and are currently being processed by the contractor. The total survey area is approximately 45 300 line-kilometres. The magnetic gradiometric system was configured with 3 cesium-vapour horizontal magnetometers and the gamma-ray spectrometric system employed 2 sodium iodide (NaI(Tl)) detectors with a total volume of 33.6 L (Photo 11.1).

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.11-1 to 11-7.

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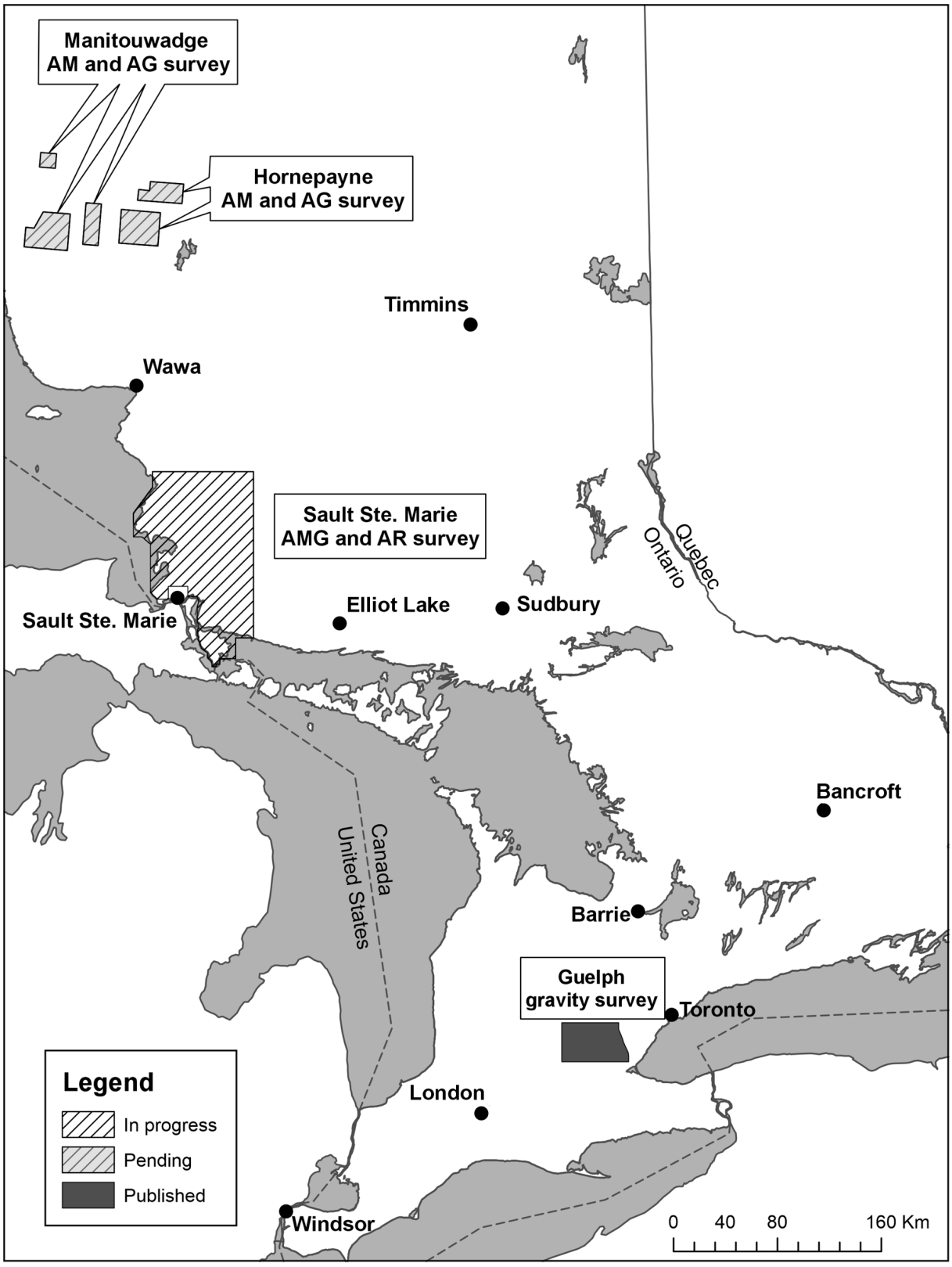


Figure 11.1. Locations of geophysical surveys (including status of the deliverables: published and pending publications, and data set(s) and report(s) in progress). Abbreviations: AG, airborne gravity; AM, airborne magnetic; AMG, airborne magnetic gradient; AR, airborne radiometric.

A report will accompany the data release and final deliverables are expected by the end of 2025. Consultant Paterson, Grant & Watson Limited has been hired to ensure that the deliverables meet OGS standards.

SUPPORT FOR THE GROUNDWATER PROGRAM

The recently published ground gravity survey (GDS 1090) consists of 3394 stations within and around the city limits of Guelph (Ontario Geological Survey 2025a). This survey complements existing ground gravity surveys in the Orangeville (Ontario Geological Survey 2013) and Niagara Peninsula (Ontario Geological Survey 2014) areas, and a study in the Kitchener–Waterloo (Marich et al. 2011).



Photo 11.1. A) Photo of Cessna® 208B Grand Caravan® (G-GSGU) used by Sander Geophysics Limited. Note the location of the 2 wingtip magnetometers and the single tail magnetometer. **B)** Photo of the 2 SGSpec gamma-ray spectrometer crystal packs installed at the rear of the aircraft.

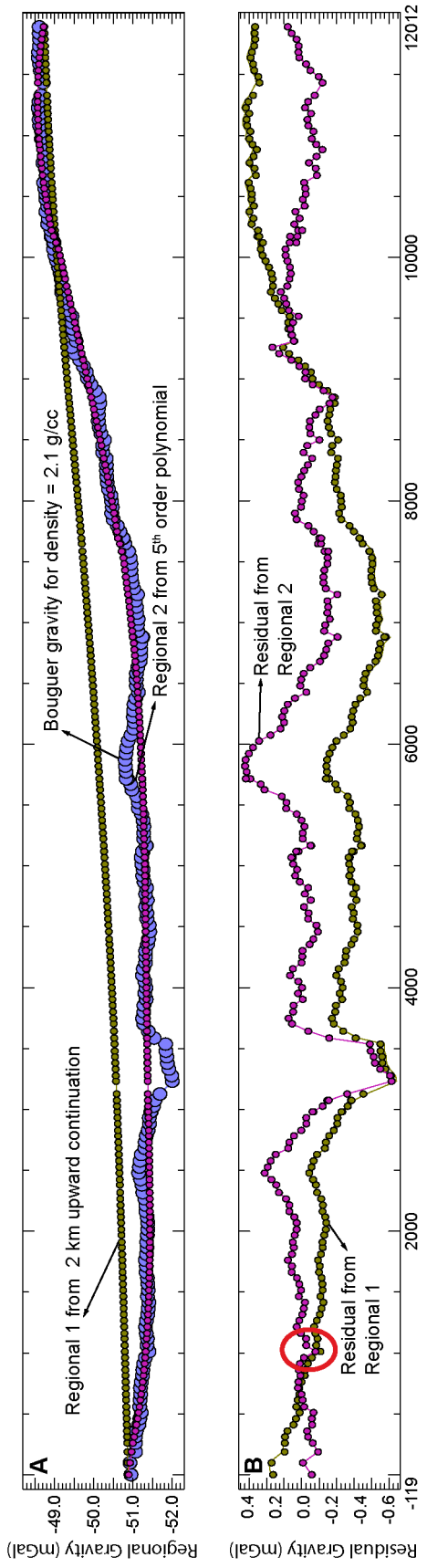


Figure 11.2. A) Bouguer gravity profile from line 8 and corresponding regional gravity profiles from 2 km upward continuation method (Regional 1) and polynomial regression method (Regional 2). **B)** Corresponding residual Bouguer gravity profiles from Regional 1 and Regional 2. The red ellipse emphasizes the low in the residual Bouguer profile from Regional 2, which is more notable than the residual Bouguer profile from Regional 1. It possibly correlates with subtle valleys in the bedrock.

In GDS 1090, the regional gravity data were created by upward continuing the Guelph area gravity data to 2 km. This regional gravity data were subtracted from the Bouguer gravity anomalies to calculate the Bouguer gravity residuals. The lows in the Bouguer gravity residuals correlated well with the prominent bedrock valleys in the area. The Guelph area gravity data were further analyzed to highlight more subtle valley features in the bedrock surface using the third- and fifth-order polynomial regression of the Bouguer gravity anomalies (Biswas and Evangelatos 2025). Figure 11.2 shows Guelph gravity profiles from line 8 highlighting the differences in the regional and residual Bouguer anomalies from the 2 km upward method and the polynomial regression method. The residual Bouguer gravity anomalies from the polynomial regression method were used to help identify potential thalwegs (Figure 11.3) in buried-bedrock valleys. These targets will necessitate further investigation to assess their true nature.

The Kitchener–Waterloo gravity data, although available in the Canadian Gravity Database (CGDB), have not been published by OGS. As such, the Kitchener–Waterloo gravity data and another unpublished ground gravity data from the South Simcoe area are being evaluated for completeness before reformatting according to OGS standards for subsequent publication.

SUPPORT FOR THE BEDROCK GEOLOGY MAPPING PROGRAM

The OGS mapping program for the 2025 field season extended across northern Ontario and included many projects. Support for this program consisted of analysis of existing geophysical data layers in preparation of mapping projects, the creation of suites of images for new projects and review of geological maps with respect to geophysical interpretation prior to publication.

Geophysical support was provided for the following new or ongoing mapping projects:

- eastern Winnipeg River bedrock geology
- Sturgeon Lake greenstone belt

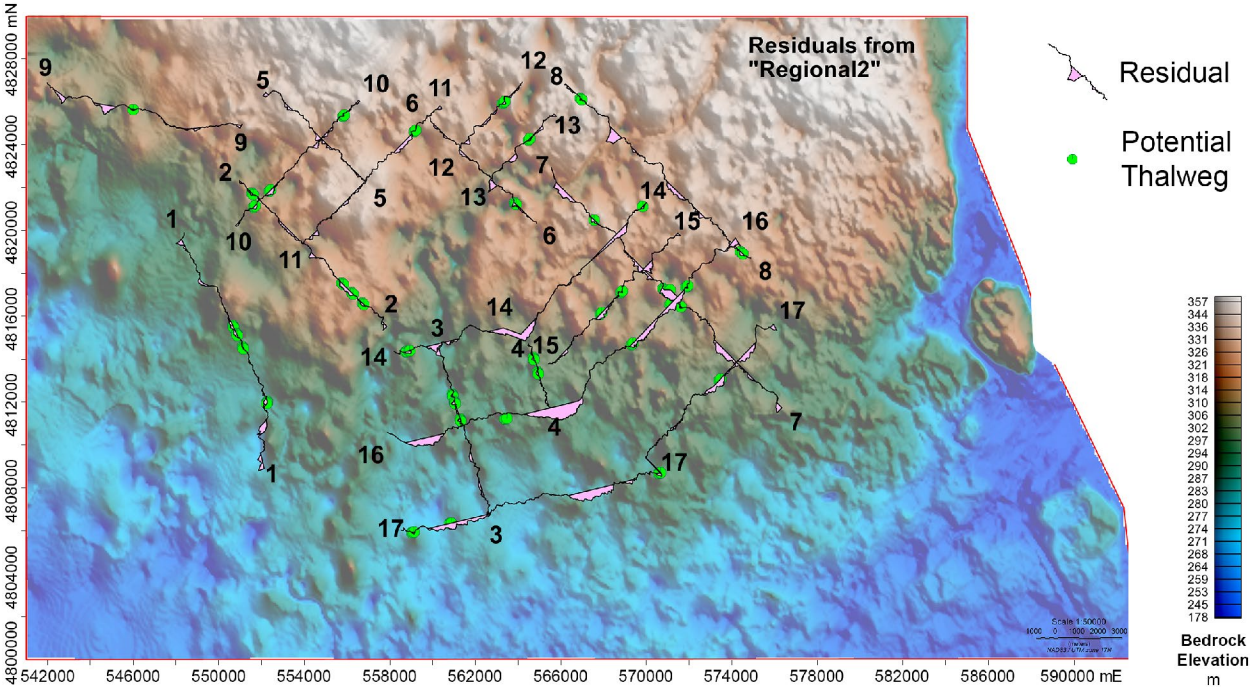


Figure 11.3. The residual Bouguer anomalies from polynomial regression method for the 17 lines in the Guelph area are overlain on the bedrock elevation map. The locations of the interpreted potential thalwegs are plotted as green symbols.

OTHER ACTIVITIES

In 2025, 14 field assistants were trained in operating the magnetic susceptibility meter. Measurements of magnetic susceptibility are used to semiquantitatively assess the concentration of magnetic minerals in outcrop. Prior to the beginning of the field season, the susceptibility meters were calibrated to OGS rock standards and their performance monitored using these same standards to ensure consistent data quality. The newly collected field measurements will be added to compilations from previous years. Data from these compilations are used by industry and academia to improve the accuracy of magnetic interpretations and, hence, subsurface models.

Handheld gamma-ray spectrometers were used by geological field crews on 4 projects. As such, training on the proper use of the OGS spectrometers was provided to field assistants accompanying OGS geoscientists during their mapping projects. Radiometric readings are very useful in the field. For example, these readings can discriminate between similar looking granitoids based on their respective concentrations of potassium, uranium and thorium. The performance of these instruments is regularly tested for consistency at a convenient field location off Municipal Road 35 in Sudbury.

A summer student was hired to reprocess and merge historical airborne radiometric data covering large swaths of Ontario. The aim is to create readily downloadable grids and images from OGSEarth of various types of radiometric data. As such, in terms of access and areal extent, the final products will be similar to the "master" grids that were created for the gravity and coarsely spaced aeromagnetic data sets (Ontario Geological Survey 2003a, 2003b).

The OGS continued to serve the public by addressing geophysical enquiries from clients in mineral exploration and by providing material support to other staff within the Ministry of Energy and Mines. Geophysics staff attended the Canadian Exploration Geophysicists Society (KEGS) Symposium in March 2025 and John Evangelatos assisted in the recruitment of summer students during the Ontario Geological Survey Student Outreach Session at the Prospectors and Developers Association of Canada (PDAC) Annual Convention.

Ontario Geological Survey geophysical and other geoscientific data can be downloaded and viewed using the OGSEarth application (www.ontario.ca/ogsearth). A geophysical survey index, which can be accessed from the OGSEarth application, continues to be maintained and updated with each new release of geophysical data. This index can be downloaded as a Google Earth™ mapping service file (*.kml*) or as ESRI® files (*.shp*). Free downloads of geophysical data can be accessed from GeologyOntario (www.hub.geologyontario.mines.gov.on.ca). Hard-copy (paper) reports and maps, and physical media (CD or DVD) of digital data are also available for a nominal fee through the Publication Sales:

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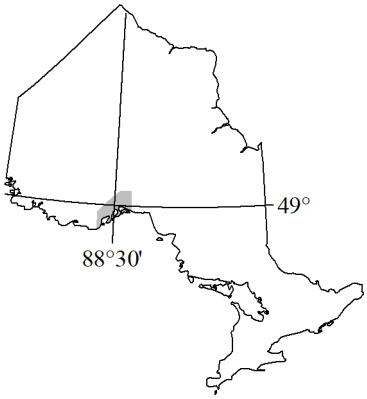
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12. Project NW-23-002. Till Sampling and Ice-Flow Indicators Between Nipigon and Thunder Bay, Northwestern Ontario



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INTRODUCTION

The Laurentide Ice Sheet covered all of Ontario during the last glacial maximum approximately 24 000 years ago (Dalton et al. 2020). Throughout the ice sheets advance, inundation and retreat, the glacier eroded, transported and deposited material in a wide variety of environments. Till, a material directly transported by movement at the base of the ice sheet, can be sampled for mineral exploration. The sampling of till for mineral exploration uses the understanding of glacial ice-flow events and the composition of the till to help identify the provenance of a till unit, often mineralized bedrock. This method of mineral exploration, called drift prospecting, is used at various scales to determine the broad mineral potential of an area down to identifying the exact location of the deposit itself.

Till sampling for regional prospectivity and striation measurements for ice-flow determination were completed in the area between Nipigon and Thunder Bay as part of the third and final field season of a till sampling and Quaternary geology mapping project in the Georgia Lake area of northwestern Ontario. The previous 2 field seasons focussed on the area surrounding Georgia Lake (Hagedorn and Beckett-Brown 2023; Hagedorn 2024a) where till samples and ice-flow measurements were collected along with observations of surficial sediments and landforms for 2 surficial geology maps, each at a scale of 1:50 000. The region was selected because the Georgia Lake rare-element pegmatite field is of interest for lithium exploration in the province. Additionally, the project area fills a gap in the provincial till sampling coverage (Hagedorn 2024b), situated between an Operation Treasure Hunt study to the northwest (Dyer and Barnett 2005), work by the Geological Survey of Canada in the Geraldton area to the north (Thorleifson and Kristjansson 1993), Schreiber to the east (Morris 2000, 2001) and Shebandowan to the southwest (Bajc 1999). The southern border of the study area is bounded by Lake Superior. The overall aim of this project is to provide an updated understanding of mineral prospectivity and glacial history of the region.

BACKGROUND

Bedrock Geology

The study area contains 6 main bedrock domains (Figure 12.1). The dominant rocks in the region are metamorphosed and deformed Archean turbidite sequences of the Quetico Subprovince (2.7–2.690 Ga). The second oldest bedrock unit is a succession of volcanic and sedimentary rocks belonging to the Shebandowan greenstone belt (2.72–2.68 Ga). This greenstone belt is located in the southwest portion of the map area near Thunder Bay. Granitic plutons (2.69–2.66 Ga) intruded supracrustal rocks of the

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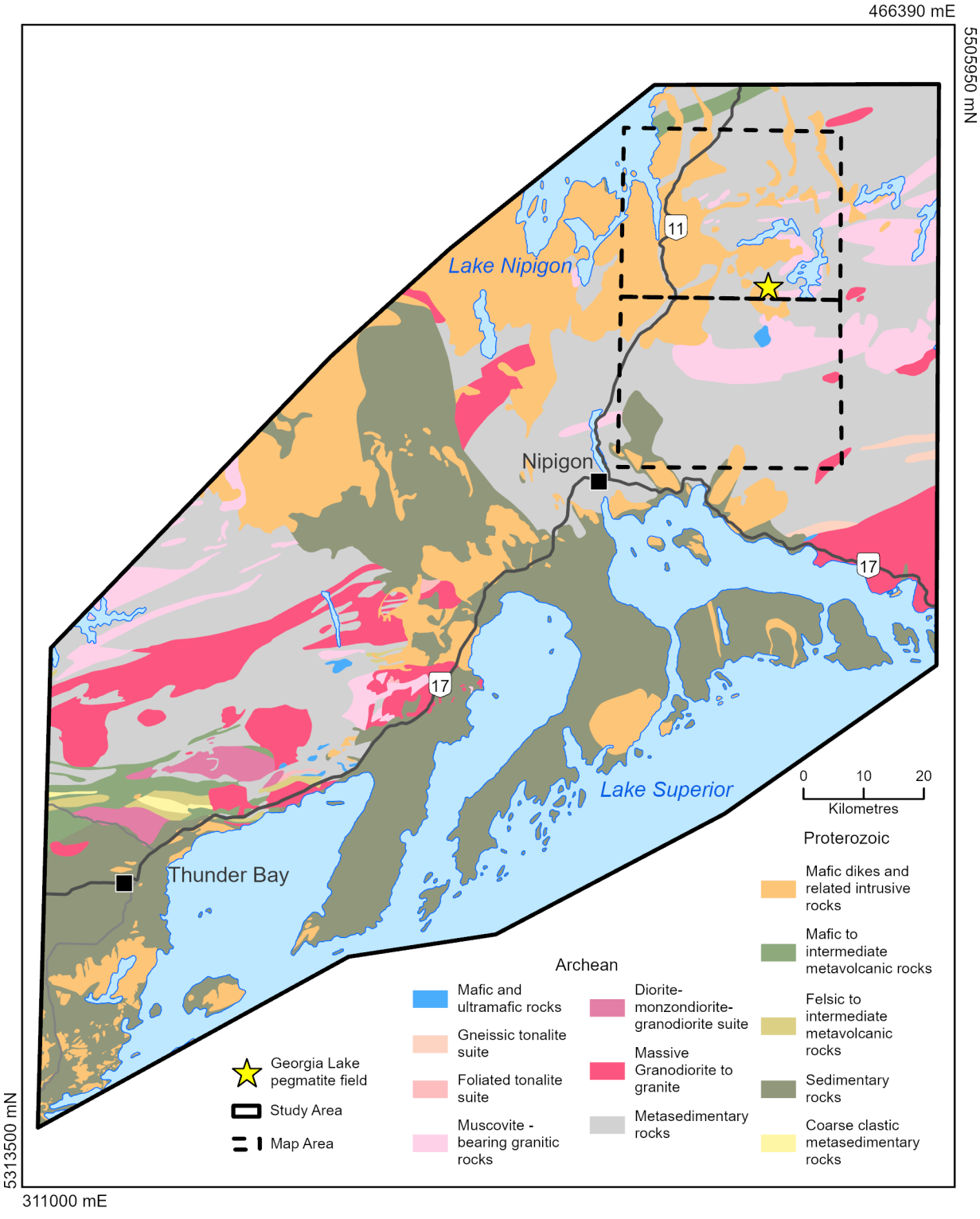


Figure 12.1. Bedrock geology of the study area *from* Ontario Geological Survey (2011). The solid line represents the total study area; the dashed lines represent the locations of the 2 planned surficial geology maps. Major bedrock rock types include metasedimentary rocks (grey), greenstone belt intrusive (light green and beige), granites (pink), sedimentary rocks (dark green), and mafic sills (orange). For the sake of clarity, the Proterozoic sedimentary units (i.e., Animikie Basin and Sibley Group) were grouped into a single category. All Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 16N.

Quetico Subprovince and the Shebandowan greenstone belt. The youngest plutonic suite is represented by peraluminous plutons (*circa* 2660 Ma) that are interpreted as the source of the lithium-cesium-tantalum (LCT)-type pegmatites found throughout the study area (Breaks, Selway and Tindle 2008). The Archean units are uncomformably overlain by Proterozoic sedimentary rocks, deposited in 2 basins. The oldest basin is represented by the Paleoproterozoic Animikie Basin (*circa* 1.88 Ga) that is exposed in the Thunder Bay area. It is composed of a series of conglomerates, shales and sandstones interlayered with mafic volcanic rocks and stromatolites. The Mesoproterozoic Sibley Group (*circa* 1.44 Ga) consists of flat-lying siliciclastic and chemical sedimentary rocks (Rogala et al. 2007). The youngest bedrock unit consists of Mesoproterozoic mafic sills (1.1–1.2 Ga) related to the Midcontinent Rift. These mafic rocks are the unit most resistant to erosion and create large uplands with steep flanks. For more detailed description of the bedrock geology, refer to Duguet (2019, 2023) in the east and Launay and Metsaranta (2024) in the west.

Quaternary Geology

Ice flow was predominantly to the southwest in the study area during the last glaciation, interpreted from ice-flow indicator, landform, striation and esker orientations. Around 10 ka BP, the ice sheet began to retreat from the study area (Dalton et al. 2020). The pattern of this retreat, based on the orientation of moraines and locations of esker–fan complexes, was broadly eastward. Minor readvances after deglaciation created crosscutting striations and overrode existing landforms. During retreat, an isostatically depressed landscape and natural drainage pathways blocked by glacial ice led to glacial lakes developing along the ice margin. The largest of these, glacial Lake Agassiz inundated the lower regions of the western portion of the study area, covering previously deposited sediments with glaciolacustrine silts and clays. Glacial Lake Agassiz had many stages of filling and draining as the ice margin fluctuated, opening lower drainage channels or blocking the lake outlets (Lowell et al. 2021; Fisher and Breckenridge 2022). The study area was completely ice free by at least 8.5 ka BP as the ice sheet continued its northeastern retreat towards Hudson's Bay (Dalton et al. 2020).

FIELD ACTIVITIES

Field work during the 2025 season focussed on the western part of the study area. A total of 198 locations were visited with a total of 85 till samples and 126 ice-flow measurements collected (*see* Figure 12.2 for till sample locations and Figure 12.3 for striation locations). The study area was accessed by truck along road networks.

Till Samples

Standard Ontario Geological Survey till sampling procedures were followed for this work (e.g., Bajc 1999). A large 10 kg till sample was collected and sent to Overburden Drilling Management for indicator mineral processing and picking. A smaller 3 kg till sample was sent to OGS Geoscience Laboratories for matrix geochemistry analysis, with both a partial and total digestion. Additionally, Chittick method analysis to determine carbonate content, grain size analysis to determine sand silt and clay content, and pebble counts to determine coarse size fraction composition will be completed to help with till unit characterization.

During previous field seasons, 2 till units were observed. One was a sandier locally derived till, the other a silt and clay rich carbonate till that contains more far-travelled material. These were easily differentiated in the field using 10% HCl with the latter reacting vigorously (Hagedorn 2024a). Field work this year farther to the west found both these tills and 3 others. One of the new tills observed

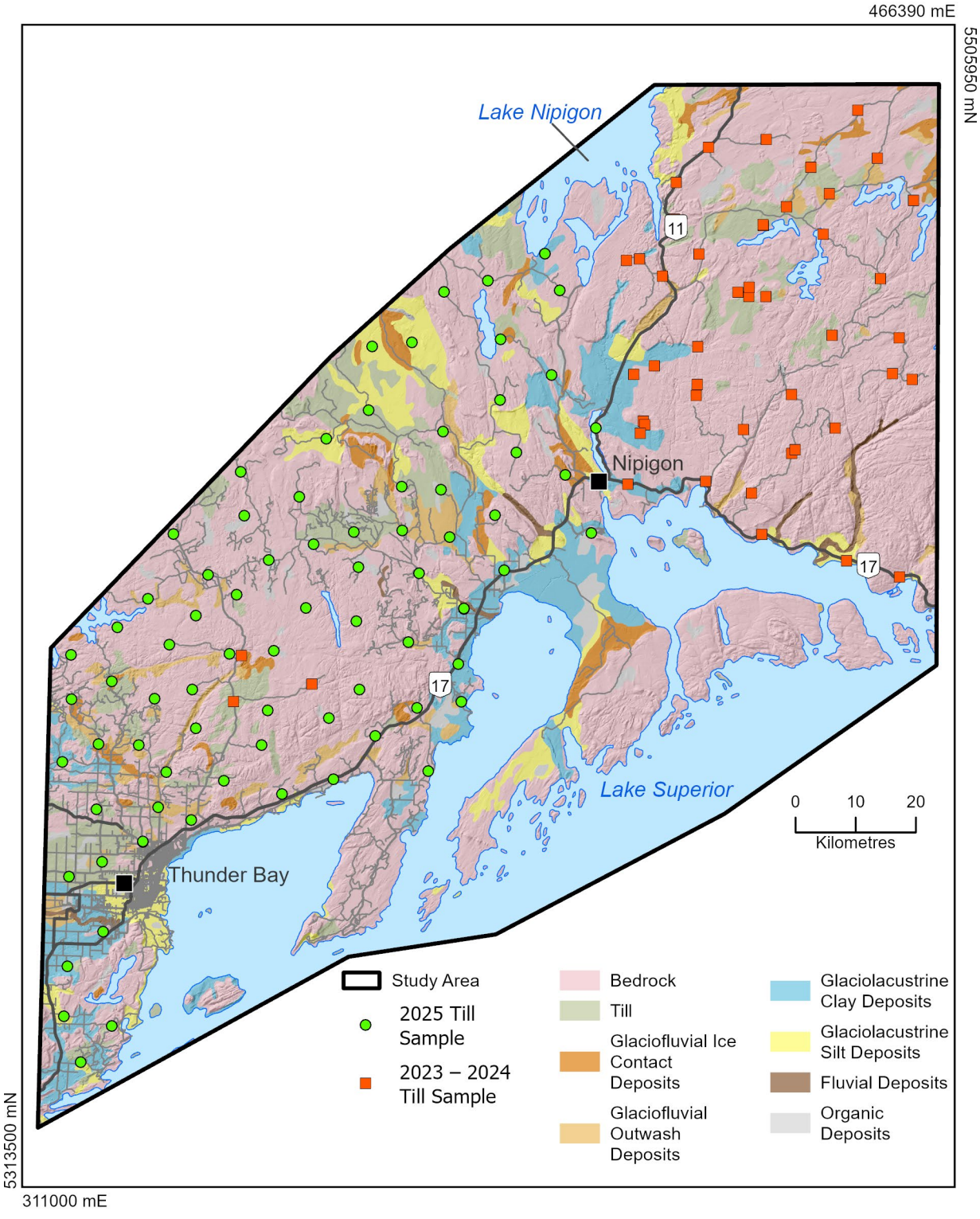


Figure 12.2. Regional (1:1 000 000 scale) surficial geology of the study area *from* Barnett, Cowan and Henry (1991) with the regional lidar as a hillshade underneath (Ministry of Northern Development, Mines, Natural Resources and Forestry 2022). Shown are all tills sample collected this year (green circles) and in previous years (red-orange squares) (Hagedorn and Beckett-Brown 2023; Hagedorn 2024a). All UTM co-ordinates provided using NAD83 in Zone 16N.

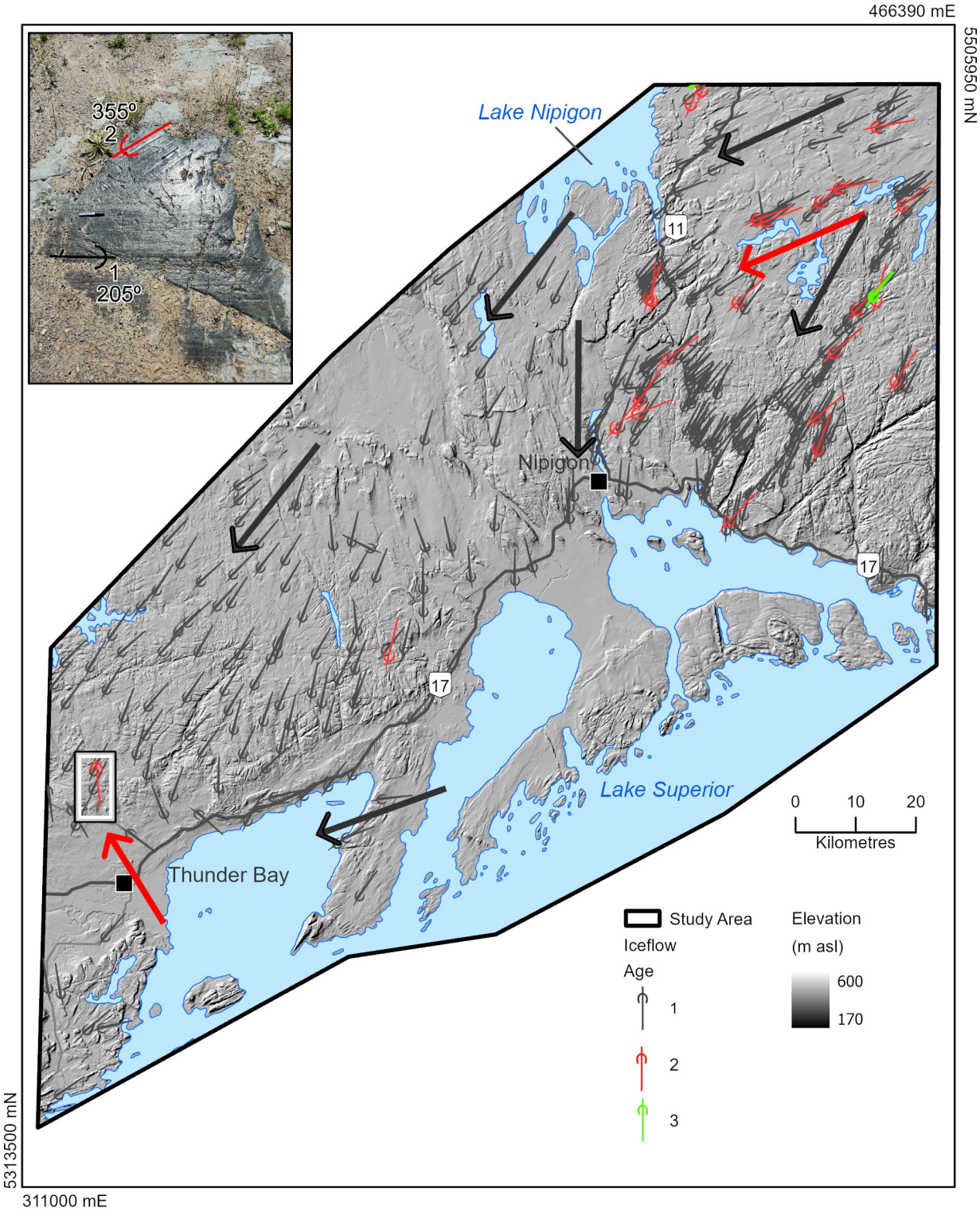


Figure 12.3. Regional lidar and hillshade (Ministry of Northern Development, Mines, Natural Resources and Forestry 2022) with striation measurements from all 3 field seasons. Black arrows are oldest or only ice flow, red arrows are the second (younger) ice flow and green arrows are the third (youngest) ice flow. Larger arrows show a summary of the ice-flow directions over the region. Note that colour of the arrow denotes the oldest flow observed in the region and are not necessarily contemporaneous. Inset image is site 25-GWH-149 highlighted with box on map. The photo shows an older ice flow (1: 205°) crosscut by a younger northward (2: 355°) flow. All UTM co-ordinates provided using NAD83 in Zone 16N.

exhibits a range of grain sizes from a red-grey sandy silt till with abundant rubbly angular Sibley Group clasts (20%) to a red-grey sandy silt till with little clasts (5–10%). The provenance of the red till is interpreted based on the colour that resembles the red rocks of the Sibley Group. A grey-brown silty sand till found in the western parts of the study area appears to be of a different provenance to other sandier tills described in the eastern portion of the study area (Hagedorn 2024a). The grey-brown till observed this year was identified based on its abundant sand matrix and light grey colour. The grain size will be measured with the grain size analysis. The last till unit observed in 2025 was only observed at 1 site west of Thunder Bay. This till was an extremely compact brown fissile till, discovered below the red fine-textured till. Both tills were sampled at the site. These are preliminary observations of new till units and they will be further characterized based on the geochemistry, indicator mineral and grain size analyses to clarify these interpretations.

Ice-Flow Indicators

Ice-flow indicators in the western portion of the study area are more complex than to the east. In the east, the prominent ice-flow direction is south-southwestward with some late west-southwestward flow (Figure 12.3). In the upland regions to the west, the south-southwestward flow is similar, but, on these upland regions, no crosscutting westward flow was observed. This could suggest that the more westward flow only impacted the eastern portions of the study area or that the bedrock in the western part of the study area are not competent enough to preserve multiple ice flows. In the lowland regions around Thunder Bay, a north-northwest ice flow was observed as a lobe extended up out of the Lake Superior basin during a glacial readvance. This is a younger flow than the regionally pervasive southwest flow with the crosscutting relationship clearly shown at site 25-GWH-149 (*see* inset photo on Figure 12.3). A synthesis of the ice-flow directions are shown as the larger arrows on Figure 12.3.

SUMMARY

This is the final field season of the “Indicator mineral and till geochemistry of the Georgia Lake rare-element pegmatite field” project. Qualitatively 5 different tills were observed in the field and the striations revealed a more complex sequence of ice flows ranging from south to west and a localized younger northward flow.

Next steps for the project include preparing 1) a presentation for OGS Showcase to provide preliminary till sample data; b) 2 surficial geology maps, at a scale of 1:50 000, of the area surrounding the Georgia Lake pegmatite field; and 3) a Miscellaneous Release—Data (MRD) comprising all the geochemistry, indicator mineral data, and Chittick and grain size data. An Open File Report, summarizing all the results from the mapping and till sampling over the region, is also planned.

ACKNOWLEDGMENTS

Andrea Marich and Sonia Préfontaine (OGS) are thanked for their reviews of this article. Summer field assistants James Barnes (Trent University) and Declan O-Flynn (Queens University) are thanked for their help in the field. Fort William First Nation, Red Rock Indian Band, Métis Nation of Ontario Region 2, Red Sky Métis Independent Nation, Animbiigoo Zaagi’igan Anishinaabek (Lake Nipigon Ojibway First Nation), Pawgasheeng (Pays Plat First Nation), Bingwi Neyaashi Anishinaabek (Sand Point First Nation), Biinjitiwaabik Zaaging Anishinaabek (Rocky Bay First Nation) Long Lake #58 First Nation, Kiashke Zaaging Anishinaabek (Gull Bay First Nation) are thanked for granting us access to their traditional lands. The Lodge at Red Rock (Red Rock) and Seasons Extended Stay (Thunder Bay) provided wonderful field accommodations during the work.

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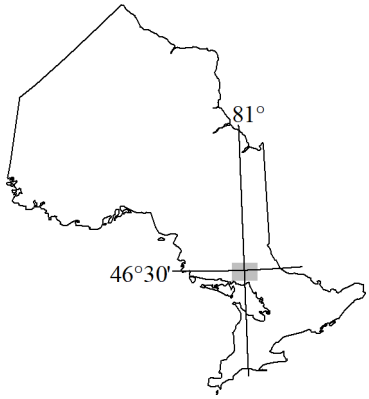
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13. A Newly Recorded Late-Glacial Varved Clay Deposit, Sudbury, Northeastern Ontario



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INTRODUCTION

Varved clay deposits developed in glacial lakes, such as Lakes Algonquin, Agassiz and Barlow–Ojibway, and they are common in northern Ontario (e.g., Antevs 1925; Harrison 1972; Guillet 1977; Veillette 1994; Breckenridge et al. 2012; Marich 2023; Gao 2007, 2024). However, varved clay deposits are infrequent in literature for the Sudbury area except in the central plain of the Sudbury Basin, e.g., around the Chelmsford area where thick glaciolacustrine deposits occur (Antevs 1925; Burwasser 1979). The earliest report on varved clay deposits for the region was from Antevs (1925) who logged the deposits in his study of varve chronology near Copper Cliff and in Chelmsford. Although there are general discussions on the deposits (Boissonneau 1968; Burwasser 1979; Barnett and Bajc 2002), the only other report for this area since was by Guillet (1977) who described a varved clay deposit at Whitefish in an assessment of clay resources.

In the summer of 2023, a varved clay deposit (2.5 m thick) with red varves was exposed at a construction site for a new housing subdivision on the western extension of Moonrock Avenue in the urban area of the city of Sudbury (46°27′5.18″N, 81°1′25.64″W) (Figure 13.1). The Sudbury area was inundated by glacial Lake Algonquin prior to the final drainage of this lake during the late glacial (Burwasser 1979; Barnett and Bajc 2002; Dyke 2004). While varved clay deposits in Sudbury might be, as Antevs (1925) suggested, insignificant for establishing the chronology of glacial Lake Algonquin because of their small extent and thickness, study of them can shed new light on the history of this lake and deglaciation of this region. Additionally, such a study can provide geochemical baseline information for future environment monitoring and assessment for the city.

FIELD OBSERVATIONS

The local bedrock of the study area is Paleoproterozoic Huronian Supergroup conglomerate, mudstone (argillite) and sandstone (*see* Figure 13.1) (Rousell, Meyer and Prevec 2002). Surficial sediments are thin and discontinuous in the study area, except in large bedrock depressions where relatively thick deposits occur (Burwasser 1979; Barnett and Bajc 2002). The varved clay deposit (shortened herein as "varved clay") studied here is exposed in a northward-aligning trench excavated in a low-lying area between bedrock ridges. Thin (<0.5 m), massive to laminated glaciolacustrine fine sand and sandy silt is also seen mantling the lower slopes of the nearby bedrock ridges and infilling some bedrock depressions atop these ridges.

Based on a lidar-derived digital terrain model (Ministry of Natural Resources 2025), the section has a surface elevation at 270.5 m above sea level (asl) and a base at 268 m asl, for a total thickness of 2.5 m above bedrock, and extends laterally for at least 20 m along the trench (Photo 13.1A). At the northern end

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.13-1 to 13-9.

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of the trench, the varved clay drapes the slope of the bedrock ridge (Photo 13.1B). Along the trench, locally, the deposit overlies a stone-rich, noncalcareous, grey sandy till with gravel clasts mostly from the local bedrock. The varved clay has well-developed, centimetre-scale varve laminations or varves in the lower 1.5 m of the section (Photo 13.1C) and becomes a massive silt and sandy silt in the upper 1 m. The colour of the deposit changes from grey to brown upward, with the uppermost 0.4 m of the section being pale grey (*see* Photo 13.1A). Pinkish red colour is seen in a 20 cm interval at 1.2 to 1.4 m depth in the middle of the section. Occasional dropstone pebbles of mudstone (argillite) and sandstone occur (*see* Photo 13.1B). No concentration of lag boulders has been observed at the contact between the varved clay and the underlying till and bedrock (*see* Photo 13.1C).

Field observations also showed that, in the varved clay, each varve consists of a couplet of layers that are interpreted to have developed in summer and winter annually in a glacial lake. The summer layer consists of light-toned silt and very fine sand and the winter layer of dark-toned clay (Photo 13.1D). The transition from the summer to winter layers in a varve is usually sharp. Trace fossils as burrowing structures by bottom-dwelling animals (e.g., larvae) are abundant in summer layers but rare in winter layers. They are now filled with light-toned sandy silt (*see* Photo 13.1D). Within the 1.2 to 1.4 m depth

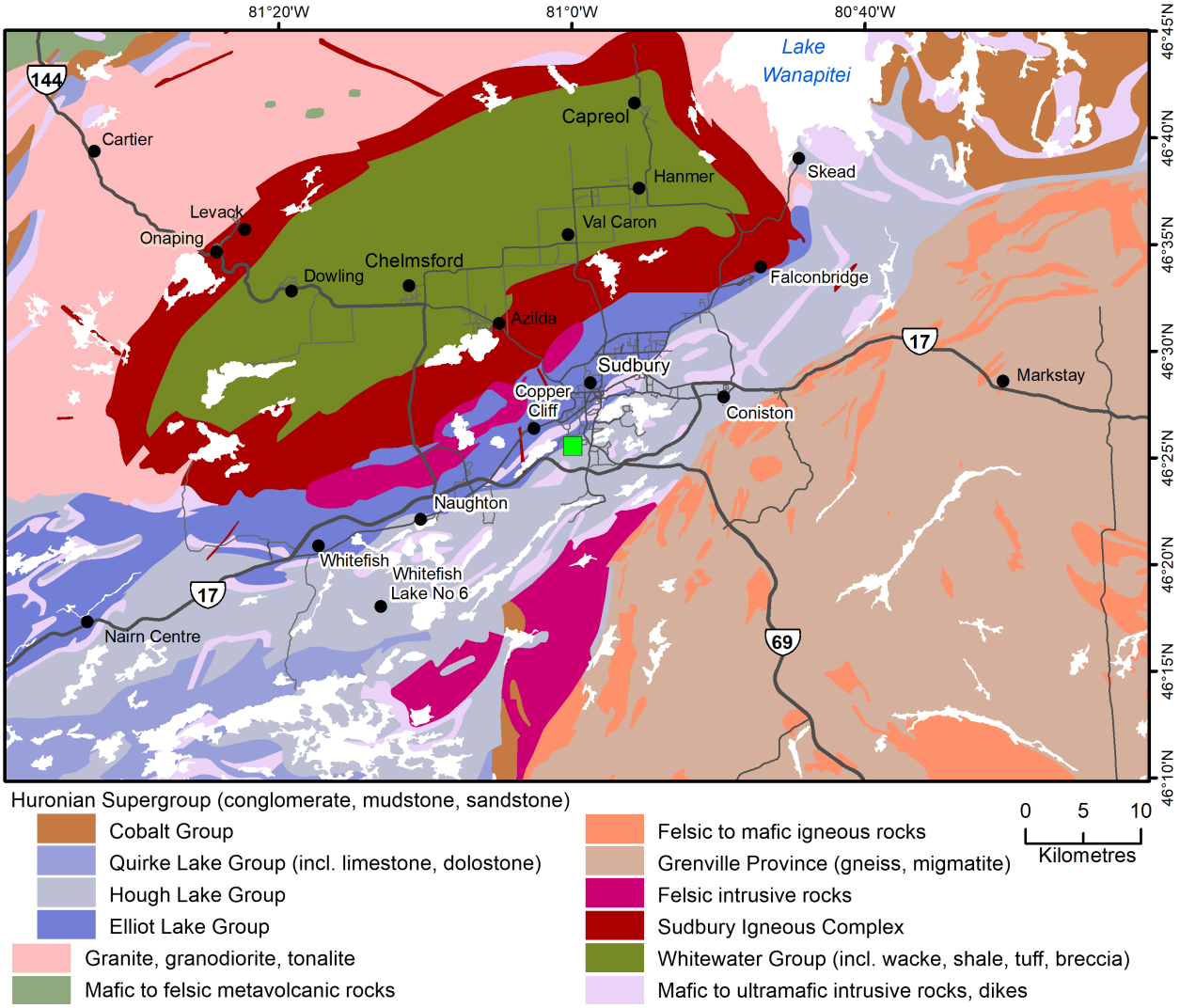


Figure 13.1. Study site (green square, 46°27′5.18″N, 81°1′25.64″W) in the city of Sudbury, and the bedrock geology in the Sudbury area and vicinity (*from* Ontario Geological Survey 2011).

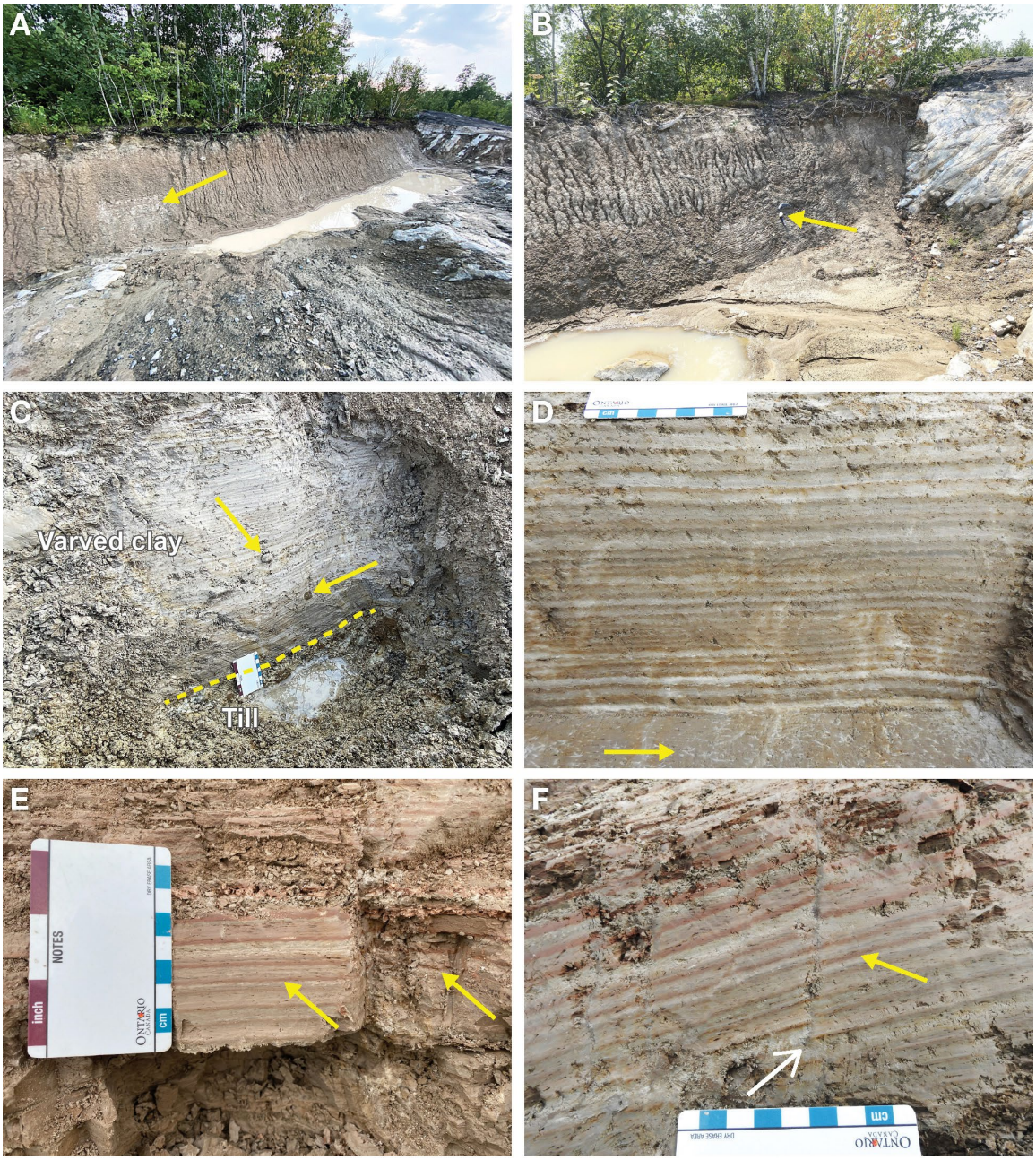


Photo 13.1. The varved clay deposit exposed in a low-lying area between bedrock ridges at the study site. **A)** The northward-aligning trench wall showing where the varved clay is exposed on bedrock. The cleared part in central left is the main section where the deposit was logged and sampled. Arrow points to the interval where varves with red winter layers occur. The local bedrock seen in the photo is Huronian Supergroup Mississagi Formation sandstone and conglomerate. Note that at the northern end of the section (upper right), the varved clay drapes the lower part of the bedrock ridge. **B)** Enlarged northern end of the section where the varved clay draping the bedrock ridge shows tilted varve lamination dipping away from the bedrock slope. A large dropstone of mudstone (argillite) (25 cm across) is seen just above the trowel head (14 cm long) (indicated by yellow arrow). **C)** Lower part of the varved clay showing its contact (dotted line) with a stone-rich, noncalcareous, grey sandy till. Yellow arrows indicate dropstones (mudstone (argillite) and quartzite). Scale card 9 cm. **D)** Close-up view of varves in the lower part of the deposit. Each varve consists of a light-toned summer layer of silt and fine sand and a dark-toned winter layer consisting predominantly of clay-size material. The flat surface at the bottom of this section is the upper surface of a winter layer (arrow) where many trace fossils, as small burrowing structures filled with light-toned sandy silt, were observed. Scale card marked in centimetres. **E)** Varves with red winter layers in the middle of the main section. Arrow indicates the first appearance of red winter layers. **F)** The same red winter layers (yellow arrow), shown in the Photo 13.1E, are observed to tilt at the northern end of the section where the varve clay drapes the bedrock ridge. Note the presence of a small vertical fault in the centre (white arrow).

interval of red varves (mentioned previously), only the winter layers of the varves are red, whereas the colour of summer layers remains unchanged (i.e., pale grey) (Photos 13.1E and 13.1F). About 15 varves were counted consecutively to have red winter layers. Upward, the red winter layers gradually fade into brown. The varved clay is noncalcareous, i.e., not reacting with 10% HCl solution, except for the interval where the red winter layers occur. There, strong reaction is always associated with the summer layers and the winter layers tend to have weak to no reaction with 10% HCl. There are 172 varves for the lower 1.5 m of the deposit where they occur. The varves are horizontal in occurrence in the section. However, where the deposit drapes the slope of the bedrock ridge, they tilt (*see* Photos 13.1B and 13.1F).

SAMPLING AND LABORATORY WORK

The varved clay was sampled continuously at interval of 5 cm from its base to top surface, with a total number of 50 samples collected. A sample from the underlying sandy till was also obtained. These samples will be analyzed for geochemistry using inductively coupled plasma (ICP) spectrometry, instrumental neutron activation analysis (INAA), clay mineralogy and particle size analyses, and Chittick method analysis to determine carbonate material.

DISCUSSION AND SUMMARY

Although the laboratory data are not available yet, some discussion can be made based on the field observations (Figures 13.2A to 13.2D). With the current understanding of the ice margin configuration in the region (Barnett 1992; Veillette 1994; Dyke 2004), the varved clay developed in glacial Lake Algonquin sometime between 12.1 and 11.5 calibrated (calendar) thousands of years before present (cal ka BP) (*see* Figures 13.2B to 13.2D). Glacial Lake Algonquin was at its maximum extent and probably drained southward around 12.1 cal ka BP when the study site was still covered by the ice sheet (*see* Figure 13.2B, black arrow). Further recession of the ice exposed the study site and vicinity, causing incursion of glacial Lake Algonquin into the newly exposed area. At that time, the lake drained eastward into the Ottawa Valley and Champlain Sea through a series of outlets across the present-day Algonquin Provincial Park (*see* Figure 13.2C, black arrow; Chapman and Putnam 1984; Barnett 1992; Dyke 2004; Lewis et al. 2008). The lack of lag boulders at the contact between the varved clay and the underlying till suggests limited to negligible lake wave erosion and winnowing and, hence, deep-water conditions at the onset of the deposition at the study site. By 11.8 cal ka BP, the ice retreated to present-day Capreol, north of the city of Sudbury, where it constructed a small end moraine (Cartier I moraine; *see* Figure 13.2C; Boissonneau 1968; Barnett and Bajc 2002). Further retreat of the ice resulted in the final drainage of glacial Lake Algonquin through the newly opened Nipissing–Mattawa outlet and termination of glaciolacustrine deposition in the Sudbury area by 11.5 cal ka BP (*see* Figure 13.2D, black arrow). The slightly coarser material of sandy silt in the uppermost part of the section, which is also common on the lower slopes of the nearby bedrock ridges, reflects shallow water conditions, consistent with the waning stage of glacial Lake Algonquin.

The red winter layers are interpreted to be the result of the amount of iron oxide, most likely hematite, the degree of hydration of the iron oxide and the size and distribution of the oxides (Antevs 1925). Because they only occur in the middle of the section rather than in the entire deposit, oxidation of ferrous iron (Fe^{2+}) during the deposition and diagenesis of the sediments can be excluded as the mechanism. The red pigment material likely is detrital origin from pre-existing red deposits and is mainly fine grained in clay-size fraction. The till in the Sudbury area is grey to brown with low carbonate in till matrix (<1%; Bajc and Hall 2000; Hashmi 2018) and is unlikely to be the source. Red beds of both Proterozoic and Paleozoic bedrock occur around the Sudbury area and farther south, which can potentially provide red material (*see* Figure 13.2A). Because the ice sheet moved to the southwest and south (Boissonneau 1968; Prest, Grant and Rampton 1968; Harrison 1972; Cowan and Broster 1988;

Henderson and Halstead 1992; Barnett and Bajc 2002; Gao 2012, 2016; Mulligan et al. 2023; Marich 2023), the red bedrock south of the ice margin, such as the Ordovician Queenston Formation that consists of red shale, can be excluded as the source (*see* Figure 13.2). The Huronian Cobalt Group locally contains red sandstone and mudstone in the Firstbrook Member of the Gowganda Formation, and the Lorrain, Gordon Lake and Bar River formations (Chandler 1980; Rainbird 1985; Bennett, Dressler and Robertson 1991; Hastie and Vice 2019; Walker 2023; Shawwa et al. 2024). The Cobalt Group in the Cobalt–Lake Temiskaming area in up-ice direction would be a candidate for the provenance (*see* Figure 13.2A). However, the local to rare red beds in the Cobalt Group and their low carbonate content, which is in sharp contrast with the carbonate-rich red varves, suggest otherwise. The Ordovician Dawson Point Formation

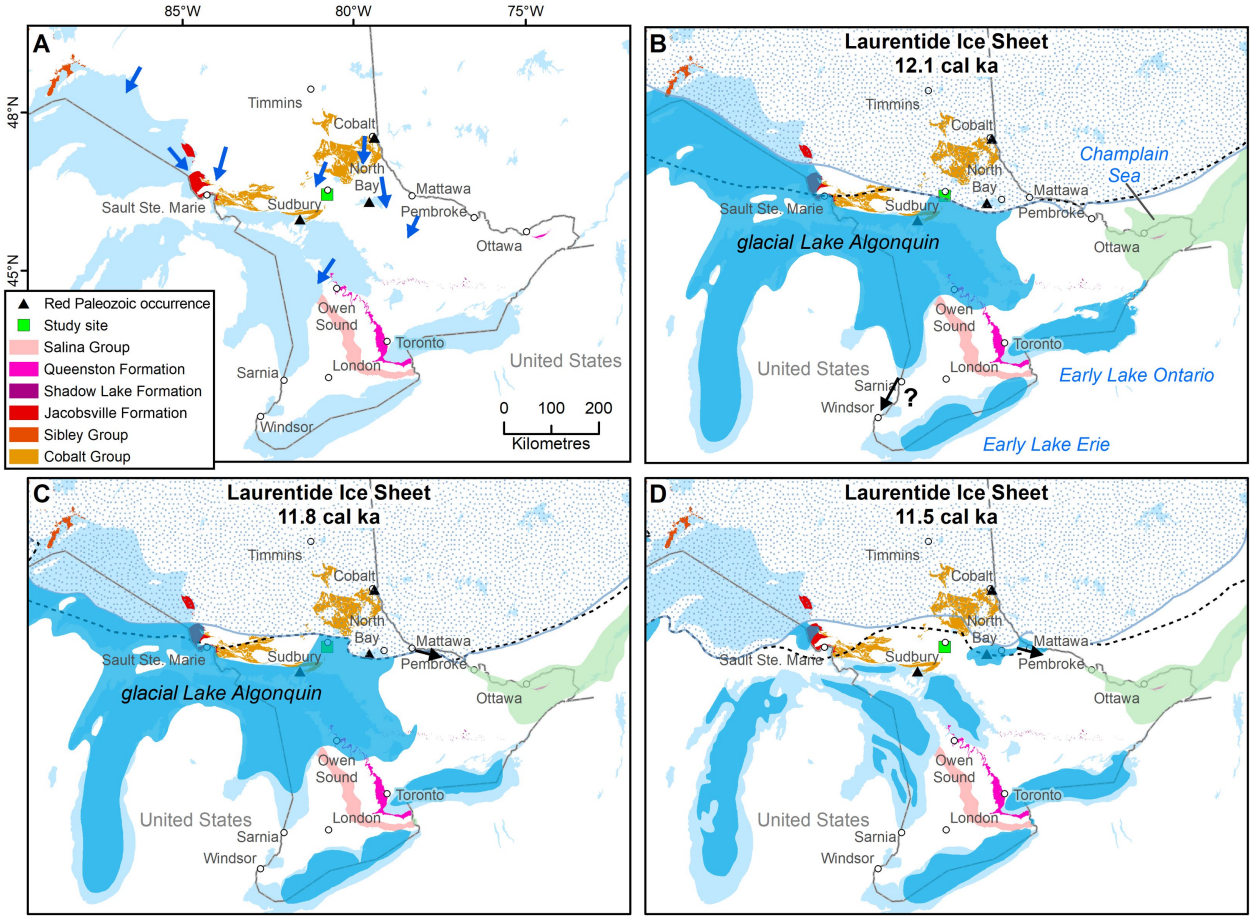


Figure 13.2. Areas of red bedrock, ice margins and development of glacial Lake Algonquin during the deglaciation. Maps were generated from various sources as shown in the caption of each map panel. **A)** Red beds of bedrock (Chandler 1980; Rainbird 1985; Russell 1987; Bennett, Dressler and Robertson 1991; Johnson et al. 1992; Armstrong and Dodge 2007; Ontario Geological Survey 2011; Brunton et al. 2023; Shawwa et al. 2024). Note that except for the Proterozoic Jacobsville Formation and Sibley Group and Paleozoic Queenston Formation that consist mainly of red sediments, the rest of the bedrock units only contain red beds locally. Blue arrows indicate regional ice-flow directions (*see* main text for discussion). Small black triangles denote the subsurface Ordovician Dawson Point Formation that contains red shale in the north, the unclassified Paleozoic red sandstone on the Iron Island on Lake Nipissing in the south, and a small outcrop of probably Ordovician Shadow Lake Formation containing red sandstone and mudstone north of Manitoulin Island (Russell 1984; Lumbers 1971; Brunton et al. 2023). **B)** to **D)** Laurentide Ice Sheet and glacial Lake Algonquin at 12.1 to 11.5 cal ka BP (Dyke 2004). Dashed black line is the updated ice margin by Dalton et al. (2020). Black arrows indicate the outlets through which glacial Lake Algonquin drained. **B**) At about 12.1 cal ka BP, glacial Lake Algonquin was at its maximum, probably draining southward to early Lake Erie; the study site was covered by the ice. **C**) Around 11.8 cal ka BP, the ice retreated to the north of the city of Sudbury forming the Cartier I moraine (at Capreol, not labelled), and glacial Lake Algonquin, which inundated the present-day Sudbury area, drained into the Ottawa Valley and Champlain Sea through several outlets across the area of the present-day Algonquin Provincial Park. **D**) At about 11.5 cal ka BP, further recession of the ice opened the Nipissing–Mattawa outlet, causing the final drainage and demise of glacial Lake Algonquin.

below Lake Temiskaming contains calcareous red shale (Russell 1984), which could have provided suitable material for the red varves. But this formation is only intercepted in subsurface at 115 m depth and has no outcrops reported (Russell 1984). Therefore, it is unlikely that this formation is the source. The till in the Cobalt–Lake Temiskaming area is typically grey to brown; red till is present but is rare, thus does not appear to constitute a significant source for red material (Gao 2007).

Glacial Lake Algonquin probably drained southward into early Lake Erie before the opening of the eastern outlets (*see* Figure 13.2B). With the opening of the eastern outlets (*see* Figures 13.2C and 13.2D), the lake drained rapidly into the Ottawa Valley (e.g., Lewis et al. 2008; Karrow 2004). The reroute of the lake drainage would have drawn lake currents to the study site from the eastern part of the Lake Superior basin where red bedrock, such as the red sandstone of Jacobsville Formation, and red till are extensive in the Sault Ste. Marie area and vicinity (Kalliokoski 1982; Russell 1987; Karrow 1982; Cowan and Broster 1988). The recent reconstruction of the ice margin configuration (Dalton et al. 2020) shows that the ice covered the red Jacobsville Formation sandstone around Sault Ste. Marie and, hence, was able to erode the bedrock for particulate red material during the eastward draining of glacial Lake Algonquin (*see* Figures 13.2C and 13.2D). The lake currents would have entrained the fine-grained, red material derived from the red bedrock and till in this area and transported it eastward. The material the currents entrained initially might have been of low carbonate content, but the currents could have become enriched with dissolved carbonate on route to the study site, for example, when passing over the extensive Paleozoic carbonate bedrock in the Manitoulin Islands area and vicinity. The fine-grained, red material accumulated in the lake in winter at the study site and the carbonate precipitated preferentially in summer because of relatively warm lake water and reduced solubility of carbonate (calcite) in the lake. The varves with red winter layers formed for about 15 years, suggesting a pulse of intensified lake currents that occurred sometime during the rapid eastward draining of glacial Lake Algonquin. Red silt and clay in glacial Lake Algonquin with or without varves are common in the Sault Ste. Marie area and they are also reported at several sites eastward along Highway 17 to Whitefish west of the city of Sudbury (Antevs 1925; Guillet 1977; Karrow 1982). The many occurrences of red glaciolacustrine deposits are consistent, in general, with a sediment provenance in the eastern part of the Lake Superior basin.

The development of the red varves appears to coincide with the early stage of the Marquette ice re-advance, which began shortly after 12.1 cal ka BP and culminated at 11.5 cal ka BP (*see* Figures 13.2B to 13.2D; Dyke 2004; Lowell et al. 1999). The re-advancing ice would have intensely eroded the Jacobsville Formation sandstone, producing abundant fine particles of red material. This material could then have been transported eastward by lake currents, increasing the chance of red sediment deposition in downstream areas. Varves with red winter layers are also reported in the North Bay–Mattawa area, east of Lake Nipissing (Antevs 1925; Harrison 1972; Marich 2023), in the Ottawa Valley and in the Champlain Sea deposits in the Ottawa area (Antevs 1925; Guillet 1977). The potential source for the red varves in the North Bay–Mattawa area could be the Paleozoic red beds in the Lake Nipissing area (*see* Figure 13.2). The eastward route of lake currents might also have brought some red material from the eastern Lake Superior basin to this area, but this requires confirmation. The occurrence of red shale of the Queenston Formation east of Ottawa may explain the red material in the Champlain Sea sediments in this area. However, it is difficult to decipher the provenance of the red material in the glaciolacustrine and glaciomarine sediments in the Ottawa Valley west of Ottawa. That said, there is a possibility that the red material was derived from the same sources of the red varves in the North Bay–Mattawa area and transported there by strong floods during the eastward draining of glacial Lake Algonquin.

In summary, the varved clay deposit with a thickness of 2.5 m likely developed in glacial Lake Algonquin between 12.1 and 11.5 cal ka BP when the lake drained eastward into the Ottawa Valley and Champlain Sea in eastern Ontario. The deposit has 172 varves in the lower 1.5 m of the section and contains 15 consecutive varves with red winter layers and carbonate-rich material. The red pigment and carbonate material were likely brought to the study site by pulsed strong lake currents from the extensive

red bedrock and till in the eastern part of the Lake Superior basin during the rapid draining of glacial Lake Algonquin to the east. Detailed study of this deposit can shed new light onto the deglaciation history for this region, but also provide important geochemical baseline information for future environment monitoring and assessment for the city of Sudbury and adjacent areas.

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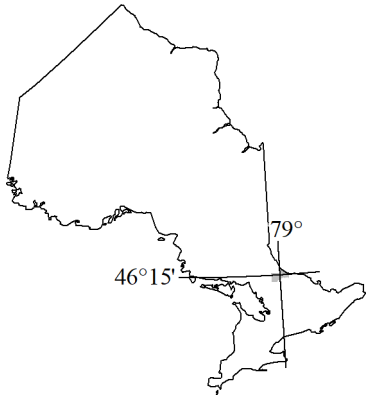
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14. Project NE-25-002. Quaternary Geological Mapping of the Lake Nipissing Basin: New Insights into the Glacial History of Northeastern Ontario



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INTRODUCTION

This report outlines the results of field work conducted during the summer of 2025 in support of a multi-year project aimed at updating the Quaternary geology of the Lake Nipissing basin and surrounding area. This study will fill a large gap in the 1:50 000 scale surficial mapping for northeastern Ontario (Marich 2022, 2023). Surficial geology maps are used for multiple purposes including land-use planning, agricultural suitability studies, aggregate resource mapping, geotechnical studies and mineral exploration activities. Existing maps for the study area were published by Boissonneau (1967) and Harrison (1972), but more detailed geological information regarding surficial landforms and sediments is now required for the aforementioned applications.

The focus of the 2025 field season was collecting data within the areas represented by National Topographic System (NTS) Powassan map (31 L/3), and parts of the Mattawa (31 L/7) and Kiosk (31 L/2) map, as well as the Highway 17 corridor between North Bay and Mattawa (Figure 14.1).

A high-resolution digital elevation model (10 cm horizontal and vertical resolution) derived from lidar (light detection and ranging) (Ministry of Natural Resources and Forestry 2022) data for the entire study area has enabled the identification of landforms in much greater detail than previously possible. Additionally, the lidar data aided in the delineation of various sediment types throughout the study area. Both are important components to making accurate surficial geology maps.

LOCATION AND PHYSIOGRAPHY

The area of focus for the 2025 field season covers approximately 2500 km^2 (*see* Figure 14.1). A major topographic control in the study area is the Ottawa–Bonnechere Graben, a 300 km long east-trending crustal structure extending from west of the study area eastward towards the City of Ottawa (Figure 14.2). The graben was formed initially in the Neoproterozoic–early Paleozoic (~590–541 million years ago) and is still active today (Rimando 1994). The Lake Nipissing Basin sits in the bottom of the broad, flat-lying graben. To the east of the lake and south of the graben is a series of deep faults that now are occupied by Trout Lake, Lake Talon and the Mattawa River. Bedrock uplands north and south of the Ottawa–Bonnechere Graben had a large influence on the glacial ice flow in the region, acting as obstacles to flow resulting in overdeepening of areas within the Ottawa–Bonnechere Graben as ice was funnelled into the area.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.14-1 to 14-8.

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The topography of the landscape is dominated by bedrock-controlled structures. Sediment thickness varies throughout the study area, but is generally less than 5 m thick and is commonly interrupted by bedrock hills or knobs.

METHODS

During the 2025 field season, observations of sediments and landforms were made using man-made and natural exposures including road ditch and river cuts along with sections in aggregate pits. The area was accessed using local township roads, provincial highways (17, 11, 533 and 630), recreational trails and active or abandoned forestry roads. Hand-dug pits, as well as auger and probe holes, were dug throughout the study area. A total of 789 sites were visited. In addition to these, samples of various media were collected, including 27 till, 1 glaciolacustrine and 2 saprolite samples. These materials will be analyzed by various laboratory methods to characterize the sediment types based on grain size, geochemistry and heavy mineral content to aid in the determination of sediment provenance. A total of 141 ice-flow measurements were also recorded, predominantly striae on bedrock.

BEDROCK GEOLOGY

The bedrock within the study area is dominated by Mesoproterozoic rocks (1.0–1.6 Ga) and are part of the Grenville Province, which was a Himalaya-scale orogen, during the formation of the supercontinent Rodinia (Easton 1992). Therefore, the rocks within the study area have been largely affected by granulite-facies regional metamorphism and ductile deformation.

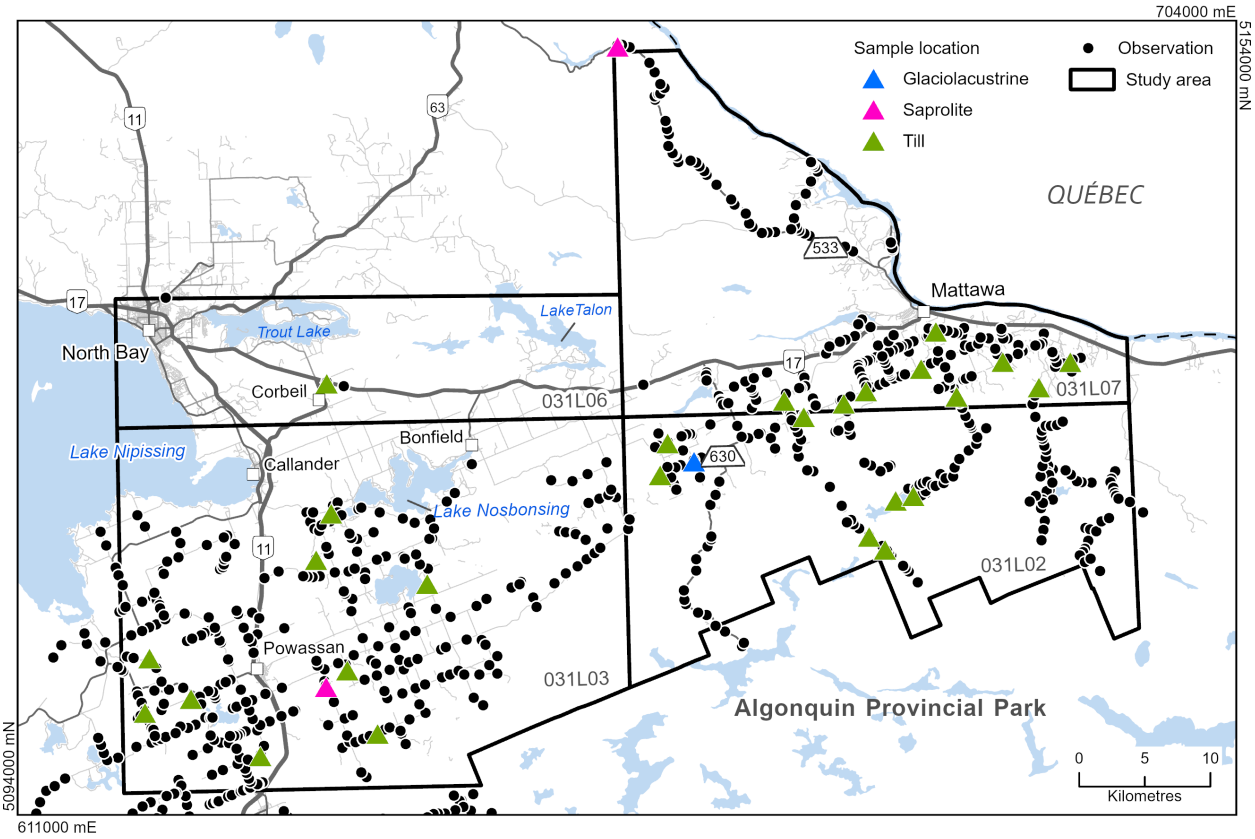


Figure 14.1. Map showing the locations of field observations, till, glaciolacustrine and saprolite samples sites in the study area. Observation sites are located along transportation routes, forestry resource roads and recreational trails. Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum (NAD83) in Zone 17.

The oldest rocks are represented by mafic and migmatitic rocks. The mafic rocks include amphibolite, gabbro, diorite and derived gneisses, whereas the migmatitic rocks are composed of migmatites and gneisses of undetermined protolith (commonly named as layered biotite gneisses and migmatites) that include quartzofeldspathic gneisses, orthogneisses and locally paragneisses (Ontario Geological Survey 2011). The age of the protolith of these rocks vary greatly from Neoarchean (2680 Ma) to Mesoproterozoic (1.8–1.4 Ga). North of Highway 17 within the eastern half of the area represented by the Mattawa NTS map are metasedimentary gneisses. These rocks include quartzofeldspathic gneisses, pelitic to semi-pelitic gneisses, calc-silicate gneisses, minor quartzite, as well as minor marble or marble breccia (Ontario Geological Survey 2011).

These rocks are intruded by felsic intrusive rocks comprising varied rock types, such as tonalite, granodiorite, monzonite, granite, syenite and their deformed equivalent (Figure 14.3) (Ontario Geological Survey 2011). They range in age from 1.4 to 1.2 Ga. In a small area, north of Highway 533 and centrally within the northern half of the area represented by the Kiosk NTS map, are anorthosite and alkalic igneous rocks that include anorthosite, anorthositic gabbro, gabbros and related gneisses, nepheline syenite and alkalic syenite.

The youngest rocks within the study area are those of the Callander Bay Alkalic Complex. These rocks are part of the Southern Province and Superior Province and are early Paleozoic to Neoproterozoic (443.7–600 Ma) in age. This alkalic intrusive suite includes carbonatite, nepheline syenite, alkalic syenite, ijolite and fenite, as well as associated mafic and ultramafic intrusions. These alkalic complexes intruded the Ottawa–Bonnechere Graben floor at Callander Bay around 565 million years ago during a distension phase of a Neoproterozoic intracratonic rift (Lowe et al. 2018).

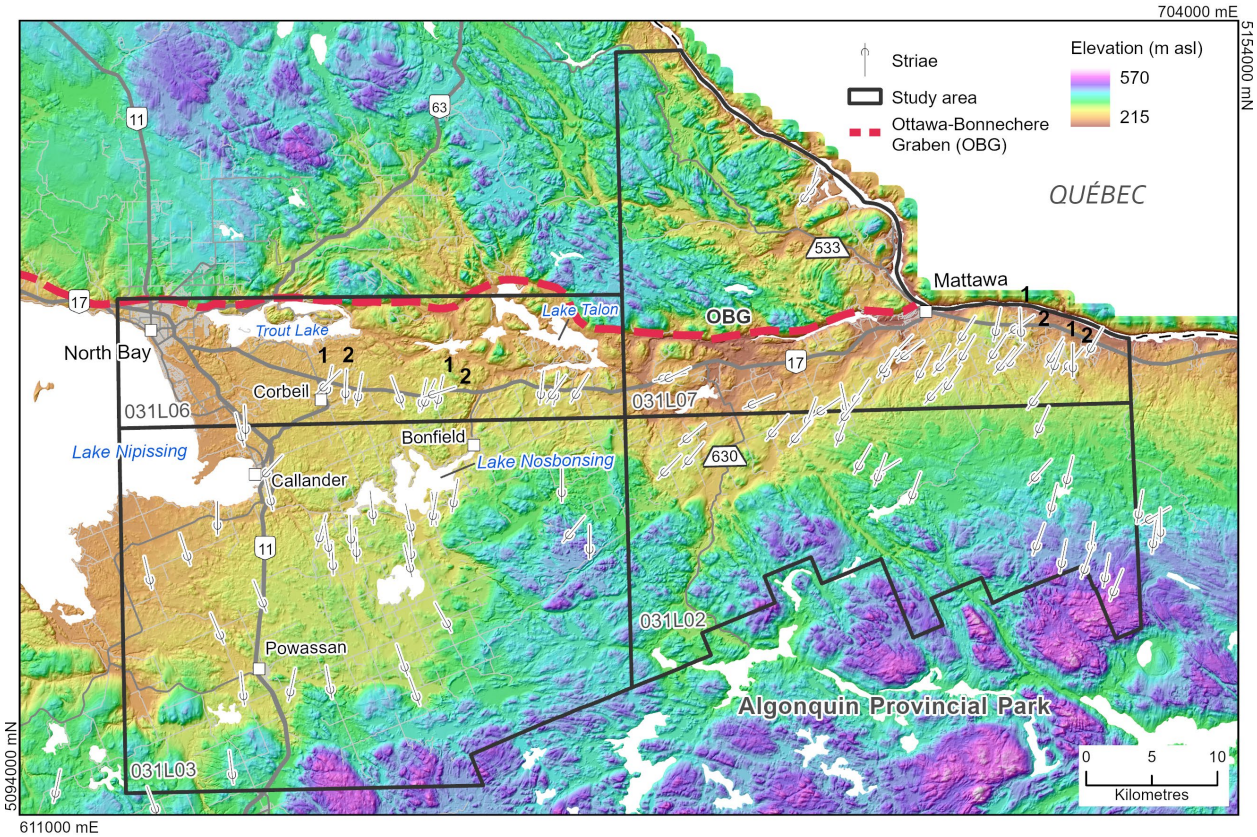


Figure 14.2. Digital terrain model (hill-shade image) of the study area (data *from* Natural Resources and Forestry 2022). For the purpose of clarity, only 103 of the 141 ice-flow indicators measured in 2025 are shown.

Also of interest in the study area is a series of highly physically and chemically weathered granitic gneiss outcrops. This saprolite has been observed in the areas represented by the North Bay, Mattawa, Kiosk and Powassan NTS maps (*see* Figure 14.3; Photo 14.1A). The outcrops are commonly found in localized lowlands or in the lee of larger bedrock hills. The thickness of weathering can vary from approximately 1 m to more than 5 m. The degree of weathering is visible at the outcrop scale, with parts of the outcrops being intact with gneissic banding still clearly visible, whereas others are weathered to unconsolidated coarse sand-sized particles. It is possible the saprolite was more extensive throughout the study area, but was subsequently removed by past glacial events. Work is ongoing to assess the timeframe required to produce weathering to coarse sand-sized particles, to determine whether the parent materials of the saprolitic outcrops are of the same age and if there was a regional erosional event resulting in the thick successions of saprolite across northeastern Ontario.

QUATERNARY GEOLOGY

Northeastern Ontario was completely covered by the Laurentide Ice Sheet during the last glacial maximum about 20 000 years ago. The modern landscape is the result of events during the later stages of glaciation and deglaciation. Deglaciation was characterized by the northward retreat of glacial ice and subsequent development of large proglacial lakes that included glacial Lake Algonquin and the Nipissing phase of the upper Great Lakes (e.g., Karrow 2004). Deglaciation occurred between ~13 500 and 11 000 calibrated radiocarbon years before present (Dalton et al. 2020).

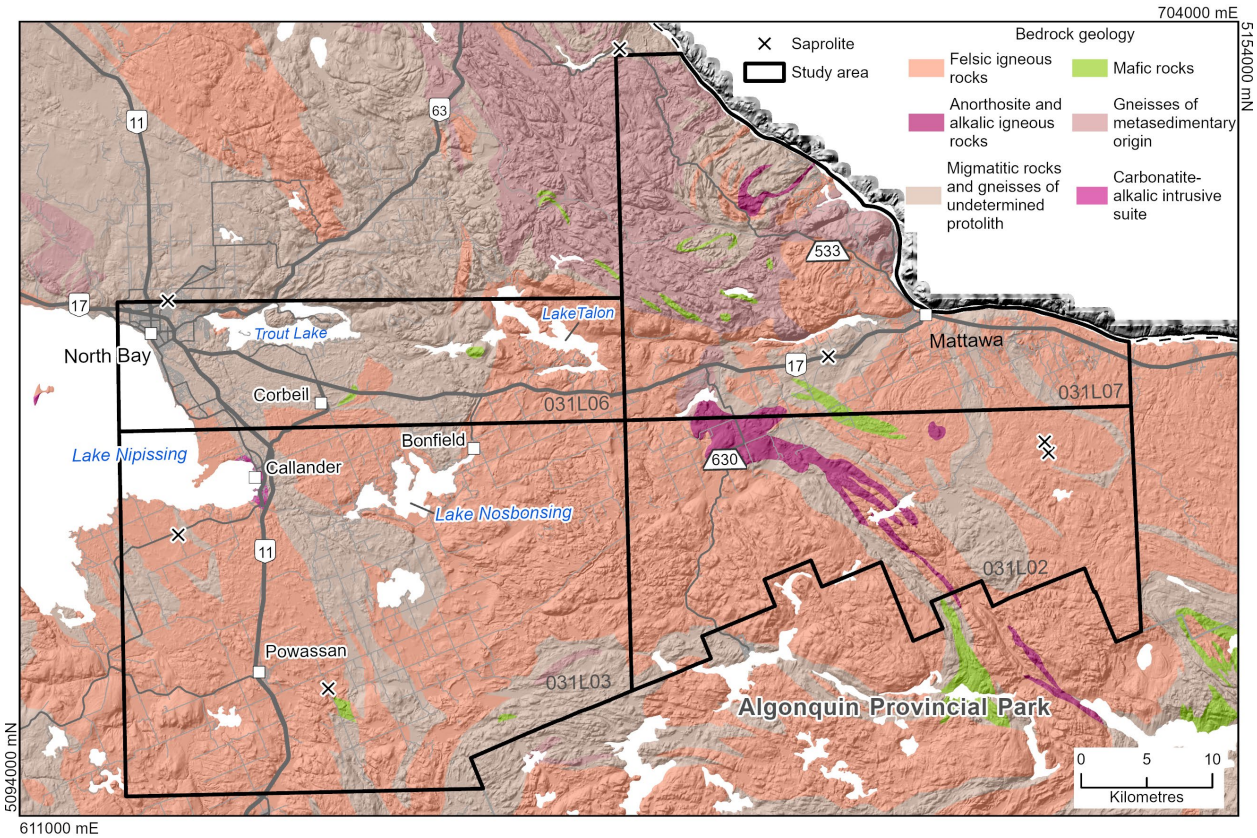


Figure 14.3. Simplified bedrock geology (*modified from* Ontario Geological Survey 2011) of the study area, including locations (indicated by ×) where saprolite was observed during the summer of 2025. All UTM co-ordinates provided using NAD83 in Zone 17.

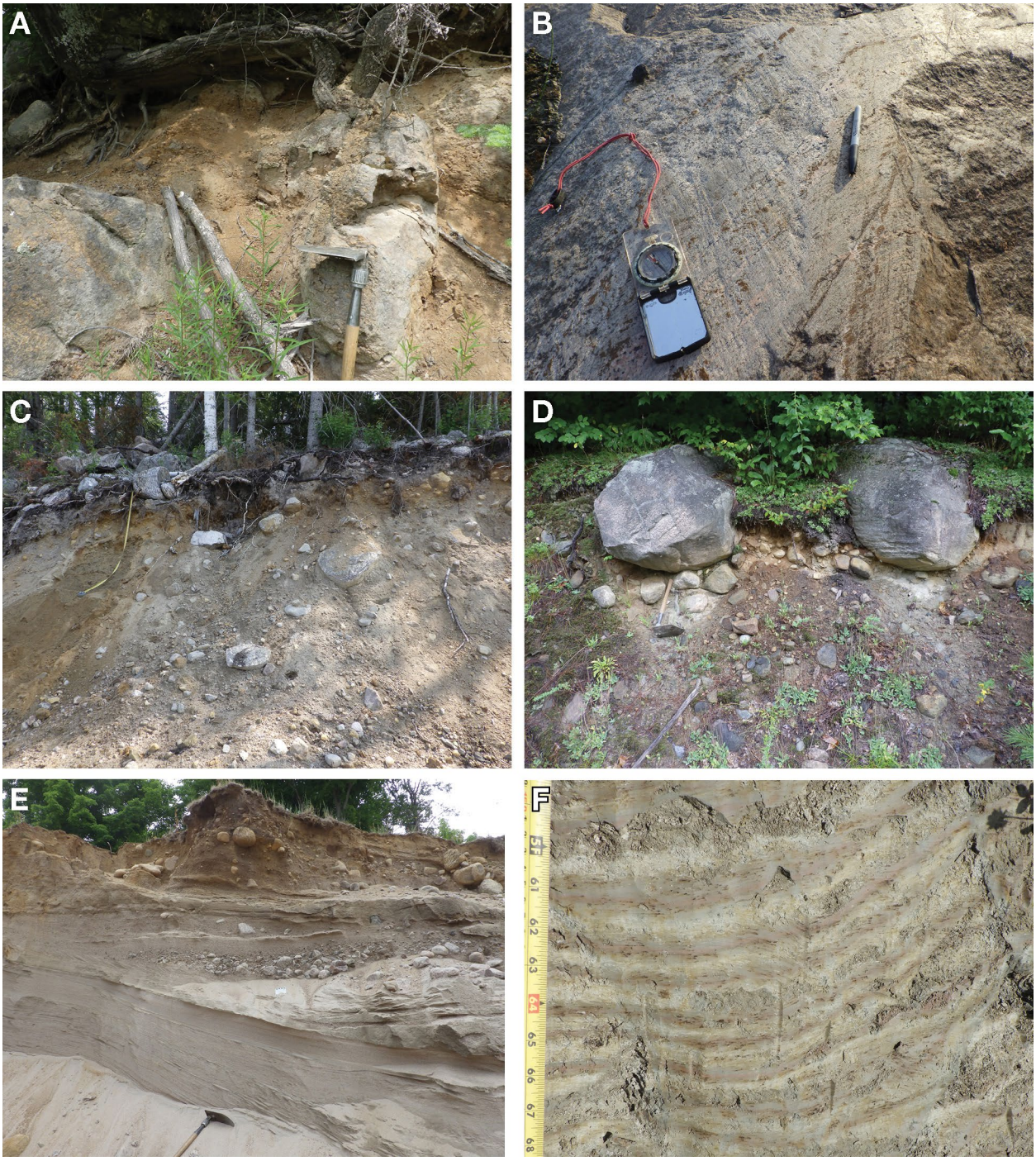


Photo 14.1. Photographs of different surficial units observed within the study area. **A)** Outcrop showing saprolite. Portions of the outcrop are intact, whereas others are highly weathered to sand-sized particles. Shovel blade is approximately 30 cm long. **B)** Outcrop with crosscutting striae, 2 ice-flow measurements identified here. The compass marks the flow at 192° and the black pen cap denotes the ice flow at 252°. The marker is 14 cm long. **C)** Roadcut showing silty sandy till with boulder lag at surface. Note tape measure in top left corner. **D)** Detailed view of boulder lag at surface of till section at a separate location to Photo 14.1C. Shovel handle is 50 cm long. **E)** Crosscutting glaciofluvial sands and gravels within a delta observed in a sand and gravel pit. Shovel blade is approximately 30 cm long. **F)** Varved fine-textured glaciolacustrine sediment. The dark grey and red clay laminae denote winter deposition within an ice-covered proglacial lake. The pale grey silt laminae are summer deposits when the surface of the proglacial lake is open and affected by wind action. The couplets (1 winter and 1 summer laminae) denote 1 year total deposition.

The study area is dominated by thin drift and exposed bedrock. The thickest sequences of sediments occur within moraines (till) eskers or ice-contact delta systems (sand and gravel).

A total of 141 ice-flow indicators (e.g., striae, grooves, chattermarks, nail head striae) were measured during the summer of 2025 (see Figure 14.2; Photo 14.1B). These measurements show a general trend of ice flow to the south-southeast near Lake Nipissing and a near westerly to southwest flow in the eastern part of the study area. Notable examples of crosscutting striae occur between Corbeil and Mattawa along Highway 17 (see Figure 14.2). Of these, the earliest ice flow appears to have been almost due south with a later event showing ice flow to the south and southwest. Many of the measured indicators show a localized deflection of ice flow around bedrock obstacles indicating a strong influence of underlying topography on regional ice-flow patterns.

The oldest sediment observed within the study area is a silty sandy till (Photo 14.1C). Clast content varies from approximately 5 to 10% consisting predominantly of local granitic clasts of the Grenville Province with minor sedimentary and volcanic rocks of Huronian Supergroup or Archean greenstone belt origin. Disintegrating granite or granitic gneiss clasts were observed in many exposures and are the result of physical and chemical weathering resulting from glacial and meltwater action. This till is found throughout the region in patches between bedrock knobs, as well as in moraines, drumlins and crag-and-tails. A silt-poor facies of this till has been found commonly in De Geer moraines, an ice-marginal landform that forms at the contact between a glacier and a proglacial lake. These moraines range in height from less than 1 m up to about 2 m, vary in length and are spaced approximately 100 m apart (Figure 14.4A). Here, sediments in

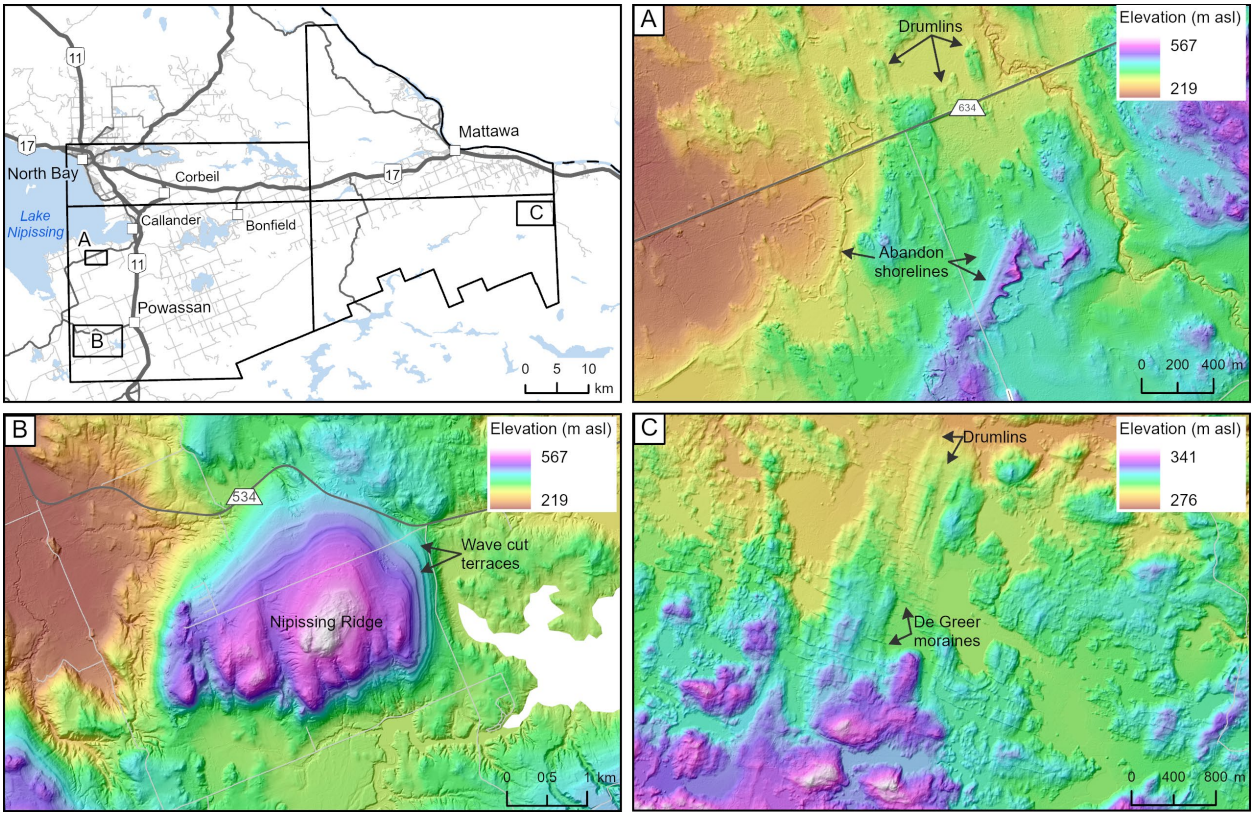


Figure 14.4. Figure in upper left shows the location of the inset figures A, B and C with respect to the boundaries of the study area. In A, B and C, the digital terrain model (hillshade image) is based on data *from* the Ontario Ministry of Natural Resources and Forestry (2022). **A)** Abandoned shorelines and drumlins close to Callander Bay. **B)** Well-developed wave-cut terraces on the slopes of the Nipissing Ridge, southwest of Powassan. **C)** Well-developed De Geer moraines and drumlins located southeast of Mattawa. De Geer moraines are oriented approximately east to west and are parallel to one another. Drumlins are oriented northeast to southwest.

the moraines are washed by wave action in the lake resulting in the removal of silt and clays. Boulder lags (accumulations of cobbles to large boulders ≥3–5 m in diameter at surface) were observed in most areas where till was exposed at surface (Photo 14.1D). Boulder lags are also an indicator of melting glacial ice, whereby boulders are deposited *in situ* as the ice melts away. These lags may also form along shorelines where finer materials are removed by wave action.

Glaciofluvial ice-contact stratified drift is found in the study area most commonly within eskers and ice-contact deltas (Photo 14.1E). Variable sorting of sand and gravels is common throughout these features, representing variations in flow regime of meltwater systems. The sands are commonly clean (lacking silt and clay).

Because most of the study area was occupied by a large proglacial lake during deglaciation, glaciolacustrine sediments are common. Fine-textured glaciolacustrine sediments, associated with deep-water settling, are observed as laminated silts and clays, as well as varves, which mark seasonal deposition of silt (summer) and clay (winter) (Photo 14.1F). Most laminae are brown or tan but, in the eastern part of the Lake Nipissing Basin, red clay laminae were observed. These occur as individual laminae, a few millimetres to up to a centimetre thick. At various locations, throughout the study area, more than 30 couplets were counted in ditch cuts or within probe samples. Work is ongoing to characterize the grain size profile and geochemical signature of the red clay laminae to interpret a provenance for the sediment.

Coarse-textured glaciolacustrine sediments, consisting mostly of sands, were observed within abandoned shoreline features, including beaches and wave-cut terraces. Multiple beaches were observed near Callander Bay marking higher water levels than modern Lake Nipissing (Figure 14.4B). A striking example of wave-cut terraces is located at Nipissing Ridge, southwest of Powassan, where multiple terraces are easily identified on the lidar DEM (Figure 14.4C). Some of these terraces are also capped with a boulder lag.

The youngest surficial deposits are observed within wetlands and modern river systems. Organic deposits in wetlands consist primarily of peat and are commonly more than 1.5 m thick. Modern alluvium deposits are a mixture of sands and organic materials collecting along modern riverbanks. Both deposit types occur throughout the study area in low-lying topography and along river channels.

FUTURE WORK

Laboratory analyses of the till, clay and saprolite samples is ongoing. Additional work will be focussed on the characterization of surficial sediments and further refinement of the regional glacial history, as well as the production of maps, report and data releases.

ACKNOWLEDGMENTS

The author would like to thank Roman Crowder and Tyler Gotfried for their outstanding assistance in the field. The success of the field season was due in large part to their hard work. Additional thanks go to Shirley Péloquin, Sonia Préfontaine and Manuel Duguet (all geoscientists with the Ontario Geological Survey) for ongoing discussion of Precambrian geology relevant to the study area.

The author would also like to thank the Algonquins of Pikwakanagan First Nation, Dokis First Nation, Nipissing First Nation, Henvey Inlet First Nation, Wolf Lake First Nation, Eagle Village First Nation, Métis Nation of Ontario – Mattawa Métis Council and Métis Nation of Ontario – Ottawa Métis Council for allowing the Ontario Geological Survey to map their traditional land use area.

A thorough and insightful review of this manuscript was completed by Grant Hagedorn and is greatly appreciated.

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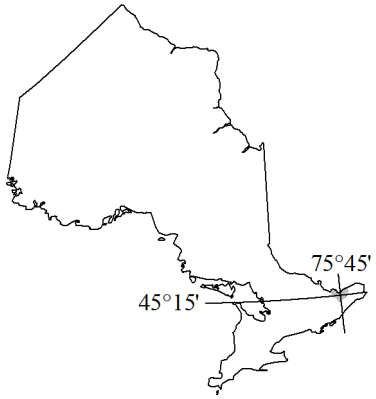
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15. Project SO-25-002. Surficial Sediment and Landform Mapping in the City of Ottawa, Eastern Ontario



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INTRODUCTION

The City of Ottawa population is growing faster than the Ontario and Canadian averages (City of Ottawa 2024). To support this increasing population, a 48% increase in total private residences is expected between 2018 and 2046, mostly in outlying communities and intensified housing density in urban areas (City of Ottawa 2019). To meet this demand, detailed surficial mapping is needed in the City of Ottawa to allow for informed decision-making in growth plans and resource management considerations.

The Ontario Geological Survey (OGS) has conducted a series of geoscience mapping projects throughout eastern Ontario and the City of Ottawa, including Precambrian (e.g., Easton and Kamo 2019) and Paleozoic (e.g., Béland-Otis 2023) bedrock mapping, as well as identification of karst features (e.g., Brunton 2019). Resource assessments have been completed for aggregate extraction potential (Lee 2013) and analysis of ambient geochemistry of regional groundwater systems is ongoing (e.g., Lemieux, Hamilton and Clark 2018; Di Iorio et al. 2017; Colgrove 2024). Surficial mapping across eastern Ontario was compiled by the Geological Survey of Canada (GSC) in 2009 (St. Onge 2009). More recently, the GSC conducted local-scale studies on landform sedimentology and stratigraphy, with a focus on eskers (e.g., Cummings et al. 2011), marine muds (e.g., Al-Mufti et al. 2024) and associated geohazards (e.g., Brooks 2019; Brooks et al. 2021). The current study adds to work performed by Mulligan (2019, 2022) to increase the coverage of ground-truthed geological data and create an updated surficial geology map for the City of Ottawa. The updated mapping will support groundwater and aggregate resource studies, groundwater–surface water interactions, and improve understanding of the geotechnical properties of sediments and geohazards within the City.

2025 FIELD SEASON

The 2025 field season focussed on collecting new geological data with the aid of the updated 0.5 m lidar digital terrain model (DTM; Ministry of Natural Resources 2025a) and high-resolution aerial orthophotos for the City of Ottawa and eastern Ontario (Ministry of Natural Resources 2024, 2025b). Field work was conducted from June to August 2025, with a total 1184 observations recorded of surficial sediments, bedrock and glacial landforms. In total, 31 samples were collected using a dutch auger, soil probe or in dug pits: 19 till samples were collected for matrix geochemistry and particle-size analysis, and 12 samples of organic matter were collected for radiocarbon age determination (Figure 15.1). Preference was given to woody organic material over shell-containing samples to avoid carbon reservoir contamination and provide more reliable age determinations for the timing of the drainage of late-stage Champlain Sea waters from the region (Cronin et al. 2008).

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.15-1 to 15-9.

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GEOLOGICAL SETTING AND GLACIAL STRATIGRAPHY

Underlying bedrock consist of carbonate and siliciclastic strata spanning the late Neoproterozoic through upper Ordovician. These sedimentary strata lie unconformably over Mesoproterozoic rocks of the Grenville Province that form the abrupt highlands to the north (Laurentian Highlands) and west (Algonquin Highlands) of the city. The city is situated within the Ottawa–Bonnechere Graben, a failed rift valley that remains seismically active today.

Bedrock is covered in glacial and postglacial sediments that vary in thickness from greater than 100 m in bedrock valleys (Medioli et al. 2012) to an absence of sediments atop upland bedrock surfaces and escarpments, resulting in subdued topography throughout the region. In locations where bare bedrock is observed, surfaces range from heavily fractured to smoothly polished and striated, providing an ice-flow indicator (Photo 15.1A).

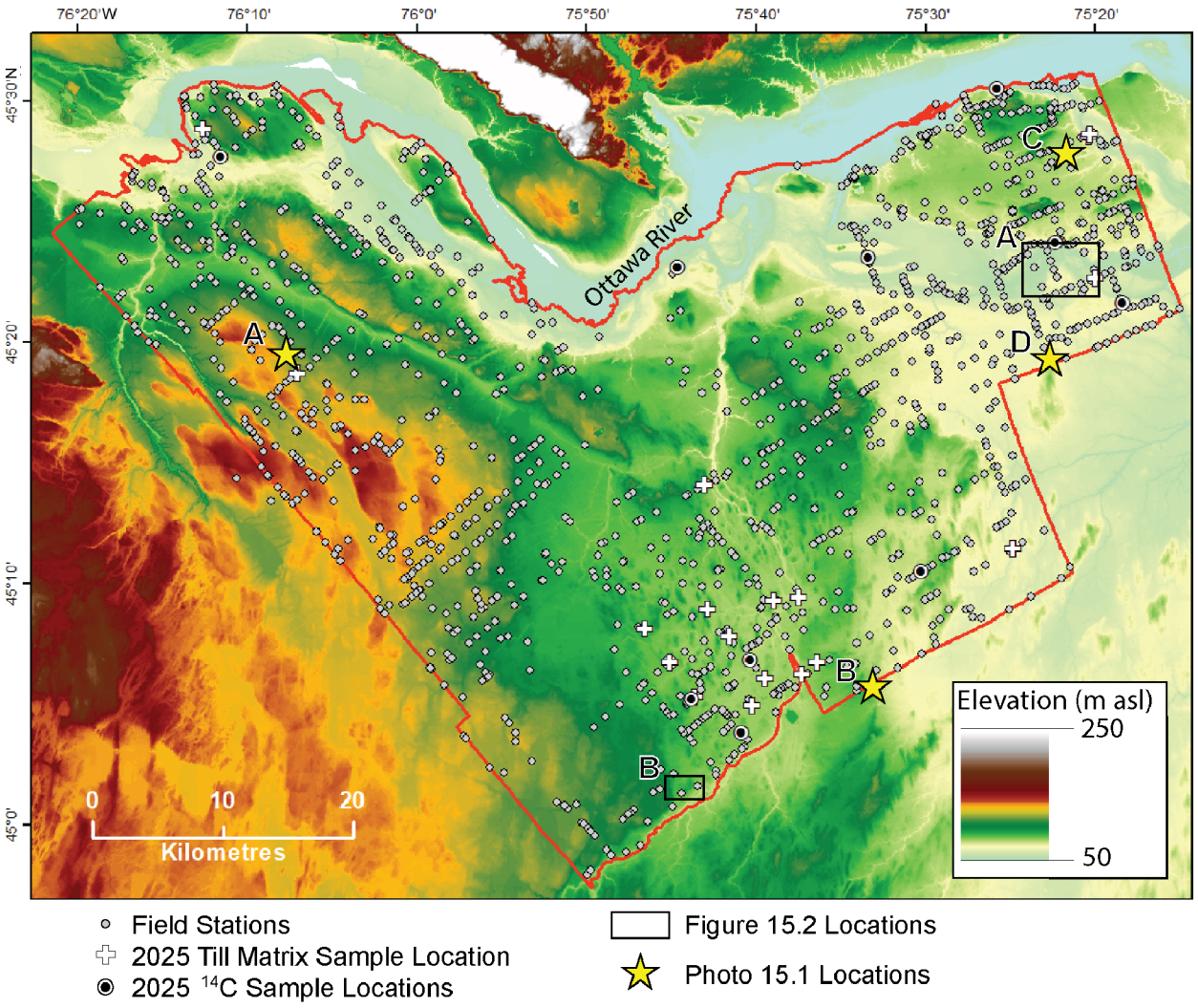


Figure 15.1. City of Ottawa boundary (red outline) with field observations and sediment samples. Locations of field photos (*see* Photo 15.1; yellow star) and Figure 15.2 (black rectangles) are shown. Data are overlain on a 1 m lidar digital elevation model (DEM) in Ontario (Ministry of Natural Resources 2025a), and a 5 m lidar DEM for Quebec (Airborne Imaging Inc. 2015) and projected in North American Datum 1983 (NAD83) Universal Transverse Mercator (UTM) in Zone 18N.



Photo 15.1. **A**) Striae on polished Paleozoic bedrock surface in northwestern Ottawa indicating ice-flow direction to the south to southeast (178–184°); scale card divisions in centimetres (blue) and inches (red). **B**) Matrix-supported and clast-supported cobble and boulder gravels overlain by stratified fine- to coarse-grained sand (units separated by lower dashed red lines) likely deposited in an esker conduit in southern Ottawa. Sands are unconformably overlain by pebble gravel deposited in a littoral environment in the upper 1 to 1.5 m of the exposure (units separated by upper red dashed line). Scale rod in the right of the photo is 2 m high. **C**) Finely laminated silt and clay beds with common sand lenses and gravelly ice-rafted debris exposed in an incising ditch. The handle of the shovel is 0.55 m long. **D**) Stratified subangular, clast-supported granule- to cobble-sized gravel located in a roadcut through a beach ridge. The Ordovician shale-dominant lithology of the gravel highlights the control that underlying bedrock has over local clast lithology. Compass along the base of the roadcut is 10.5 cm long.

Till Deposits

Glacial till is commonly observed overlying bedrock surfaces in the south and east of the city. This till is sandy to silty and clast lithologies are largely controlled by bedrock topography and underlying bedrock. In the northwest, clasts in till are predominantly shield derived, whereas clasts in the east are more often of locally derived limestone and shale. This till unit is thought to represent the entire phase of Wisconsinan ice cover, equivalent to the Border, Fort Covington, Gentilly, Argentuil and Oka tills (Ross et al. 2006).

Till composes streamlined bedforms oriented north-northwest within south and west central Ottawa. These bedforms overprint larger ridges oriented to the southwest beyond the city's southern boundary. In combination with crosscutting striae sets and till fabric analyses from multiple sites in the region (Mulligan and Paulen 2025), the orientation of the north-northwest bedforms are interpreted to represent later stages ice flow across the study area, following a significant regional phase of ice flow toward the southwest (Ross et al. 2006; Mulligan and Paulen 2025). A smaller cluster of low-relief drumlins oriented northwest-to-southeast occurs to the west of the Rideau River and overprints the north-northwest–trending bedforms, indicative of a younger change to ice-flow dynamics (Mulligan 2022). Till is also observed in drumlins sporadically exposed along the beds of paleochannels in the northeast (Figure 15.2A; *see* "Paleochannels"). In the northwest of Ottawa, observations of till are limited to a series of low-relief, parallel-running ridges. These features, composed of very poorly sorted, clast-rich sandy till are interpreted as De Geer moraines, recording the position and orientation of the ice margin within a proglacial water body as ice retreated northwest within the Ottawa–Bonnechere Graben.

Glaciofluvial and Ice-Contact Deposits

Multiple esker–subaqueous fan deposits are observed at surface and at depth (Cummings et al. 2011). The most prominent esker-fan complex extends southeast from the Ottawa International Airport then southward, beyond the city boundary. Similar complexes occur in the northwest and northeast of the city. These features are steep irregular ridges which terminate as broad subaqueous fan deposits along regional moraine systems (Cummings et al. 2011).

Two gravel pits were visited along the most prominent esker-fan complex. Sections showed packages of moderately to well-sorted cobble- and boulder-rich gravels typically overlain by well- to very well-sorted sands. Clasts in the boulder-rich facies reached 0.75 m in diameter. Ice-contact glaciofluvial deposits observed in the pits were locally unconformably overlain by horizontally bedded shoreface sand and gravel (Photo 15.1B).

Glaciolacustrine and Offshore Marine Deposits

Flat-lying terrain across the study area was commonly composed of silt and clay at surface, particularly across the northwest to northeast extents of the city. Where exposed at surface, the clay and silt are commonly fractured and oxidized. In the limited exposures that capture the lower parts of the silt and clay, mud units exhibit thinly bedded clay–silt rhythmites, ice-rafted debris and thin sand laminae (Photo 15.1C). Above this, the silt and clay are more massive, with minimal coarser debris and rare sand laminae. In the northeast of the city, the upper unit is marked by thick red clay interbeds and increased occurrences of sand lenses that thicken upward. Muddy sediments were less common on bedrock highlands, streamlined till, and above ice-contact deposits exposed at surface.

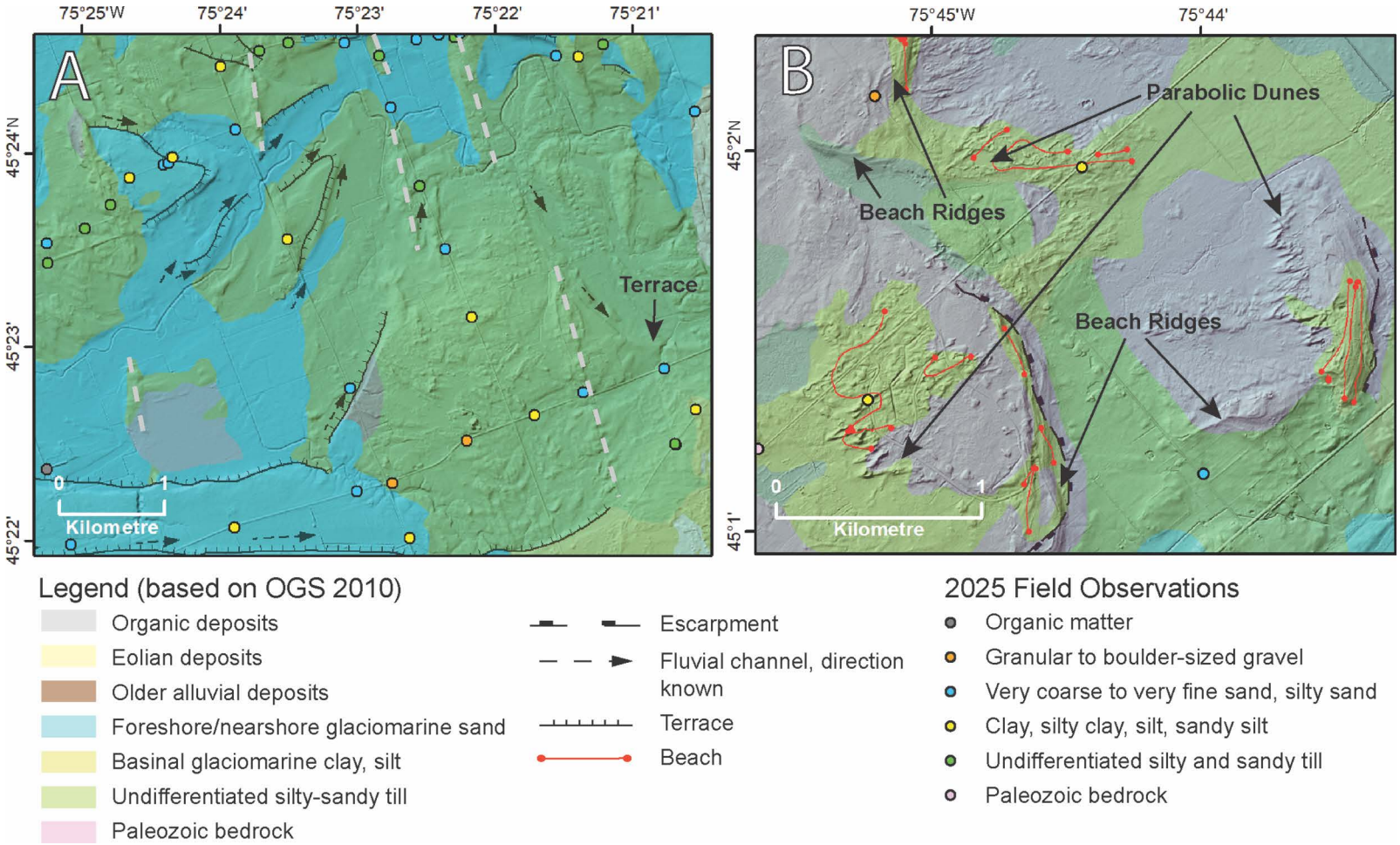


Figure 15.2. Surficial geology (*from* Ontario Geological Survey 2010) and observations at field stations recorded during the 2025 field season overlain on a 0.5 m lidar hillshade model (Ministry of Natural Resources 2025a) and projected in NAD83 UTM in Zone 18N to highlight areas where increases in model resolution and ground-truthed data support updates to surficial mapping. **A)** 2025 field observations throughout an abandoned paleochannel in northeastern Ottawa (*see* Figure 15.1) indicate where greater detail is needed in forthcoming map updates to address sediment heterogeneity within the existing mapped polygons. Additionally, 0.5 m hillshade model allows for additional fluvial terraces (highlighted by solid black arrow) and partially uncovered drumlins (white dashed line overlays) to be observed and included. **B)** Parabolic eolian dunes and additional beach features (highlighted by black arrows) not previously identified in surficial geology maps are common in the southern portion of the map area (*see* Figure 15.1). New field data will permit improved delineation of polyline features and polygon boundaries in updated mapping.

Nearshore Marine Deposits

Deposits of silty very fine to medium sand of nearshore marine origin are observed over much of central and western Ottawa. In south-central Ottawa, sand plains are observed overlying subglacial till, blanketing low relief streamlined landforms and locally developed into beach ridges (*see* "Beach Ridges"). Exposures within 1 m of the surface often reveal normal grading, with lower beds containing more granule and pebble-sized clasts, as well as mollusk and bivalve shells and shell fragments. Farther northeast, surficial sand plains overlying muds are exposed along the margins of paleochannels, indicative of water levels dropping in the area.

Beach Ridges

Beach ridges are common along the flanks of topographic highs, such as exposed bedrock, esker ridges and streamlined landforms. Beaches are composed of sand and gravel reworked from local shallow marine, ice-contact, and subglacial deposits or bedrock (Photo 15.1D). Most beach ridges are found within the west-southwestern part of study area on east-facing slopes of exposed Paleozoic bedrock.

Paleochannels

Much of the area along the flanks of the Ottawa River has been reworked by flows of a larger paleo-Ottawa River that created paleochannels (15 m deep and up to 6 km wide) incised through marine and glaciolacustrine muds. The margins of these channels are commonly marked with large landslide scars, a series of which extends over 4 km wide (Brooks 2019; Mulligan 2019). In northeastern Ottawa, paleochannel incision has exposed older sediments and landforms, including portions of the drumlinized till sheet, segments of esker ridges and clay deposits. Large bars, up to 4 km long and 800 m across, form local highs within the channels and are composed of sand and gravel. Elsewhere, bars are erosional, composed of silt and clays. In the topographic lows within the paleochannel beds, wetlands are common and modern underfit streams drain north to the Ottawa River. In the northwest, similar paleochannel features are observed confined to the topographic lows between the exposed Paleozoic bedrock highlands.

Eolian Deposits

Two distinct sets of sand dunes occur within the study area: one set in the southwestern part of the study area, and another in the northeast. The ridges in the southwest occur to the west of sand plains with abundant beach ridges and have a parabolic shape indicating an eastward wind direction (Figure 15.2B). Dunes found in the east and northeast of the study area occur along the terraces of paleochannels, are lower relief and have orientations consistent with predominantly westerly wind directions.

INTERPRETATIONS

Evidence of a north-northwesterly ice flow across the City of Ottawa include regional striae and north-northwest–oriented drumlins. Just south of the city boundary, the north-northwest–trending drumlins overprint a series of larger mega-scale glacial lineations oriented to the southwest that record an earlier phase of ice flow from the northeast (Ross et al. 2006; Mulligan 2019). Local-scale ice-flow reorientation and phases are recognized within the city by overprinted low-relief northwest-trending bedforms onto drumlins located west of the Rideau River. Multiple sets of crosscutting striae support a similar interpretation.

During the late phases of glaciation and into deglaciation, large volumes of water were drained though channelized subglacial systems recorded by esker complexes that locally terminate in subaqueous fans along prominent moraine systems south of the study area. Flanking and overlying the esker and fan deposits are thick successions of glaciomarine muds atop less common glaciolacustrine mud rhythmites. Ice-rafted debris, found in laminated sequences of glaciolacustrine clay and silt beds, indicate the ice margin was actively calving. The direction of ice retreat, as indicated by clusters of De Geer moraines, was likely controlled by local topography within the Ottawa–Bonnechere Graben.

Grounded ice in the St. Lawrence valley dammed eastward drainage of the proglacial lake toward the Atlantic, allowing elevated lake levels in Lake Candona (Parent and Occhietti 1999). Continued ice retreat around 12 800 years BP exposed the St. Lawrence valley, allowing for the inundation of marine waters of the Champlain Sea into the isostatically depressed lake basin and lowlands (Lewis, Breckenridge and Teller 2021). This marine environment is recorded in the City of Ottawa by thick, homogenous beds of muds, nearshore sand and gravel, marine mollusk and bivalve shell fragments and beach ridges.

Glacial isostatic adjustment outpaced eustatic sea level rise, leading to a progressive shallowing of water levels in the Champlain Sea. As relative sea levels fell, marine sediments became exposed earliest in the southwest and were reworked into dunes by easterly winds, before westerly winds became prevalent to form the dunes found along the terraces of the Ottawa paleochannels (Schaetzl et al. 2016; Mulligan 2019). Continued ice retreat west of the study area exposed drainage outlets along the Ottawa–Bonnechere Graben allowing drainage of glacial lakes (i.e., glacial lakes Algonquin and Barlow–Ojibway) to release large volumes of water through the study area to the Atlantic Ocean (Cummings et al. 2011; Lewis, Breckenridge and Teller 2021). These drainage events first deposited large sandy deltas, then, during peak flows, incised wide paleochannels into the muds of the Champlain Sea. The steep walls of the paleochannels are geotechnically susceptible to disturbances, such as seismic events, toe-slope erosion and variable groundwater conditions. Disturbances to the sensitive marine clays result in abundant landslides in and surrounding the City of Ottawa (Brooks et al. 2021; Mulligan, this volume).

CONCLUSIONS

The City of Ottawa sits atop glacial and postglacial sediments that influence the city's capacity for ongoing growth and development. The mapping aided by the 50 cm resolution DEM will provide a new, more detailed look at the different sediments in the region. In tandem with the ground truthing and samples collected, foundational Quaternary geoscience data were collected for the City of Ottawa.

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The authors would like to thank Abigail Dubois for her exceptional assistance in the field. Kei Yeung's (OGS) assistance with all things GIS is always appreciated. Thank you as well to the owners and operators of the sand and gravel pits visited in the area for allowing us access. Grant Hagedorn and Manuel Duguet (OGS) are thanked for providing technical reviews of this article, and Julien Bonin (OGS) for his review of the included figures.

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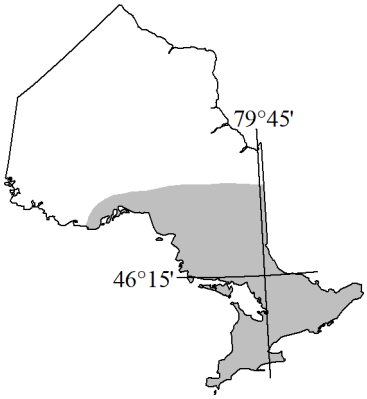
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16. Project ON-25-003. Relict Shorelines and Landslides in Ontario: An Emerging Digital Compilation



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INTRODUCTION

Ontario's glaciated landscapes provide natural beauty, host important resources like groundwater and aggregates, disperse or bury mineral deposits, and provide clues to deep geological processes beneath the earth and the climate response to ice sheet build-up and decay. Glacial sediments locally pose challenges for land-use planners and large infrastructure projects by influencing groundwater flow patterns and creating terrain unsuitable for development, and/or conditions that generate significant geohazards and potential associated risk.

In addition to the ongoing field investigations by Ontario Geological Survey (OGS) staff to develop new surficial maps (Gao and Szumylo, this volume; Hagedorn, this volume; James and Mulligan, this volume; Marich, this volume;) and study the deeper stratigraphy beneath the ground surface (e.g., Burt, this volume, Article 20), new tools allow for the development of provincial-scale compilations of features that hold relevance for a wide range of potential uses and users. High-resolution and regional-scale lidar data sets provide a basis to remotely identify geological features that would have been virtually undetectable in past field mapping efforts because of the lack of road access, dense tree cover, or subtle topographic expression hindering landform mapping.

This report outlines efforts to remotely map landslides and abandoned shorelines across Ontario (Figure 16.1) based on 0.5-m lidar data (Ministry of Natural Resources and Forestry 2022; Ministry of Natural Resources 2025). High-resolution aerial photography was used locally to assist in feature identification and delineation, especially for landslide features that postdate lidar data collection. Landforms were manually digitized into a geographic information system (GIS) environment using ESRI® ArcMap® 10.3.2 and ArcGIS® Pro.

LANDSLIDE MAPPING

Landslides are identified by a sharp headwall scarp, often with an amphitheatre or box-like plan view shape, with a debris lobe downflow and irregular terrain in between, characterized by a hummocky or horst-and-graben appearance (*see* Figure 16.1). They occur most commonly along steep slopes cut into glacial or postglacial sediments, such as those formed by abandoned shorelines (*see* "Shoreline Mapping"), fluvial terraces, and modern incised river valleys. In total, 1001 landslide areas have been mapped (*see* Figure 16.1). Many, including some of the largest individual features, were already included in compilations in eastern Ontario and southwestern Quebec by the Geological Survey of Canada (St. Onge 2009) and OGS mapping (Ontario Geological Survey 2010). In some areas, it is challenging to differentiate between a landslide and a groundwater piping scar, which shares a similar morphology.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.16-1 to 16-6.

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Because of this ambiguity, a classification system is applied to the identified features modified from Brooks (2019) based on the geomorphic criteria they meet: 1 = definite landslide; 2 = probable landslide; 3 = possible landslide; and 4 = disturbed terrain (Figure 16.2). The fourth class (*see* Figure 16.2A) is, to the author's knowledge, a new terrain type associated with landslides, but without any of the key geomorphic indicators described above or shown in Figure 16.1D. To this point, class 4 terrain has only been observed in the Ottawa–Bonnechere Graben along the Madawaska and Bonnechere rivers, near probable and definite landslides, the Paleozoic–Precambrian unconformity, and prominent fault systems associated with the Ottawa–Bonnechere Graben. As such, this terrain is presently inferred to represent some form of ground disturbance, possibly the result of earthquake shaking. This terrain is grouped with similar landscapes previously described from the lower Ottawa River near Lefaivre (Aylsworth et al. 2003). This region also has some of the highest seismic activity in the province: radiocarbon age determination of material beneath more than 50 landslides in the Ottawa Valley region suggests that many of the largest individual landslides were triggered by earthquakes (Brooks et al. 2013).

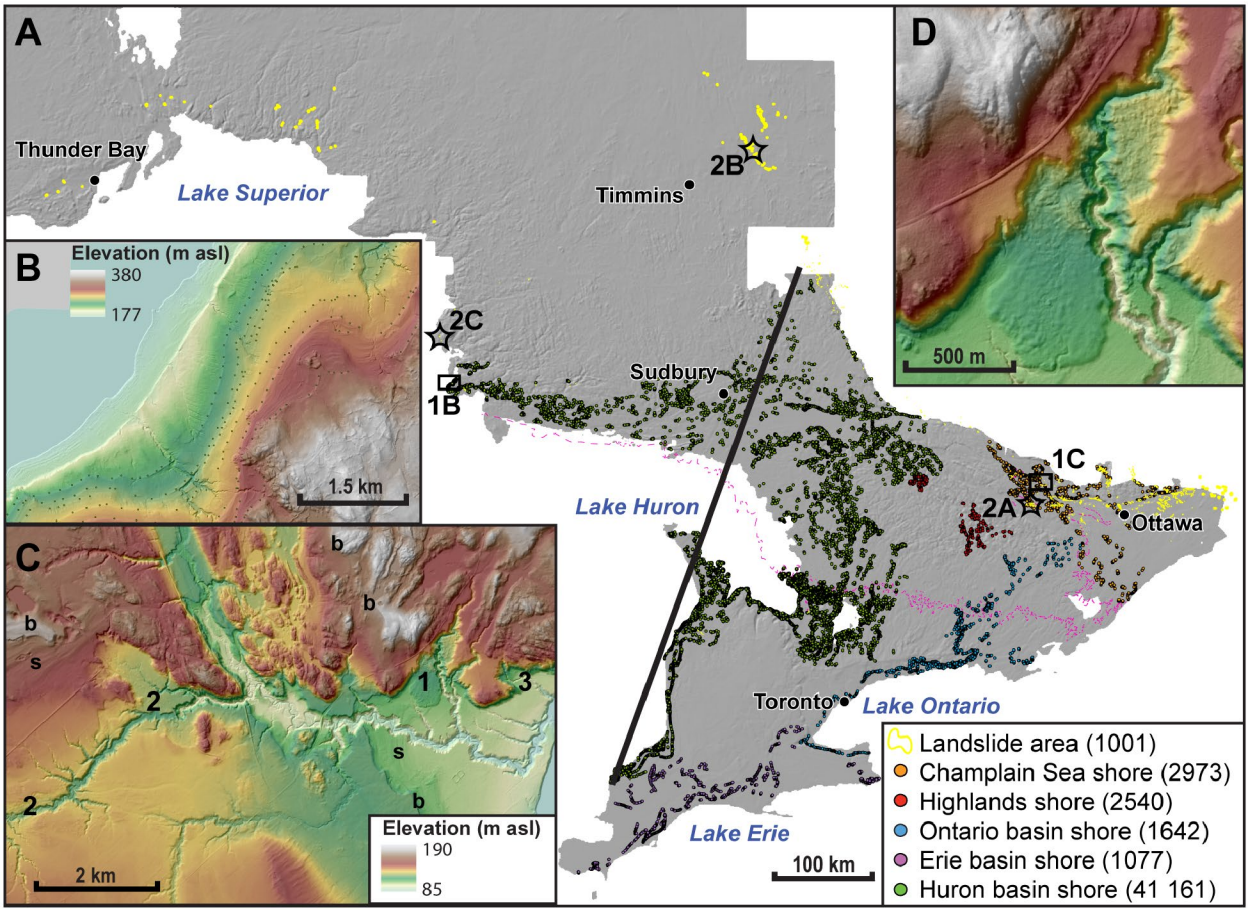


Figure 16.1. A) Map of shoreline points and landslide areas across Ontario. Numbers in the legend indicate the number of points on the map (generally shown as lines of colour-filled dots). Base map is a hillshade relief model derived from lidar data (Ministry of Natural Resources and Forestry 2022; Ministry of Natural Resources 2025). Locations of insets B and C are shown in black rectangles, and locations of panels in Figure 16.2 shown with stars. Black line shows the orientation and position of the profile of shoreline elevations shown in Figure 16.3. Pink dashed line shows the location of the Precambrian–Paleozoic unconformity. **B)** Digital elevation model and hillshade showing the southeastern shore area of Lake Superior north of Sault Ste. Marie. Green dots represent individual points along well-developed and continuous shorelines high above modern water levels. These data are included in Figure 16.3. **C)** Digital elevation model and hillshade of the area around Foresters Falls in the Ottawa–Bonnechere Graben showing multiple wave-cut bluffs (b), strandplains (s), and 1 = definite, 2 = probable and 3 = possible landslides. **D)** Close-up view of a definite landslide that consists of a sharp headwall scarp in the north, irregular, hummocky, or horst and graben-like terrain in the central area, and a well-defined debris lobe in the downflow area. This landslide likely postdates the development of the lower bluff and strandplain shown in Figure 16.3C.

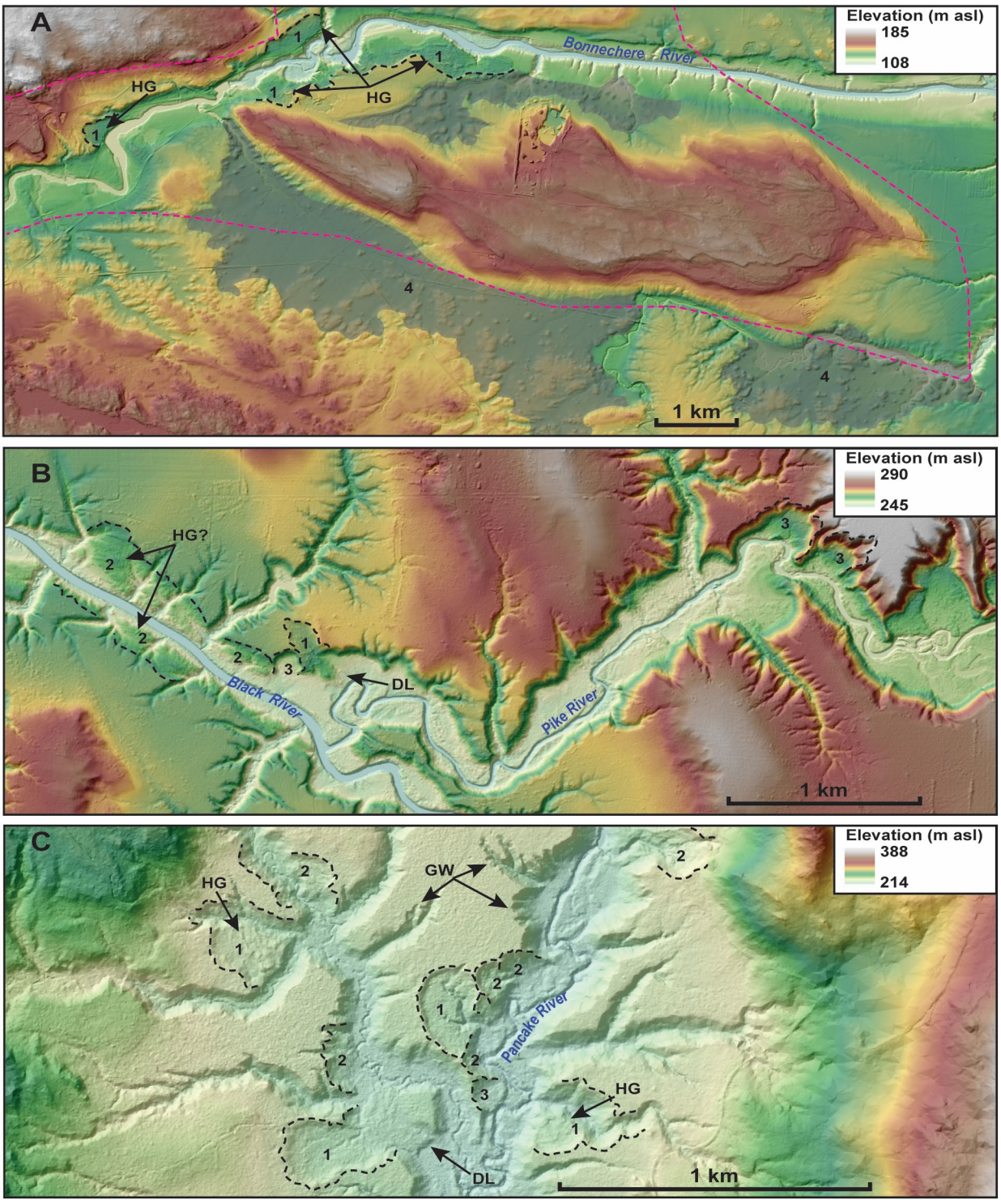


Figure 16.2. **A)** Lidar elevation and hillshade of the Bonnechere River area around Douglas. Pink dashed line shows the Paleozoic–Precambrian unconformity. Black dashed lines show the head wall areas of multiple landslides, which are characterized by horst and graben terrain (HG). Semi-transparent grey areas denote the distribution of class 4 disturbed terrain, which has a distinct character when compared to adjacent flat and dissected clay plains. **B)** Lidar elevation and hillshade of the Pike and Black rivers in northeastern Ontario where multiple terrain types exist corresponding to 3 different mapped landslide classes in close proximity. **C)** Lidar elevation and hillshade of the Pancake River valley, showing a cluster of mapped landslide features, as well as many large groundwater piping scars (GW) and groundwater-enhanced gullies. Numbers on the maps are defined as followed: 1 = definite landslide; 2 = probable landslide; 3 = possible landslide; 4 = disturbed terrain.

SHORELINE MAPPING

Abandoned shorelines are identified as prominent steps in regional topography, in places accompanied by smooth beach ridges, or other features like deltas, outlet channels or broad sand plains. The focus of the work so far has been on identifying prominent shoreline features that are more likely to record a stable water plane (*see* Figures 16.1 and 16.3). Initially, large bluffs were digitized as polylines in ArcMap®, then converted to points spaced at 500 m. During follow-up work, converted points were edited if necessary, and new data points were manually digitized and added to the compilation. Work has been completed in the Lake Huron and southeastern Lake Superior basins (n = 41 161), and preliminary work is underway for the Algonquin Highlands in central Ontario (n = 2540), the Ottawa–Bonnechere Graben (n = 2973), the Lake Ontario basin (n = 1642) and the Lake Erie basin (n = 1077). This work will assist in establishing correlations between shoreline levels in different regions during deglaciation (*see* Figure 16.3). Data are attributed with x, y and z information, but have not yet been assigned glacial lake stage information. Preliminary interpretations of the shape of glacial lake water planes in the Lake Huron basin are provided in Figure 16.3 as an example.

USES AND USERS

These newly compiled landform data, once reviewed, will be stored and made available through GeologyOntario, along with other Quaternary information available, including OGS seamless surficial maps (Ontario Geological Survey 2010), proposed new information collections (for example, till samples

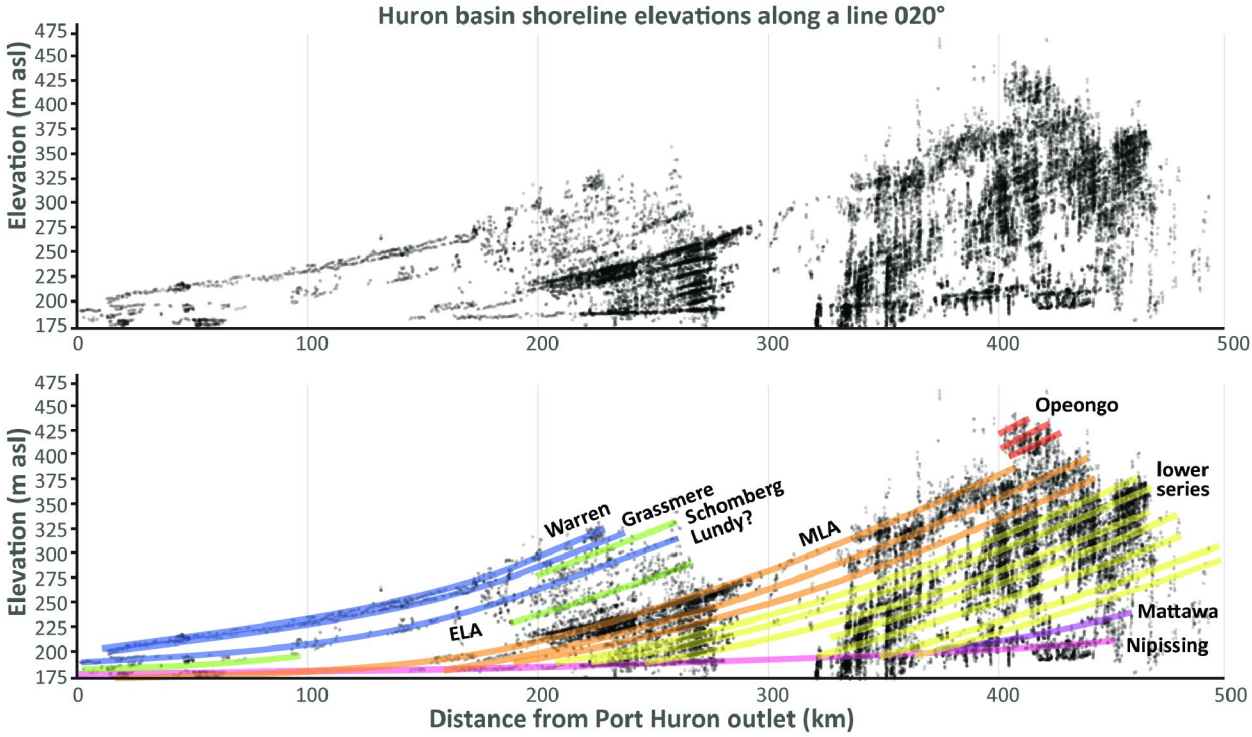


Figure 16.3. Mapped shoreline points in the Lake Huron basin plotted along a line bearing 020° between the Port Huron outlet south of Sarnia and the Temagami area (*see* Figure 16.1 for location). Areas where points create continuous, dark lines represent the best-developed shorelines formed in glacial lakes during deglaciation, which can be correlated with previous studies (e.g., Lewis, Breckenridge and Teller 2022), shown in the lower portion. This graph represents a simplification of the shape of the water planes, as the orientation of the line of maximum uplift in the Lake Huron basin ranges between 013° in the northeast and 021° in the northwest. Coloured lines show individual water planes related to different stages of glacial lakes (as labelled). Abbreviations: MLA = Main Lake Algonquin, ELA = Early Lake Algonquin.

(Hagedorn 2024); ice-flow indicators (Marich 2024)), and links to regional three-dimensional geological models of Quaternary stratigraphy in southern Ontario, among others. The landslide inventory will assist in assessment of geohazard risks in various areas across Ontario. In addition, these data may provide an enhanced framework for understanding the geological conditions susceptible to landslides so that more detailed risk assessments can be completed. Shoreline data have multiple uses, including informing future archaeological site assessments because many currently known sites occur along relict shorelines of glacial lakes in Ontario. A detailed delineation of shoreline distribution will also assist in both aggregate and groundwater resource studies because these landforms commonly host sand and gravel deposits and locally form important recharge areas for groundwater systems. Lastly, the shoreline data can be used in regional reconstructions of glacioisostasy to better understand deep geological structures and crustal response to glacial loading during glaciations and provide critical constraints in interpreting former ice-margin retreat patterns during deglaciation.

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Andy Breckenridge (University of Wisconsin–Superior) provided very helpful discussions on shorelines in the Lake Huron–Lake Superior basins and suggestions on improving the methods to enhance the overall confidence in correlation of the shorelines. Andrea Marich (OGS) provided many discussions on shorelines of the northeastern Lake Huron basin. Greg Brooks (Geological Survey of Canada) assisted with many discussions on landslide mapping, morphology and triggers. Cunhai (George) Gao (OGS) provided a technical review of this report.

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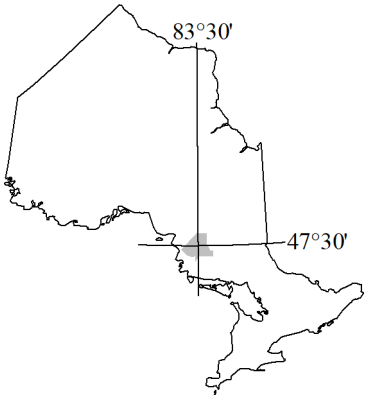
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17. Project NE-24-006. Lake Sediment and Surface Water Geochemistry Program: Chapleau–Montreal River–Mississagi River



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INTRODUCTION

Field work for a high-density lake sediment and water geochemical survey of the Chapleau–Montreal River–Mississagi River area (Figure 17.1), in northeastern Ontario, was carried out between July 25 and August 27, 2025, following the successful return of the lake sediment program last year (Beckett-Brown and Handley 2024). The survey area covers northeast of the town of Chapleau, including the Borden Lake deposit, and extends down to the southeast to meet up with the Batchawana greenstone belt survey (Beckett-Brown and Handley 2024), the Swayze survey to the northeast (Takats 2005a, 2005b), and the Foleyet–Missinaibi survey to the north (Ontario Geological Survey 2000a, 2000b). Improvements to the program were made this past year, including an updated supplemental type certificate (STC) for the lake sediment platform (a plywood sampling platform affixed on top of the helicopter fixed floats), as well as the addition of a fixed water sample intake and depth finder (Photos 17.1A to 17.1D). For this survey, a total of 3447 deep (>15 cm) lake sediment samples and 3447 surface lake water samples were collected over an approximate area of 9500 km^2 (*see* Figure 17.1). The sampling coverage corresponds to an average density of 1 sample site per 2.8 km^2. Aside from the Borden Lake area and the Batchawana greenstone belt, this area has been largely overlooked for exploration and, thus, the mineral potential is poorly understood. Results from this survey will provide significant regional geochemical data that can be used for environmental baseline and mineral exploration purposes.

REGIONAL SETTING AND GEOLOGY

The study area lies within the Superior Province (*see* Figure 17.1A). Several nomenclatures have been presented for the area (Grunsky 1991; Percival and Card 1983; Moser 1993). For simplicity, the area can be subdivided into 3 dominantly intrusive areas (from east to west): the Ramsey–Algoma granitoid complex, the Kapuskasing Structural Zone (bounded by the Ivanhoe and Saganash Lake faults) and the Wawa gneiss domain. In addition, there are 2 greenstone belts: the Batchawana greenstone belt and the Borden Lake greenstone belt. The Batchawana greenstone belt is dominated by tholeiitic mafic metavolcanic rocks with minor calc-alkalic intermediate to felsic metavolcanic rocks and local metasedimentary rocks that are mostly affected by greenschist-grade metamorphism. In comparison, the Borden Lake greenstone belt is typically amphibolite-grade metamorphism and composed of intermediate- to felsic-dominated metavolcanic rocks overlying mafic-dominated metavolcanic rocks with local occurrences of Timiskaming-type metaconglomerate (Duguet and Szumylo 2016).

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.17-1 to 17-8.

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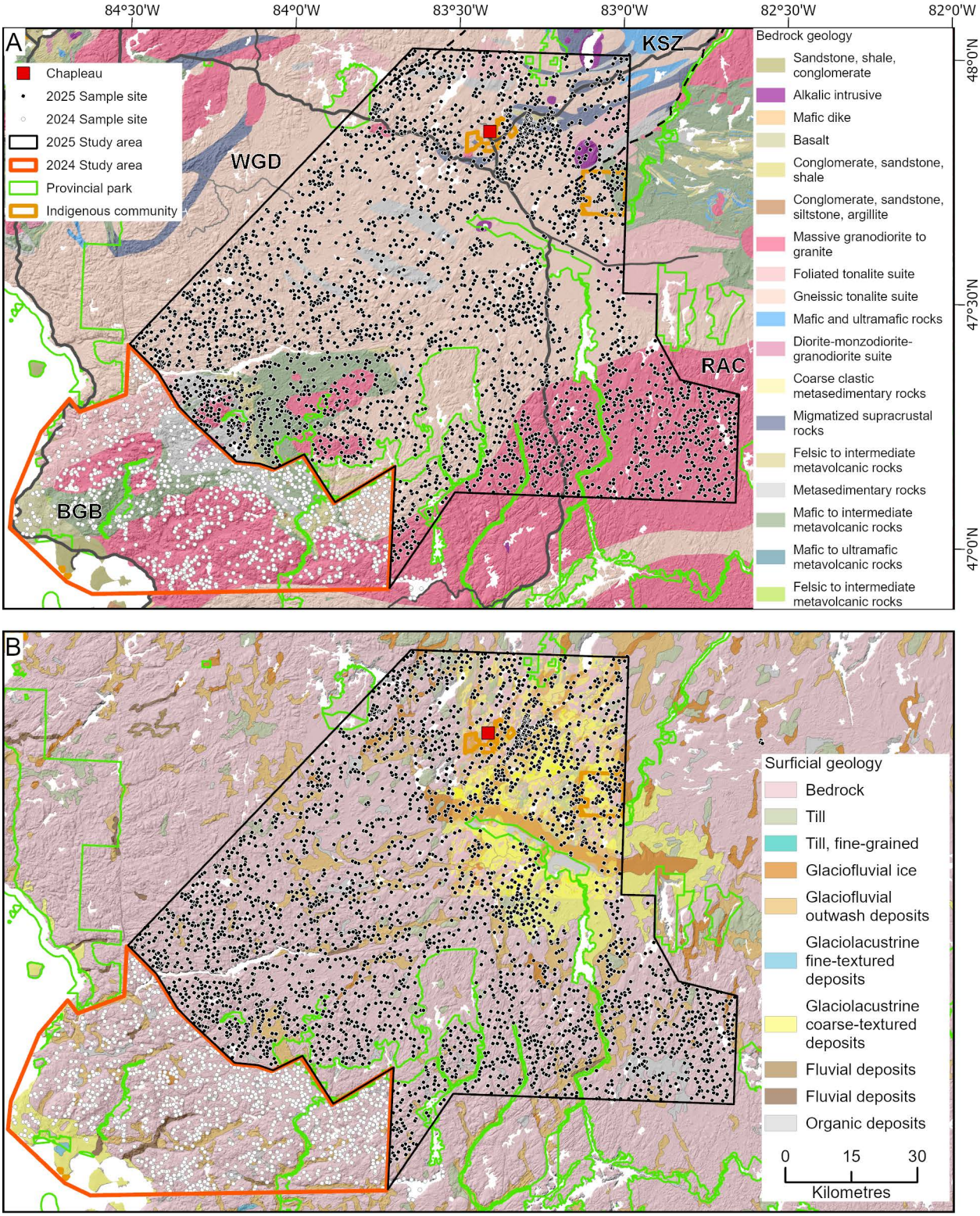


Figure 17.1. Lake sediment and surface water sample sites for the 2024–2025 field seasons overlain on **A)** bedrock geology (geology *from* Ontario Geological Survey 2011) and **B)** Quaternary geology (geology *from* Ontario Geological Survey 2010; and *from* Gao 2016b, 2016c, 2016d) for the region. In Figure 17.1A, major geological areas shown are the Batchawana greenstone belt (BGB), Wawa gneiss domain (WGD), Ramsey–Algoma granitoid complex (RAC), and the Kapuskasing Structural Zone (KSZ) (area between black dashed lines).



Photo 17.1. Photos depicting improvements to the OGS lake sediment sampling platform STC. **A)** Close-up view of assembled sample intake and depth finder enclosure, showing 1) housing for depth finder, 2) housing for foot-valve sample intake, 3) angle support strut, and 4) silicone tubing sample intake. **B)** Macro view showing position on the helicopter between fixed floats. **C)** Disassembled sample intake enclosure to show the stainless-steel foot valve (5) where the sample is drawn up from. **D)** Assembled sample intake and depth finder enclosure showing the setup when landed on a lake and how deep below the water's surface it sits.

The Quaternary geology of the study area has been investigated by Gao (2016a) and consists of till-veneered Precambrian bedrock terrain in the north, with thick deposits of Late Pleistocene glaciolacustrine sand and glaciofluvial sand and gravel along the Wenebegon River and transitions back to a bedrock-dominated terrain with minor till-veneered regions in the south (*see* Figure 17.1B). Regional ice-flow direction is 190°, with a range of 155° to 230° (Gao 2016a).

Mineral exploration activity has been almost completely focussed on the greenstone belts, with the most notable being the discovery of the Borden Lake deposit, which was discovered in 1990 by prospectors J. Robert and M. Tremblay, acquired by Probe Mines in 2010, followed by Goldcorp in 2015 (now Newmont) bringing the deposit into production in 2019, and most recently acquired by Discovery Silver Corp. in April 2025 (Ontario Geological Survey 2025: MDI000000000908). Production at the Borden Mine for 2024 totalled 130 000 ounces at an average grade of 6.54 g/t Au, with a current mine life of 8 years (Discovery Silver Corp., https://discoverysilver.com/projects/porcupine/borden). Additional exploration in the northeast part of the study area for rare earth elements (REE) and critical minerals mineralization on the Lackner Carbonatite (Ontario Geological Survey 2025: MDI000000001278). Greenfields exploration is ongoing in the northern part of the Batchawana greenstone belt for gold and base metals (Maity and Gagnon-Coderre 2025).

SAMPLING METHODS

Organic-rich deep (>15 cm) lake sediment samples were collected from a helicopter equipped with floats, using the OGS-designed gravity corer. Samples were collected from an OGS-designed platform (STC) mounted to the top of the fixed helicopter floats. Deep sediment samples were targeted because they represent geochemical signatures void of any anthropogenic contamination. The average sedimentation rate within lakes on shield landscapes is approximately 1.5 cm per decade (e.g., Hunt 2003; Dickman and Fortescue 1991) and, as such, any contaminants introduced in the last 100 years were avoided by collecting sediment deeper than 15 cm below the sediment–water interface. This deep sediment, therefore, reflects sedimentation older than 100 years showing natural effects of geochemical inputs related to local geological features. Sediment sample metadata were collected using an Apple® iPad® with a QField® custom form. Global positioning system (GPS) data were collected at each site using the tablet with an average vertical, and horizontal accuracy of less than 3.0 m.

Lake water samples were collected at each site from a depth of approximately 0.35 m using a mounted foot valve intake attached to silicon tubing enclosed by a PVC-stainless steel enclosure (part of the proprietary OGS–STC). Water samples were drawn up using a Waterra® 1UP peristaltic pump using 0.25-inch inner diameter (UP 24) silicone tubing. Real-time water parameters were collected using a Xylem® YSI (Yellow Springs Instrument)-EXO1™ (referred to as "sonde" herein) with pH, oxidation–reduction potential (ORP), dissolved oxygen (DO) and temperature–conductivity probes mounted within a flow cell (*see* Beckett-Brown and Handley 2024). Sonde data for the 2024 and 2025 areas are presented in Figure 17.2.

While sediment sampling occurred, lake water was continuously pumped through the flow cell, which started empty at each site, and, after approximately 1 minute of purging, equating to greater than 3 tube volumes, a sonde measurement was collected. Once the sonde measurement was collected, the valve for the flow cell was closed, forcing water through the sampling tube for approximately 3 tube volumes (~15 seconds), to purge the tubing before sampling. Once the tubing was sufficiently purged, a high-capacity Waterra® 0.45 µm filter was attached to the end of the sampling tubing before filling 2 sample bottles. First, a 60 mL HPDE bottle is filled to the bottle neck (to allow for acidification later) for metals analyses, and then a second 60 mL HDPE bottle is filled, with minimal headspace, for anions analyses. Water samples were cooled within 3 hours of collection and remain refrigerated until laboratory analysis. Sample acidification with nitric acid will be completed at the Ontario Geological Survey Geoscience Laboratories (Geo Labs) prior to metals analysis.

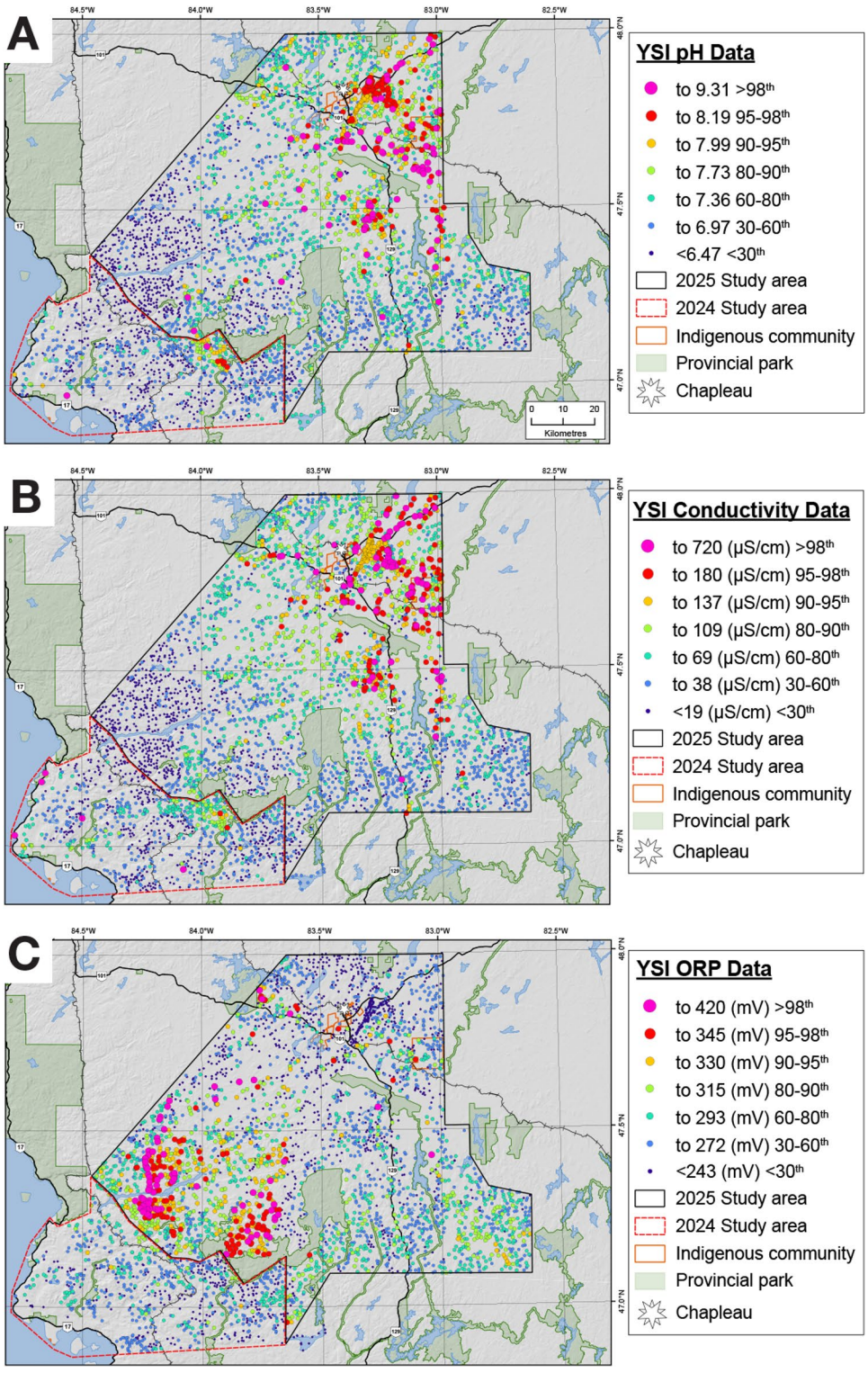


Figure 17.2. Graduated dot plot maps. **A)** YSI pH data, with percentile classifications as follows: 4.28–6.47 (<30th), 6.48–6.97 (30–60th), 6.98–7.36 (60-80th), 7.37–7.73 (80–90th), 7.74–7.99 (90–95th), 8.00–8.19 (95–98th) and 8.20–9.31 (>98th). **B)** YSI specific conductivity data (µS/cm), with percentile classifications as follows: 3–19 (<30th), 20–38 (30–60th), 39–69 (60–80th), 70–109 (80–90th), 110–137 (90–95th), 138–180 (95–98th) and 181–720 (>98th). **C)** YSI oxidation–reduction potential (ORP) data (mV), with percentile classifications as follows: −56–243 (<30th), 244–272 (30–60th), 273–293 (60–80th), 294–315 (80–90th), 316–330 (90–95th), 331–345 (95–98th) and 346–420 (>98th).

SAMPLE PREPARATION AND ANALYTICAL METHODS

Lake sediment samples were collected into breathable polypropylene bags and allowed to air dry prior to transport to Sudbury. Final drying was completed in ovens at temperatures less than 38°C prior to pulverization in a ceramic ring mill and sieving to obtain the under 60 mesh (<250 µm) size fraction necessary for further analysis. Sediment samples will be submitted for aqua regia digestion followed by inductively coupled plasma mass spectrometry (ICP–MS) and inductively coupled plasma atomic emission spectrometry (ICP–AES) to determine major, minor and trace elements.

The metals water samples will be submitted for major, minor and trace element analyses by ICP–MS and ICP–AES. The anions water samples will be submitted for ion chromatography to determine several anions of geological and environmental importance, such as bromide, chloride, fluoride, nitrate, nitrite, phosphate and sulphate. Quality control will be monitored through field and laboratory duplicates, blanks, and certified reference materials.

PRELIMINARY RESULTS

Preliminary results of the water physical properties measured at each site, for both the 2024 and 2025 field seasons, are presented in Figure 17.2. Considering the dearth of knowledge in a large portion of the study area, and a lack of exploration (past and present), these data provide a new look at an overlooked area in the province.

The pH values (Figure 17.2A) range from 4.28 to 9.31, with an average of 6.80 and median of 6.81. Lake water pH can be influenced by factors, such as bedrock type; for example, carbonate rocks result in higher pH lakes because of greater buffering capacity, whereas lakes overlying granites are typically more acidic. Soil and Quaternary sediments can also influence pH depending on their buffering capacity or lack thereof (April and Newton 1985). Other factors could include precipitation or biologic activity through photosynthesis consuming CO_2 and subsequently raising pH. In the 2025 study area, some notable pH trends are present, including generally higher pH values to the north, which could reflect unrecognized mafic rocks, carbonates, or could reflect basic Quaternary sediments. In comparison to the study area from 2024, where the bedrock geology is better known, the greenstone belt distribution is accurately denoted by higher surface water pH values.

Specific conductivity (Figure 17.2B) (µS/cm), referred to as conductivity herein, ranges from 3 to 720 µS/cm, with an average of 46 µS/cm and median of 30 µS/cm. Conductivity in lake water can be influenced by bedrock with elevated concentrations of soluble elements, such as calcium, magnesium, sodium and potassium. Therefore, in general, lake water overlying mafic rocks display higher average conductivity, whereas those overlying felsic rocks display lower average conductivity (Brousseau, Baccante and Maki 1985). Similarly, Quaternary and/or surficial sediments that contain elevated concentrations of soluble elements can influence the surface water conductivity. The last significant influence of surface water conductivity in this region is anthropogenic, including road salt and dust suppression sprays. Lakes that are adjacent to roads or downstream of runoff areas experience significantly elevated conductivity values months after their application (Hintz and Relyea 2019). Conductivity patterns are similar to the pH map with higher values observed in the northern part of the study area and lower values to the south. The Batchawana greenstone belt in the 2024 study area registered higher conductivity values compared to the surrounding granites. In the northern part of the study area, the cause of the higher conductivity values is currently unknown. Could the higher conductivity values be represented by unrecognized greenstone belts or are there other influences affecting the surface water conductivity, such as Quaternary sediment composition? Further results from this study, such as surface water geochemistry and lake sediment chemistry, will help determine the significance of these results.

Oxidation–reduction potential (Figure 17.2C) (ORP, mV) ranges from −56 to 420 mV, with an average of 262 mV and median of 263 mV. In general, the ORP in lake water is primarily influenced by the decomposition of organic material, a process that consumes oxygen, lowering ORP and can also be influenced by microbial processes. Additionally, ORP is pH-dependent at lower pH, where redox reactions tend to be more oxidizing (Linnik et al. 2023). In the study area, the highest ORP values are concentrated around the northern section of the Batchawana greenstone belt and are significantly lower in lakes to the north.

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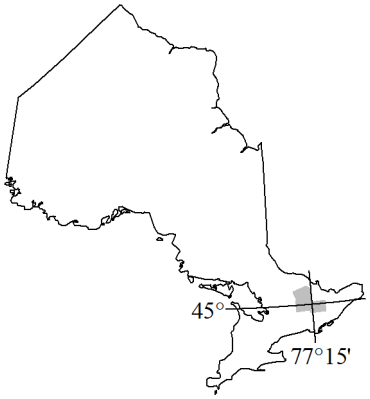
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18. Project SO-25-001. Ambient Groundwater Geochemistry Project: Bancroft, Madawaska Highlands and North Frontenac Region, Southeastern Ontario



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INTRODUCTION

Groundwater is a critical source of freshwater for domestic, municipal, industrial and agricultural uses in Ontario. To better understand this important resource, the Ontario Geological Survey has been mapping regional groundwater chemistry, since 2007, through the Ambient Groundwater Geochemistry Project (AGGP). The goal of the AGGP is to map the chemistry of groundwater at the regional scale to establish a baseline, to study geological controls on groundwater chemistry and to better understand aquifer flow and conditions. The Project functions by collecting data on a large suite of parameters at a consistent spacing density using a standardized protocol (Bocking, Hamilton and Dell 2023).

The southern Ontario section of the AGGP covered the extent of Paleozoic bedrock across the south from Windsor up to Tobermory and across to Kingston and Ottawa to the Quebec border (Figure 18.1; Hamilton 2021). The southern Ontario part of the AGGP was the basis for numerous academic theses, journal articles and Ontario Geological Survey Groundwater Resources Studies (e.g., Freckelton 2013; Colgrove 2016; Smal 2017; Mcintosh et al. 2014; Priebe and Hamilton 2022), all of which demonstrated that regional mapping like this reveals large-scale trends in water quality that can be attributed to the geological characteristics of the aquifers. The northeastern Ontario section of the program, conducted from 2016 to 2018, examined the groundwater chemistry in an area characterized by a predominance of Precambrian bedrock, encompassing Iron Bridge, Blind River, Manitoulin Island, Sudbury, French River, and North Bay to Mattawa (*see* Figure 18.1; Dell, Fudge and Hamilton 2016; Dell, Francis and Hamilton 2017; Dell and Francis 2018; Dell 2024; Dell and Hamilton 2024).

In 2024, a new AGGP initiative was launched to begin bridging the gap between the northeastern and southern AGGP project areas. The new initiative began with collecting samples across the Ottawa Valley in 2024 (Colgrove 2024; *see* Figure 18.1). Between June and July 2025, samples of groundwater were collected in a previously unmapped region in the Bancroft, Madawaska Highlands and North Frontenac regions to extend the coverage of the AGGP and further close the gap between the southern and northeastern programs. Samples were also collected in the Ottawa Valley to infill gaps and resample in the 2024 AGGP study area (Colgrove 2024). The new samples will yield data that allow the characterization of the groundwater quality and provide insight into the corresponding geological controls.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.18-1 to 18-7.

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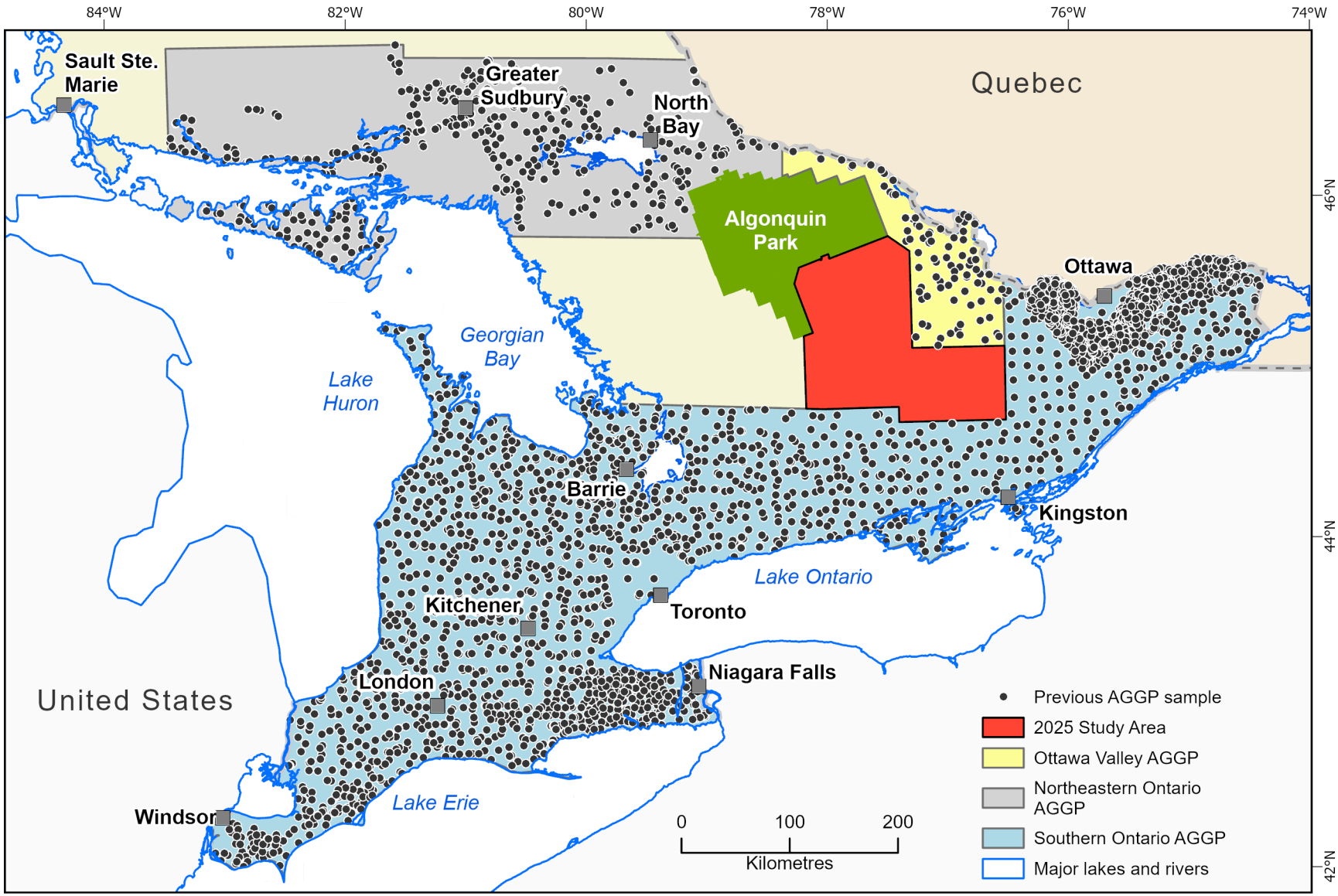


Figure 18.1. Location of the 2025 AGGP relative to previous AGG programs and samples, including the 2024 Ottawa Valley AGGP (L.M. Colgrove, unpublished data, 2024), the southern Ontario AGGP (Hamilton 2021) and northeastern Ontario AGGP (Dell and Hamilton 2024).

STUDY AREA

The main 2025 AGGP study area is bound in the northwest by Algonquin Park, and extends to about Killaloe in the northeast, Clarendon in the southeast and Arden in the south. Some additional geographic landmarks within the study area include Bancroft, Barry's Bay, Cloyne and Bon Echo Provincial Park (Figure 18.2).

The study area lies entirely in the Grenville Province, spanning 2 major lithotectonic subdivisions: the Central Gneiss Belt (CGB) and the Central Metasedimentary Belt (CMB) (Easton 1992). The Central Gneiss Belt consists of Archean, Paleoproterozoic and Mesoproterozoic migmatitic rocks and gneisses whose protolith is generally unknown. These rocks are cut by Mesoproterozoic to Neoproterozoic intrusions. All rocks of the CGB have been metamorphosed to upper amphibolite to granulite facies (Easton 1992). The CMB is a supracrustal terrane composed of marble, metavolcanic rocks and clastic metasedimentary rocks, which have been intruded by plutonic rocks of diverse composition. Rocks of the CMB have all been metamorphosed to varying grades ranging from greenschist to amphibolite facies (Easton 1992). A plethora of mineral deposits reside within the CMB (Ontario Geological Survey 2025), giving Bancroft its reputation as the "Mineral Capital of Canada". Deposits in the CMB of the study area include zinc, uranium, molybdenum, magnetite, sulphides (mainly pyrite and chalcopyrite), gold and industrial minerals (Ontario Geological Survey 2025). The boundary between the CGB and CMB is a major shear zone of highly deformed rocks known as the CMB boundary zone (Easton 1992). The youngest bedrock in the study area consists of Ordovician carbonate outliers present mainly in the Ottawa Valley study area (Ontario Geological Survey 2011). Bedrock geology was noted as one of the controls on groundwater chemistry in the adjacent northeastern Ontario AGGP, which included rocks of the CGB (Dell 2024; Dell and Hamilton 2024).

The majority of the study area has bare bedrock, or thin to discontinuous drift (Ontario Geological Survey 2000). There is a greater prevalence of drift in the northwest section of the study area, consisting of till and glacial outwash deposits (Ontario Geological Survey 2000). Near Combermere, till can reach a thickness of over 100 m and creates topographic highs (Gao et al. 2006). The interplay between drift thickness and bedrock topography were found to be important controls on groundwater chemistry in eastern Ontario nearby (Colgrove 2016).

According to a regional study, fractured bedrock is the major aquifer in the region, with the top 30 m being identified as "vulnerable". Overburden aquifers were typically localized and commonly associated with outwash deposits in Hastings Highlands, Carlow–Mayo and Bancroft. Regional recharge occurs at topographic highs and bedrock plateaus, and discharge occurs in low-lying areas. Groundwater quality is generally described as "very good" (Dillon Consulting Limited 2004), although a more localized study near historical uranium mines in the Bancroft area by the Geological Survey of Canada found elevated levels of uranium, thorium and rare earth elements, with uranium concentrations exceeding 100 times the Health Canada Maximum Acceptable Concentration (Desbarats and Percival 2016).

METHODS AND ANALYTES

The study area was divided into a 10 by 10 km sampling grid. Within each 100 km^2 grid square, work for the AGGP typically collects (or attempts to collect) 2 samples: 1 from a well drilled into bedrock and 1 from a well completed in overburden sediment. Because of the thin, discontinuous or absent nature of overburden aquifers in most of the study area, priority was given to collecting samples from bedrock aquifers. In some cases, additional bedrock samples were collected to characterize different rock types. Overburden aquifers were also sampled where possible.

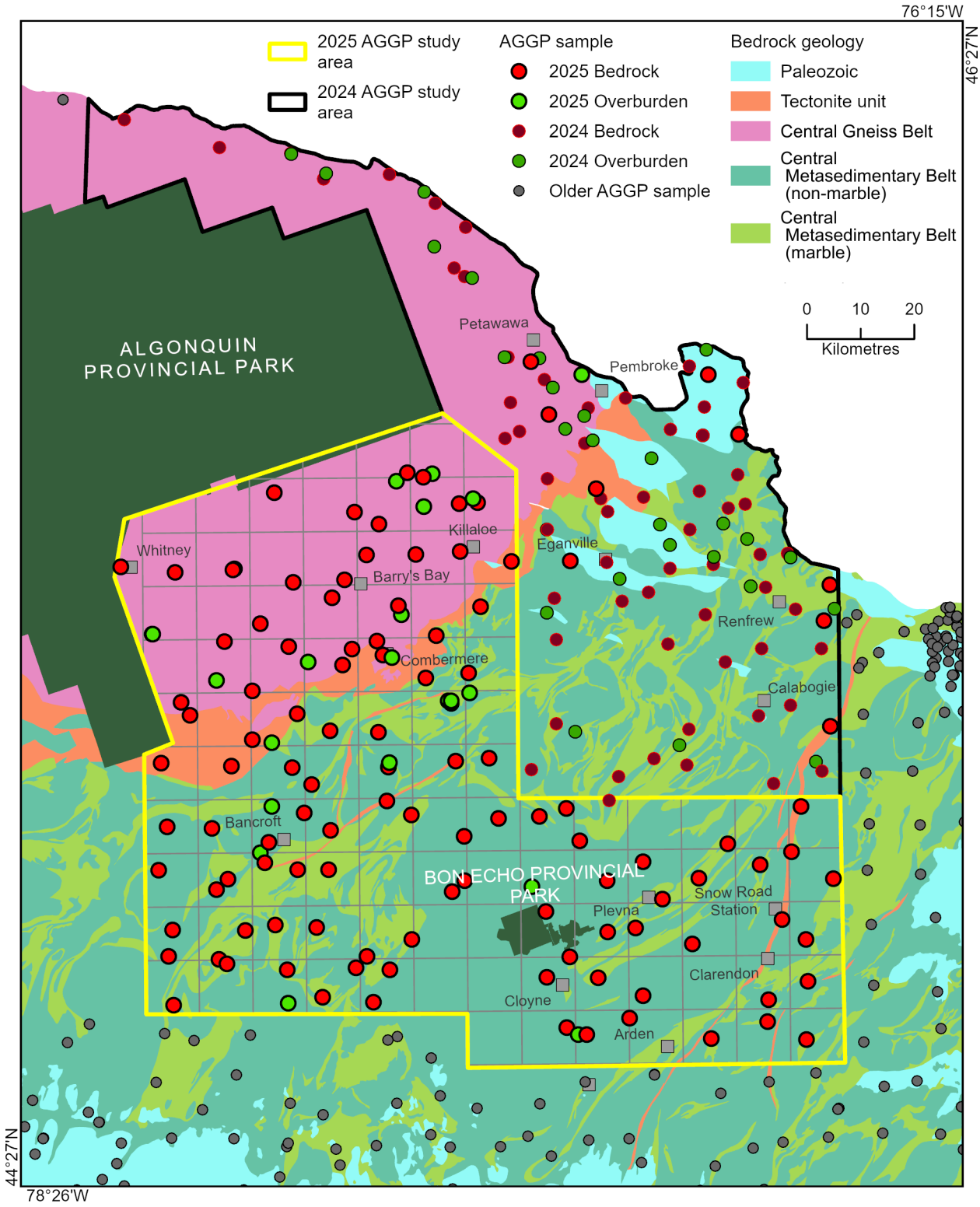


Figure 18.2. Expected distribution of bedrock and overburden sample locations from the 2025 AGGP, within the context of 2024 samples and older AGGP samples and bedrock geology (*from* Ontario Geological Survey 2011).

Table 18.1. Information on analytes, laboratories, collection and preservation of the 2025 AGGP samples.

Laboratory	Bottle Name	Analyte(s)	Volume	Preservation
OGS Geoscience Laboratories	Metals	Suite of metals and trace elements analyzed using ICP–MS and ICP–AES	60 mL, disk filtered	Refrigeration, nitric acid
	Anions	Br, Cl, F, I, NO_2, NO_3, PO_4, SO_4	60 mL, disk filtered	Refrigeration
	Hg	Hg	60 mL, disk filtered	Frozen, BrCl acid
	DIC/DOC	Dissolved inorganic carbon, dissolved organic carbon	60 mL, HC filtered	Refrigeration
Field Laboratory	Iodide	Iodide	60 mL, HC filtered	Refrigeration, nickel acetate
	Field Gases	CH_4, CO_2, O_2	600 mL, unfiltered	None
SGS Canada	Bacteria	Total coliform, fecal coliform	250 mL, unfiltered	Refrigeration, sodium thiosulphate
	DIC/DOC	Dissolved inorganic carbon, dissolved organic carbon	60 mL, HC filtered	Refrigeration
	NH_3/TKN	NH_3, Total Kjeldahl nitrogen	60 mL, unfiltered	Refrigeration, sulphuric acid
	NO_2/NO_3	NO_3, NO_2	60 mL, unfiltered	Refrigeration
	Colour	Colour	60 mL, unfiltered	Refrigeration
	Sulphide	Dissolved S^{2-}	60 mL, HC filtered	Refrigeration, zinc acetate, sodium hydroxide
Saskatchewan Research Council	Gross Alpha Beta	Gross alpha, gross beta	1000 mL, unfiltered	Nitric acid
	Radon	Radon	2 × 40 mL, unfiltered	None
Isotope Tracer Technologies	Isotopes	$\delta^{18}O$–H_2O, $\delta^{2}H$–H_2O	60 mL, unfiltered	Refrigeration
	Tritium	^{3}H	250 mL, unfiltered	None
Isotope Tracer Technologies	Sulphur Isotopes	$\delta^{34}S$–S^{2-}, $\delta^{34}S$–SO_4, $\delta^{18}O$–SO_4	250 mL, HC filtered	Zinc acetate
Jan Veizer Stable Isotope Laboratory	Dissolved Gases	CH_4, CO_2, O_2/Ar, N_2	125 mL, unfiltered	Refrigeration, copper sulphate

Abbreviations*: HC, high-capacity filter; ICP–AES, inductively coupled plasma atomic emission spectrometry; ICP–MS, inductively coupled plasma mass spectrometry.*

Samples were collected from private domestic wells where members of the public volunteered to assist the program. A recruitment campaign was developed using flyers, social media posts and social media ads, which directed members of the public to information on the program and an online application form. Sampling was conducted consistent with AGGP field protocols (Bocking, Hamilton and Dell 2023), with several methodological updates, including the following:

- The bottle for mercury analysis was frozen the day of sampling to preserve the sample prior to acidification with bromine chloride acid and analysis by the laboratory. This protocol change was instituted in 2024 to minimize mercury volatilization prior to acidification.
- Filtration required for specific analytes was done using Waterra® high-capacity 0.45 µm filters, with the exception of the samples for metals, mercury and anion analyses, which were filtered with a 0.45 µm Millipore® disk filter to be consistent with prior years of the program.
- The bottles for iodide, sulphur isotopes and laboratory sulphide were filtered to reduce potential interferences from particulate.
- Dissolved gas was analyzed by a second (laboratory) method. Water was collected in 125 mL glass Wheaton bottles with rubber butyl septum lids and preserved with $CuSO_4$ and refrigeration.

The analytes and associated information on collection, preservation and laboratories can be found in Table 18.1. The 2025 AGGP sample information and analytes will ultimately include

- Sample and station observations: well information (age, type, geometry, well-head security), plumbing information (pump type, pressure tank type), water observations (colour, clarity, smell, gas phase).
- Standard AGGP field-determined analytes: pH, oxidation–reduction potential (ORP), specific conductivity, temperature, dissolved oxygen, alkalinity, hydrogen sulphide (H_2S), iodide and dissolved gases (CH_4, CO_2, O_2).
- Standard AGGP laboratory-determined analytes: metals, anions, mercury, dissolved inorganic and organic carbon (DIC, DOC), nitrogen species (NO_2, NO_3, NH_3, TKN), colour, bacteria (total coliform, fecal coliform), water isotopes ($\delta^{18}O–H_2O$, $\delta^{2}H–H_2O$, tritium).
- Additional analytes: radionuclides (gross alpha, gross beta, radon), sulphate and sulphide isotopes ($\delta^{34}S–S^{2-}$, $\delta^{34}S–SO_4$, $\delta^{18}O–SO_4$), dissolved sulphide (where H_2S detected by smell), laboratory-determined dissolved gases (CH_4, CO_2, O_2/Ar, N_2).

SAMPLE COVERAGE

The program sampled a total of 139 wells, with 10 of those within the 2024 Ottawa Valley area to fill gaps or resample (*see* Figure 18.2). The anticipated distribution of overburden and bedrock samples are displayed on Figure 18.2; however, a full station audit has not been completed at the time of writing. Gaps in the density of overburden samples are the result of low availability of overburden wells, although future gap filling may be possible. Gaps in the density of bedrock samples exist as a result of the lack of or very few residents (and therefore few available wells) in undeveloped rural areas, especially near Algonquin Provincial Park and Bon Echo Provincial Park. In addition to the 139 samples, blind quality control "samples" were submitted to the laboratories to assess precision and accuracy, including duplicates, blanks, certified reference materials and in-house standards. At the time of writing, most laboratory results and internal quality control analysis were pending. Ultimately, the data will be released in a Miscellaneous Release—Data (MRD) that is compatible for integration with both the northeastern and southern Ontario AGGP databases.

ACKNOWLEDGMENTS

I would like to extend a big thank you to the volunteers who allowed us to access groundwater through their wells—the AGGP would not be possible without this kind of support from members of the public. Thank you to summer students Lucas Perreault, Maggie Laird, Sophia Missikowski, Jessica Stewart, Nathan Taylor and James Barnes for their hard and excellent work making the program a success. Many thanks to Laura Handley for providing critical help getting the program set up, training the crew, sampling and keeping spirits high. Chris Beckett-Brown provided important technical and advisory support to the program and students. The outreach and recruitment strategy were made possible by ideas and technical support from Kei Yeung, Kayla Kalmo, John Dodge and Tessa Di'Iorio. Thank you to the various individuals and organizations who helped spread the word about our program. Kei additionally provided invaluable information technology (IT) support leading up to and during the sampling campaign. Thank you to Chris Beckett-Brown, Julien Bonin and the staff of Publication Services for editorial and drafting support.

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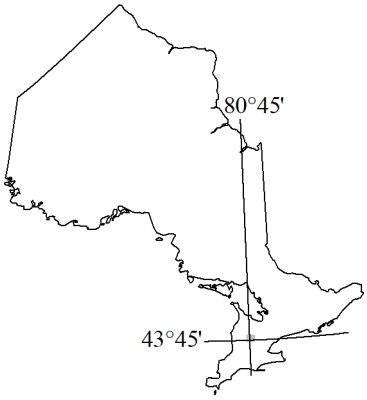
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19. Project SO-24-002. Drilling Down in Mount Forest–Elmira



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INTRODUCTION

The Ontario Geological Survey (OGS) has been mapping southern Ontario subsurface Quaternary sediments in three-dimensions (3-D) since 2002. This information is required for source water protection planning, subwatershed studies, numerical groundwater flow modelling, improving volumetric estimations of the provincial groundwater resource, and assisting in the discovery of sediment-hosted aquifers. Subsurface information collected through these mapping efforts is further used to develop sound land-use planning decisions for our built environment, in conjunction with supporting both agricultural and aggregate industries.

In 2012, the OGS initiated a 3-D mapping project in the Mount Forest–Elmira area (Burt 2012) where groundwater is currently the primary source of water for domestic, agricultural and industrial uses. Population growth and increasing demand on water resources are placing growing pressure on groundwater resources. The area (Figure 19.1) encompasses approximately 2000 km^2 extending from Grey Road 9 northwest of Mount Forest south to Elmira. Portions of the County of Grey, the County of Wellington, the County of Perth and the Regional Municipality of Waterloo are included within the study area. The towns of Mount Forest, Harriston, Palmerston, Arthur and Elmira are the largest urban centres.

The results of previous 3-D projects in the adjacent Orangeville–Fergus area to the east (Burt and Webb 2013; Ontario Geological Survey 2013a, 2013b, 2013c; Burt and Chartrand 2014; Burt and Dodge 2016; Burt 2018) and Waterloo Region to the south (Bajc and Hunter 2006; Bajc and Shirota 2007; Bajc, Russell and Sharpe 2014) published by the OGS are available through GeologyOntario (*see* Figure 19.1 for locations of cored boreholes). Preliminary observations and results for the ongoing Guelph area project to the southwest (Burt and Hagedorn 2022; Brunton and Burt 2024; Burt, this volume, Article 20) provide additional context. These projects are centred over the Late Wisconsin interlobate zone, an area with complex regional sediment stratigraphy hosting aggregate deposits at surface and productive aquifers at depth, which extends southwest from the city of Orangeville toward London. The regional-scale hydrostratigraphy of this zone, as well as the Brantford–Woodstock (Bajc and Dodge 2011), Long Point (Marich 2014) and Niagara Peninsula (Burt 2020) areas to the southeast, have been studied extensively.

In the Orangeville–Fergus and Waterloo Region areas, a series of older tills confine the Paleozoic bedrock aquifer and older sediment aquifers (Bajc and Shirota 2007; Burt and Dodge 2016). The regionally significant last glacial maximum Catfish Creek Till aquitard is mapped across most of the area, whereas the centrally located Orangeville and Waterloo sandy and gravelly stratified moraines were deposited in an interlobate lake as the ice thinned and retreated from its maximum position. Muddy glaciolacustrine sediments and fine-grained tills, referred to collectively as Maryhill Drift, were also deposited within the interlobate zone and are found under, within, and overlying stratified moraine deposits.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.19-1 to 19-7.

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Tills deposited during late glacial advances of Erie–Ontario and Huron–Georgian Bay ice lobes form an upper aquitard partially burying the flanks of the moraines.

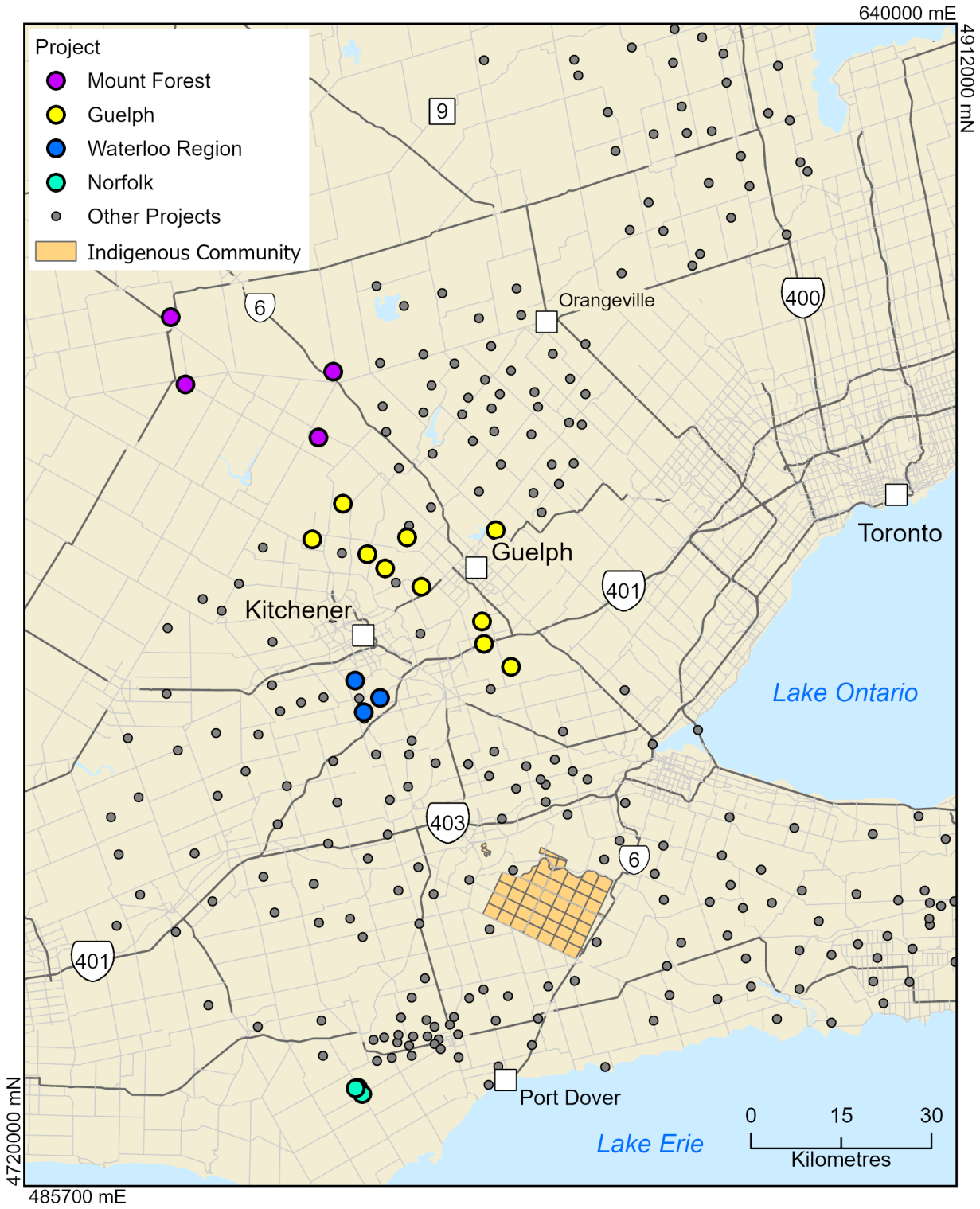


Figure 19.1. Locations of cored boreholes in southwestern Ontario. New boreholes drilled in the Mount Forest–Elmira area (this study) are shown as purple-filled circles. New boreholes drilled in the Guelph 3-D project area (*see* Burt, this volume, Article 20) are shown as yellow-filled circles, in the Region of Waterloo (*see* Burt and McKie, this volume, Article 21) are shown as blue-filled circles, and Norfolk County (*see* Burt, this volume, Article 22) are shown as teal-filled circles.

To date, there has been little subsurface work focussed northwest of the interlobate zone. Previous mapping (Cowan 1979; Feenstra 1975; Karrow 1993) indicates the existence of numerous distinct late glacial till units, with facies and composition reflecting local bedrock and substrate materials entrained by the Huron and Georgian Bay lobes flowing south and south-southeast across the study area.

FIELD ACTIVITIES

The 2024 field season focussed on drilling continuously cored boreholes and converting the boreholes to monitoring wells in collaboration with local municipalities, consultants and the Grand River Conservation Authority. Sites were selected in areas with little geological or hydrogeological information, and minimal to no long-term groundwater monitoring.

Four PQ (8.5 cm inner diameter) continuously cored mud-rotary boreholes, penetrating the Quaternary sediments and upper few metres of bedrock, were drilled during the fall of 2024 (*see* Figures 19.1 and 19.2). The boreholes range from 21.34 to 114.3 m in depth with a combined drill length of 212.75 m. The core was logged, photographed at 0.25 m increments and representative samples were taken from each major sediment interval in the field. Samples were collected for particle size analysis (diamicton and stratified sediments), heavy mineral analysis (diamicton), carbonate content (diamicton and fine-textured stratified sediments) and clast lithology counts (diamicton and gravelly stratified sediments).

After coring was complete, the holes were converted into monitoring wells with 5 or 10 foot long (1.5 or 3 m) slotted screens. Boreholes BH01-MF-2024, BH02-MF-2024 and BH03-MF-2024 were converted to monitoring wells using 2-inch inside diameter threaded, flush-joint polyvinyl chloride (PVC) and 2.5-inch PVC was used in BH04-MF-2024. Overburden–bedrock interface wells were installed in boreholes BH01-MF-2024 and BH02-MF-2024 and gravelly intervals were screened in BH03-MF-2024 and BH04-MF-2024. The monitoring wells have been equipped with automatic water level recorders for long-term monitoring. The borehole locations, bedrock and borehole depths, and monitoring well owners are listed in Table 19.1.

PRELIMINARY RESULTS

Preliminary graphic borehole logs and hydrostratigraphic correlations for boreholes BH01-MF-2024 (Harriston), BH02-MF-2024 (Palmerston) and BH03-MF-2024 (Arthur) are presented in Figure 19.3. Borehole BH04-MF-2024 (Mapleton) requires further consideration before presenting hydrostratigraphic correlations. Early observations are as follows:

- Bedrock was intersected at depths generally consistent with provincial-scale sediment thickness and bedrock topography mapping (Gao et al 2006). This area is located on a regional bedrock high, and the bedrock surface slopes down to the northwest (boreholes BH01-MF-2024, BH02-MF-2024 and BH03-MF-2024) and southwest (boreholes BH03-MF-2024 and BH04-MF-2024). Borehole BH04-MF-2024 intersected bedrock approximately 35 m deeper than described on nearby water well records suggesting the presence of a buried-bedrock valley.
- Bedrock varied from fractured dolostone (BH01-MF-2024 and BH03-MF-2024) to beds (or glacially transported blocks) of highly weathered, deformed shale and weathered, rubbly and fractured dolostone (BH02-MF-2024) to weathered shale and dolostone (BH04-MF-2024). Quaternary sediments were observed within some fractures.
- Muddy glaciolacustrine sediments, thick beds of monolithic diamicton and blocks of highly weathered rock observed overlying bedrock in borehole BH04-MF-2024 may record debris flows into water ponded within the bedrock valley.

Table 19.1. Borehole name, location, depth to bedrock, depth of hole and monitoring-well ownership of boreholes drilled in 2024.

Borehole ID	Location	Easting[1] (m)	Northing[1] (m)	Depth to Bedrock[2] (m)	Depth of Hole (m)	Well Owner
BH01-MF-2024	Blind Line, Harriston	509845	4863854	18.2	21.34	Town of Minto
BH02-MF-2024	Cavan Street, Palmerston	512264	4852644	22	28.19	Town of Minto
BH03-MF-2024	Wells Street, Arthur	536863	4854779	46.25	48.92	Township of Wellington North
BH04-MF-2024	Sideroad 18, Mapleton	534345	4843754	112.3	114.3	Grand River Conservation Authority

[1]Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 17.
[2]Assigned at top of rubble, fractured and highly weathered rock.

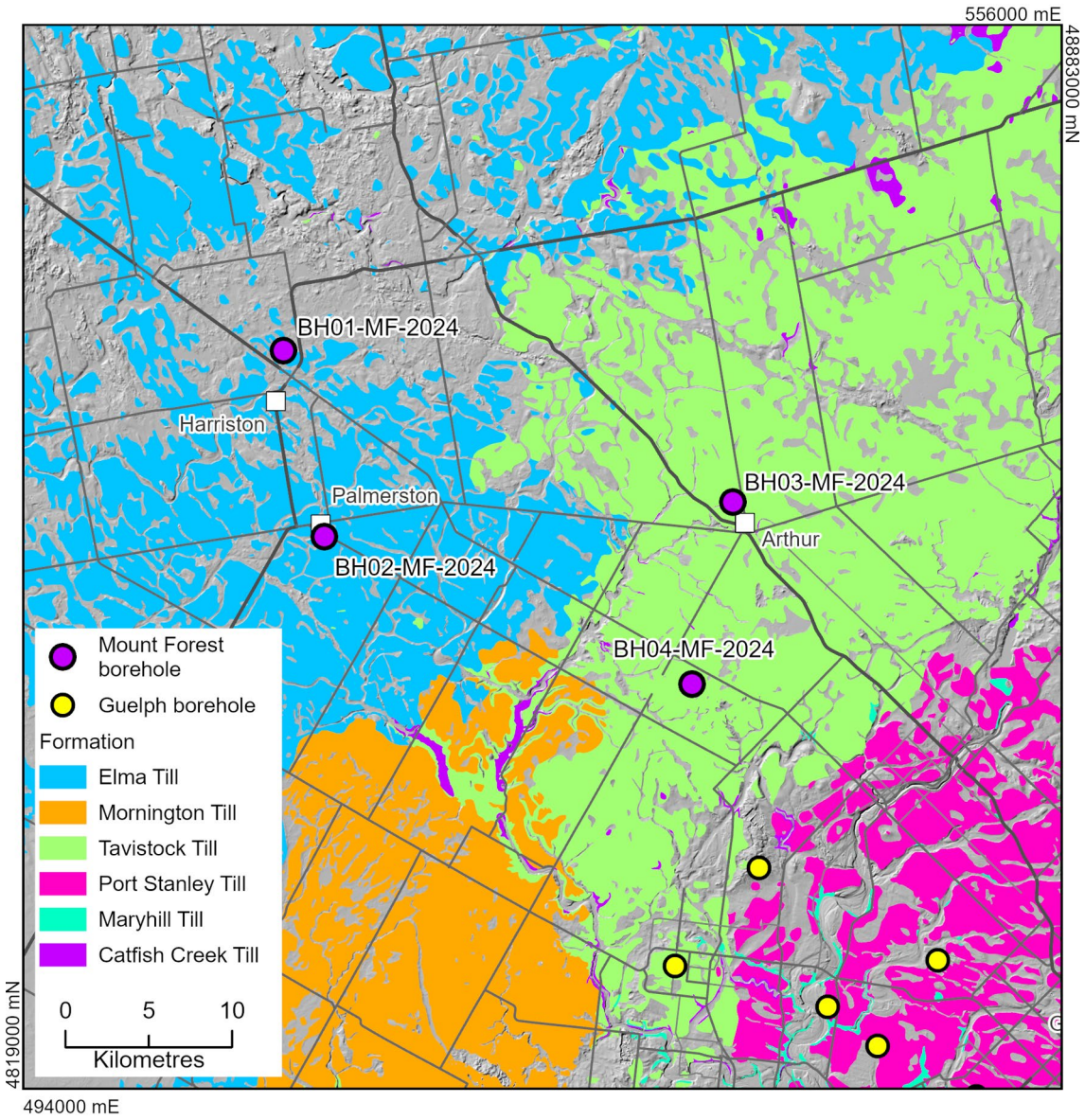


Figure 19.2. Surficial tills mapped in the 2024 Mount Forest–Elmira field area (geology *from* Ontario Geological Survey 2010) overlain on a lidar-derived digital terrain model hillshade (Ministry of Natural Resources 2025). Stratified deposits are not shown on this figure. New boreholes drilled in the Mount Forest–Elmira area (this study) are shown as purple-filled circles and in the Guelph 3-D project area (this volume, Article 20) are shown as yellow-filled circles. Data are projected using North American Datum 1983 (NAD83) Universal Transverse Mercator (UTM) in Zone 17N.

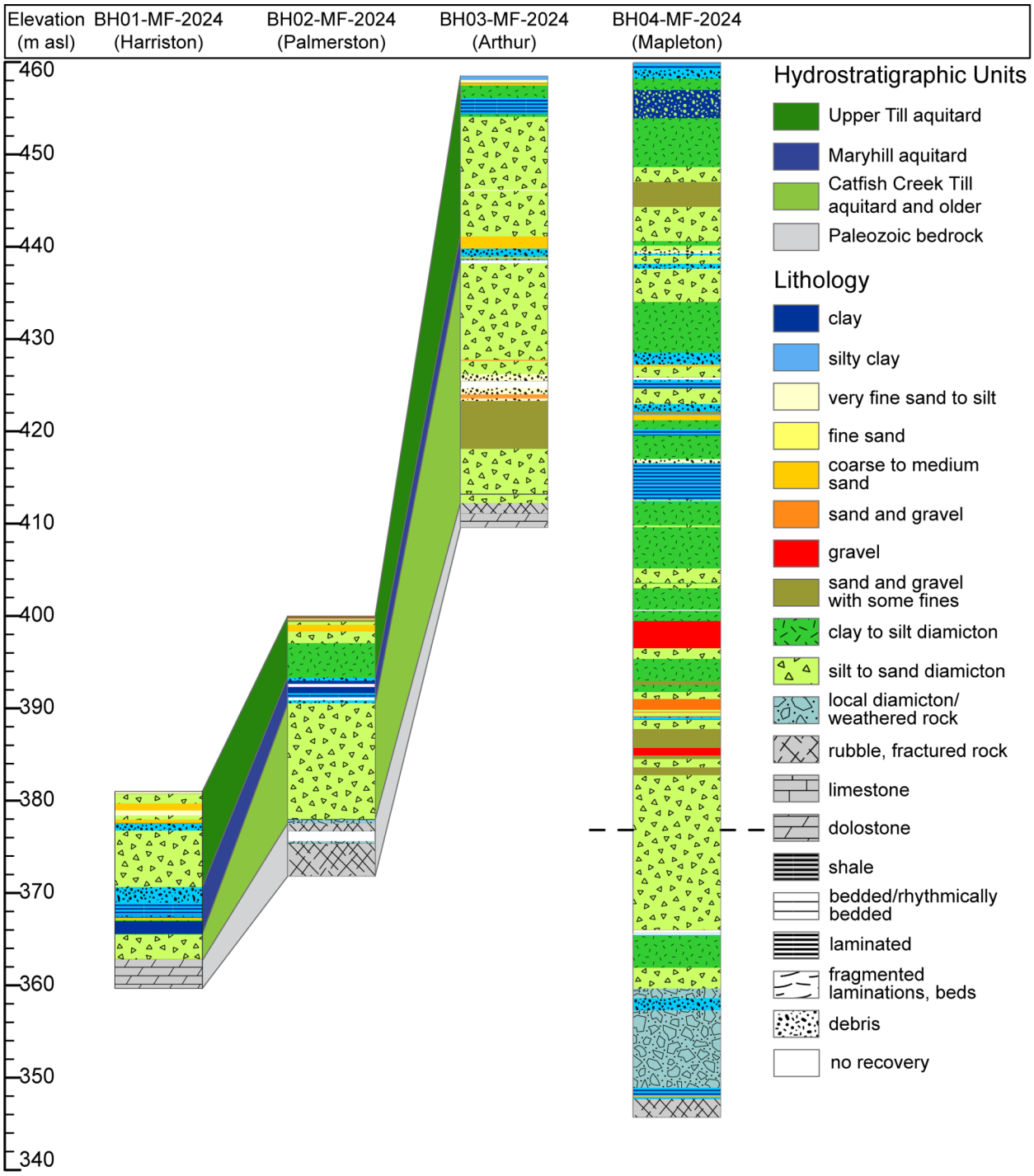


Figure 19.3. Preliminary graphic borehole logs and tentative correlations for Mount Forest–Elmira area boreholes drilled in 2024. Logs are shown in metres above sea level (m asl). Hydrostratigraphic units correspond with regional-scale 3-D model layers from adjacent Orangeville–Fergus and Waterloo Region projects (Bajc and Shirota 2007; Burt and Dodge 2016). The dashed line on BH04-MF-2024 shows approximate bedrock elevation reported in nearby water well records.

- Multiple stacked tills and predominantly fine-textured glaciolacustrine deposits overlie the debris flow deposits in borehole BH04-MF-2024 and bedrock in the remaining boreholes. In boreholes BH01-MF-2024, BH02-MF-2024 and BH03-MF-2024, the lower tills are tentatively identified as last glacial maximum Catfish Creek Till with potentially older deposits in BH03-MF-2024.
- Well-laminated to weakly bedded muddy glaciolacustrine sediments with ice-rafted debris and, in places, beds of sand, overlie Catfish Creek Till. Tentatively identified as Maryhill aquitard, this records subaqueous and ice-marginal sediment deposition in the interlobate zone during retreat from the last glacial maximum and the shift to lobate ice flow.
- Silty to sandy and silty to clayey tills, muddy glaciolacustrine sediments and sand record late glacial fluctuations along the ice margin and are tentatively identified as Upper Till aquitard deposits. Silty to sandy tills observed in boreholes BH01-MF-2024, BH03-MF-2024 and possibly the upper part of BH04-MF-2024 may reflect early Georgian Bay lobe ice flow.
- The uppermost tills are consistent with previously mapped and described stony silty to sandy Elma Till (BH01-MF-2024), Elma Till overlying silty to clayey silty Tavistock Till (BH02-MF-2024), Tavistock Till (BH03-MF-2024), and Tavistock Till overlying silty to clayey Stirton Till (BH04-MF-2024).
- The depth to the water table at well BH04-MF-2024 at the time of the well installation is approximately 27 m below ground surface. Preliminary water quality analysis for nutrients shows an absence of nitrate and nitrite at the site. A deeper 6-inch diameter bedrock test well was drilled by the municipality adjacent to BH02-MF-2024 to allow for completion of a long-term pumping test of the bedrock aquifer as part of a water supply municipal class environmental assessment.

It is anticipated that laboratory grain size and carbonate content analyses and clast lithology counts will confirm these correlations and ice-flow directions. A data release comprising detailed borehole descriptions, graphic logs, analytical results and core photographs is planned.

The lithological and long-term groundwater level data provided by monitoring wells installed at the 4 borehole locations will support groundwater modelling projects to update source water protection Wellhead Protection Areas for municipal wells in the area.

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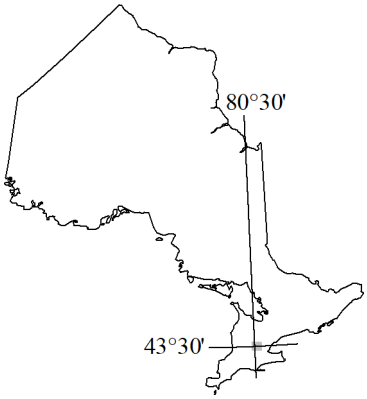
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20. Project SO-22-005. Finding the Good Spots in Guelph



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INTRODUCTION

In 2022, the Ontario Geological Survey (OGS) initiated a three-dimensional (3-D) mapping project centred on the City of Guelph in southwestern Ontario in support of source water protection and to inform land-use planning decisions (Burt and Hagedorn 2022). The study area, approximately 1500 km^2 in size, is located west of the Niagara Escarpment Greenbelt area and includes parts of the County of Wellington, the Regional Municipality of Halton, the Regional Municipality of Waterloo and the City of Hamilton. The project goals are to build a regional-scale 3-D model of Quaternary deposits that form both regional and local aquifers and aquitards and control recharge pathways to underlying regional bedrock aquifers. Existing 1:63 360 and 1:50 000 scale surficial maps will be refined, as summarized in Burt and Hagedorn (2022) and Brunton and Burt (2024).

FIELD ACTIVITIES

A 2024–2025 winter field season focussed on drilling continuously cored boreholes and converting 2 boreholes into monitoring wells in collaboration with the Regional Municipality of Waterloo and the City of Guelph. Sites were selected along a transect straddling the late Wisconsin interlobate zone, primarily targeting areas where, because of burial by younger till units, the Orangeville and Waterloo moraines have little surface expression, but may occur in the subsurface. Boreholes were drilled through the Elmira, Breslau and Paris–Galt moraines, till plains with mega-scale glacial lineations and a site identified to support ongoing 3-D and numerical groundwater flow modelling for the City of Guelph (A. Shaw, University of Guelph, personal communication, 2024).

Nine PQ (8.5 cm diameter) continuously cored mud-rotary boreholes, penetrating the Quaternary sediments and upper few metres of bedrock, were drilled as part of this project (Figures 20.1 and 20.2). An additional borehole, previously drilled and converted into a monitoring well drilled by the City of Guelph and logged by OGS, is included in this article (Brunton and Burt 2024). The boreholes range from 16.6 to 83.52 m in total depth, with a combined drill length of 383.63 m. The core was logged, photographed at 0.25 m increments and representative samples were taken from each major sediment interval in the field. Samples were collected for particle size analysis (diamicton and stratified sediments), heavy mineral analysis (diamicton), carbonate content (diamicton and fine-textured stratified sediments) and clast lithology counts (diamicton and gravelly stratified sediments).

After coring was complete, the Region of Waterloo converted borehole BH02-G-2024 into a 2-inch inside diameter threaded, flush-joint polyvinyl chloride (PVC) monitoring well with a 3 m long slotted screen. The City of Guelph converted borehole BH10-G-2024 into a bedrock well by widening the cored

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.20-1 to 20-10.

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overburden hole, and hammer drilling through a set casing to a depth of 90 m. The borehole locations, bedrock and borehole depths, and well owners are listed in Table 20.1.

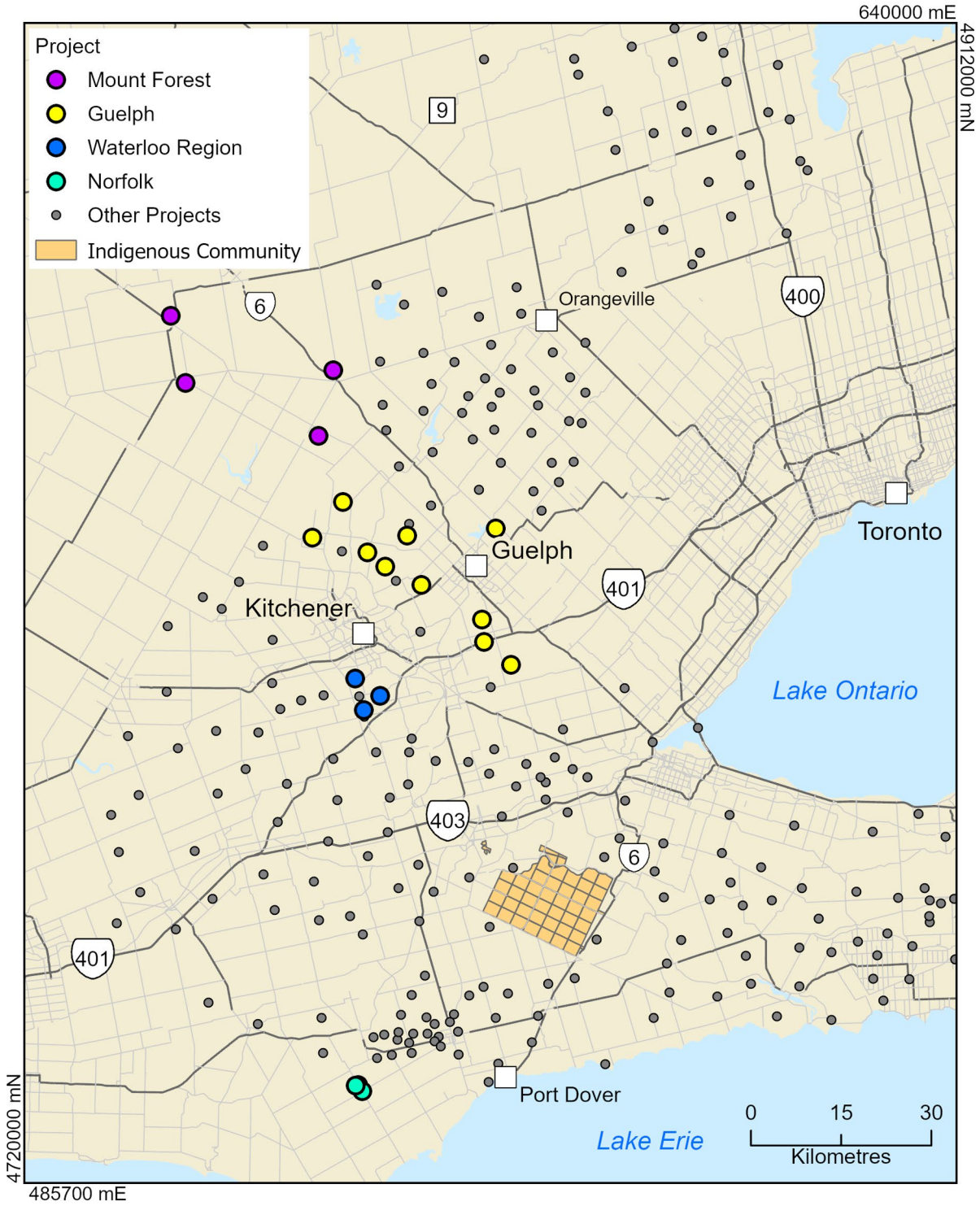


Figure 20.1. Locations of cored boreholes in southwestern Ontario. New boreholes drilled in the Guelph area (this study) are shown as yellow-filled circles. New boreholes drilled in the Mount Forest–Elmira 3-D project area (*see* Burt, Strynatka and Baxter, this volume, Article 19) are shown as purple-filled circles, in the Region of Waterloo (*see* Burt and McKie, this volume, Article 21) are shown as blue-filled circles, and Norfolk County (*see* Burt, this volume, Article 22) are shown as teal-filled circles.

Table 20.1. Borehole name, location, depth to bedrock, depth of hole and monitoring-well ownership of boreholes drilled in the Guelph area. Note that only the sediment and bedrock interface zones of boreholes BH01-G-2024 (Brunton and Burt 2024) and BH10-G-2024 are described in this article.

Borehole ID	Location	Easting[1] (m)	Northing[1] (m)	Surface Elevation (m asl)	Depth to Bedrock[2] (m)	Depth of Hole[3] (m)	Well Owner
BH01-G-2024	Sideroad 10	563858	4828433	352	14.15	16.6	City of Guelph
BH02-G-2024	Elmira Tank Farm	533352	4826860	375	80.8	83.52	RM of Waterloo[4]
BH03-G-2024	Sandy Hills Road	538383	4832766	403	53.9	58.05	–
BH04-G-2024	Lundy Road	545488	4822047	338	39.65	42.67	–
BH05-G-2024	Letson Drive	542492	4824412	343	34.2	36.58	–
BH06-G-2024	Sideroad 14	549110	4827210	355	29.2	31.9	–
BH07-G-2024	Village View Road	551437	4819039	333.5	30.45	33.53	–
BH08-G-2024	Sideroad 10 S	561830	4809481	312	25.4	27.43	–
BH09-G-2024	Gore Road	566370	4805722	300	18.1	21.35	–
BH10-G-2024	Sideroad 12 N	561535	4813205	329	29.1	32	City of Guelph

[1]*Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 17.*
[2]*Assigned at top of rubble, fractured and highly weathered rock.*
[3]*Depth of PQ cored hole.*
[4]*Regional Municipality of Waterloo.*

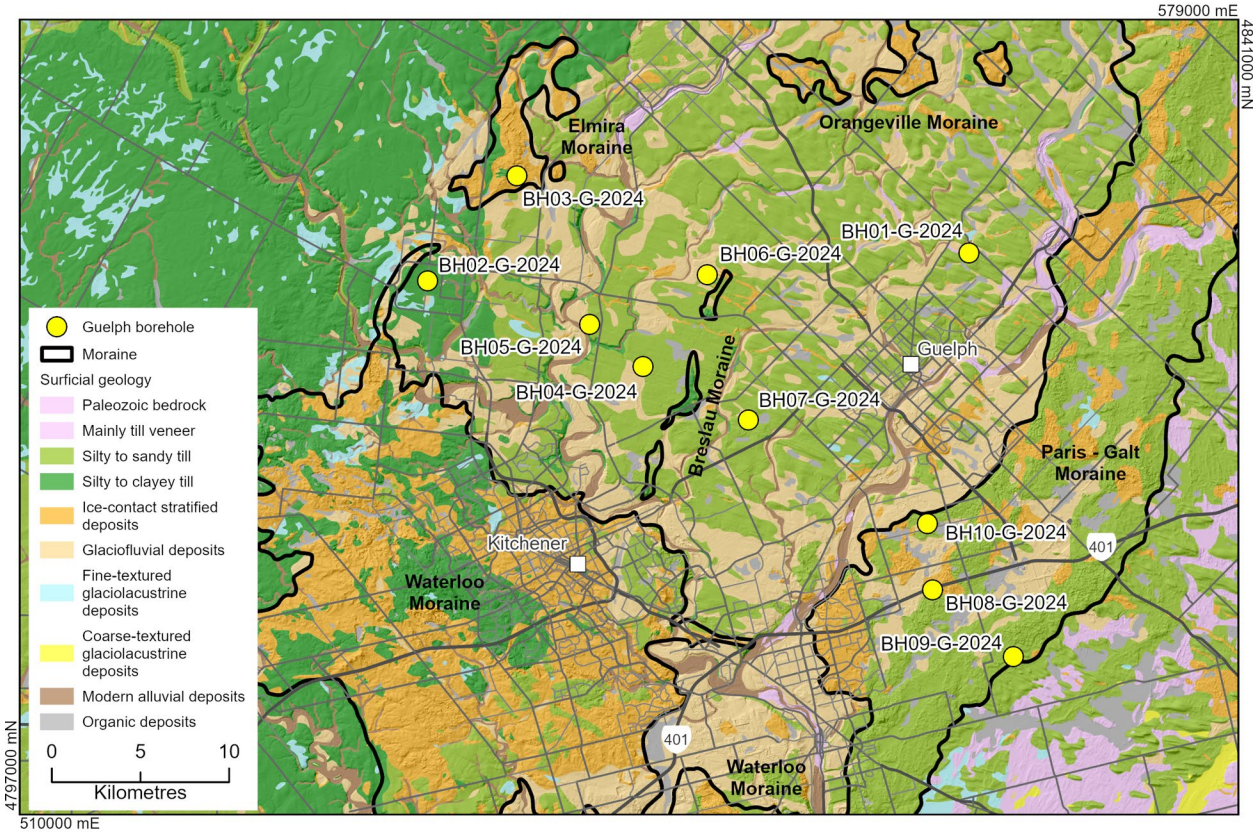


Figure 20.2. Surficial sediments mapped in the Guelph area (geology *from* Ontario Geological Survey 2010) overlain on a lidar-derived digital terrain model hillshade (Ministry of Natural Resources 2025). Moraines referred to in the text are outlined in black (*from* Ontario Geological Survey 2010). New boreholes drilled in the Guelph 3-D project area are shown as yellow-filled circles. Data are projected using North American Datum 1983 (NAD83) Universal Transverse Mercator (UTM) in Zone 17N.

PRELIMINARY RESULTS

Preliminary graphic borehole logs and lithologic correlations for boreholes drilled as part of the Guelph 3-D mapping project are presented in Figure 20.3. The graphic logs are grouped by geography and the surface landforms through which they were drilled: western Elmira Moraine area (boreholes BH02-G-2024 and BH03-G-2024); a central area characterized by mega-scale glacial lineations (boreholes BH05-G-2024, BH04-G-2024, BH07-G-2024 and BH06-G-2024) and drumlins (borehole BH01-G-2024); and eastern Paris–Galt Moraine area (boreholes BH10-G-2024, BH08-G-2024 and BH09-G-2024). Preliminary observations and interpretations are presented in the following sections. Note that only the PQ cored sediment and upper bedrock zones of boreholes BH01-G-2024 and BH10-G-2024 are described in this article.

Bedrock

The bedrock surface slopes south from the Algonquin Arch regional topographic high and west from the Niagara Escarpment cuesta. The upper part of the bedrock strata occurs as variably weathered, rubbly, fractured or competent rock and was reached in all boreholes, at depths consistent with regional mapping (Gao et al. 2006). A buried-bedrock valley approximately 20 to 25 m lower than the surrounding regional surface, informally referred to here as the Elmira buried-bedrock valley, was intersected in borehole BH02-G-2024. Salina Group shale, dolostone and evaporites are mapped in the western portion of the Guelph area, and Guelph Formation dolostone is mapped in the eastern and central portion of the area (Armstrong and Dodge 2007). However, the contact between the Salina Group and underlying Guelph Formation is modelled up to 6 km westward of the mapped extent in this area in the more recent 3-D Paleozoic bedrock models (Carter et al. 2019, 2021). Several boreholes were drilled in the zone between mapped and modelled rock extents, and some intersected shale-rich units suggesting there is potential for refining the contacts in the future. Probable Guelph Formation dolostone with stylolites, vuggy intervals, and open and sealed horizontal and vertical fractures was observed in the remaining boreholes.

Modification of the upper few metres of bedrock by groundwater and/or glacial ice varies across the area. In general, intersected dolostone units were more competent than shale units. Large boulders or slabs of locally derived dolostone were observed above competent bedrock at some locations (for example, borehole BH09-G-2024; Photo 20.1). These can be difficult to distinguish from bedrock unless the upper bedrock surface is glacially polished, as observed in borehole BH06-G-2004. Vertical and horizontal fractures are common and, in places, are filled with Quaternary stratified sediments. Borehole BH10-G-2024 is noteworthy as the uppermost fractures are filled with reddish clayey sediments often associated with older deposits (for example, Pre-last glacial maximum Canning equivalents; e.g., Burt 2018) and lower fractures were filled with more grey-brown sediments often associated with more recent deposits (*see* Photo 20.1). The preliminary interpretation is that sediments were injected into the upper fractures first, essentially plugging and sealing them, then, during more recent glaciations, meltwater and sediments were injected into lower fractures (*see* Photo 20.1). In other boreholes, the fractures remain open and oxygenated groundwater flow is suggested by orange iron staining adjacent to horizontal fractures, as observed in borehole BH04-G-2024 (*see* Photo 20.1). In contrast, some boreholes revealed a highly weathered bedrock surface with disaggregated intervals, referred to as local diamicton/weathered rock on Figure 20.3, which may be analogous to décollement surfaces attributed to low angle shear below sliding ice (Hall and van Boeckel 2024).

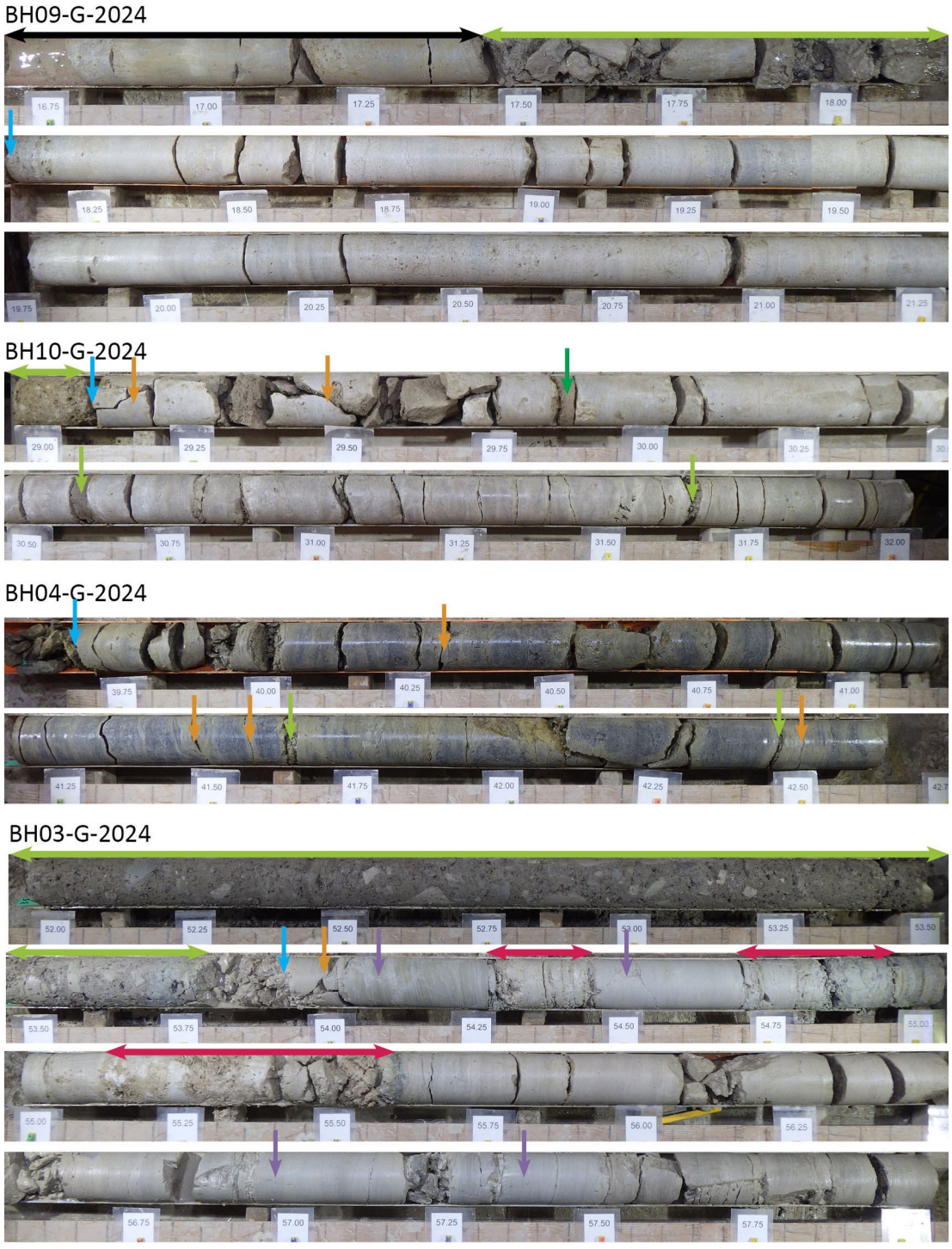


Photo 20.1. Examples of core from 4 boreholes in the Guelph area (*see* Figure 20.2 for borehole locations). Representative examples of features mentioned in the text include a large boulder or slab (black arrow), Quaternary sediments (older deposits (dark green arrow) and younger deposits (light green arrows)), bedrock surface (blue arrows), open fractures (orange arrows), closed fractures (purple arrows), possible décollement surfaces (burgundy arrows). The selected boreholes show a large boulder or slab overlying stony diamicton and competent bedrock (borehole BH09-G-2024), oxygenated groundwater flow suggested by staining in till overlying fractured bedrock (borehole BH10-G-2024) and adjacent to horizontal fractures (borehole BH04-G-2024), upper fractures plugged with older Quaternary sediments forcing later sediments into lower fractures (borehole BH10-G-2024) and the transition from regional to local Quaternary till, fractured bedrock and possible décollement surfaces (borehole BH03-G-2024).

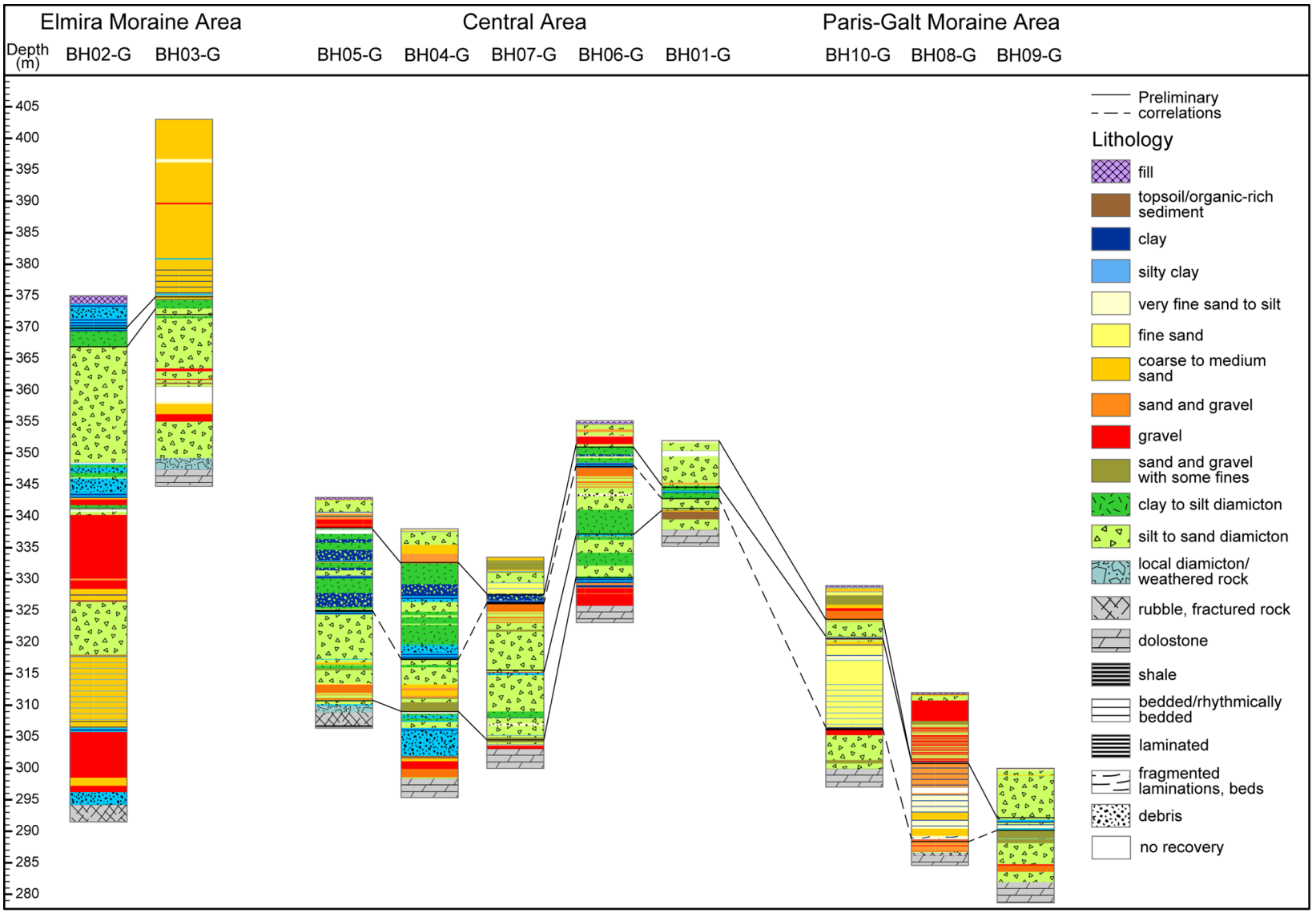


Figure 20.3. Preliminary graphic borehole logs for the Guelph 3-D project area boreholes drilled in 2024–2025. Solid and dashed black lines show preliminary lithologic unit correlations. Logs are shown in metres above sea level (m asl). The borehole names have been shortened because of space constraints; for example, borehole BH02-G-2024 is labelled as " BH02-G" on this figure.

Table 20.2. Comparison of the regional-scale hydrostratigraphic units mapped in 3-D within the Regional Municipality of Waterloo, Orangeville–Fergus and Niagara Peninsula 3-D project area (Bajc and Shirota 2007; Burt and Dodge 2016; Burt 2020). Units previously identified in Guelph 3-D area boreholes are also shown (Brunton and Burt 2024).

Relative Age	Hydrostratigraphic Unit	Regional Municipality of Waterloo	Orangeville–Fergus	Niagara Peninsula	Guelph Area
Younger	Regressive aquifer	—	—	AFA0	AFA0
	Whittlesey aquitard	ATA1	—	ATA1	ATA1
	Halton aquifer	—	—	AFR1	—
	Halton aquitard	—	—	ATR1	—
	Pre-Halton aquifer	—	—	AFR2	—
	Lower Whittlesey aquitard	—	—	ATR2	—
	Whittlesey/Wentworth aquifer	AFA1	AFA1	AFA1	—
	Wentworth aquitard	ATA2	ATA2	ATA2	ATA2
	Caledon–Grand River Outwash aquifer	AFA2	AFA2	AFA2	—
	Grand River aquitard	ATA3	—	—	—
	Upper till/Port Bruce phase aquitard	ATB1	ATB1	ATB1	ATB1
	Upper Waterloo/Orangeville moraine aquifer	AFB1	AFB1	—	—
	Upper Maryhill drift/Erie Phase aquitard	ATB2	—	—	—
to	Middle Waterloo Moraine/Erie Phase aquifer	AFB2	—	—	—
	Lower Maryhill drift/Erie Phase aquitard	ATB3	ATB3	ATB3	ATB3
	Lower Waterloo/Orangeville moraine/ Erie Phase aquifer	AFB3	AFB3	AFB3	—
	Upper Catfish Creek Till aquitard	ATC1	ATC1	ATC1	ATC1
	Catfish Creek aquifer	AFC1	AFC1	—	—
	Lower Catfish Creek Till aquitard	ATC2	ATC2	—	—
	Pre-Catfish Creek Till aquifer	AFD1	AFD1	AFD1	AFD1
	Pre-Catfish Creek Till aquitard	—	—	ATD1	—
	Lower Pre-Catfish Creek Till aquifer	—	—	AFD2	—
	Canning aquitard	ATE1	ATE1	ATE1	—
	Pre-Canning aquifer	AFF1	AFF1	AFF1	AFF1
Older	Pre-Canning aquitard	ATG1	ATG1	—	ATG1
	Contact aquifer	—	AFH1	—	—
Oldest	Bedrock	BR	BR	BR	BR

Elmira Moraine Area

The thickest sediments drilled during this program are associated with the Elmira buried-bedrock valley (borehole BH02-G-2024) and the Elmira Moraine (borehole BH03-G-2024) located in the western part of the area (*see* Figure 20.3; *see* Table 20.1). Glaciolacustrine to lacustrine silt and clay, with debris derived either from overlying ice or from the valley walls, overlies bedrock within the buried valley. Gravel, interpreted as a glaciofluvial deposit with flow confined to the bedrock valley as observed in similar settings (Burt 2017), is tentatively correlated with hydrostratigraphic unit AFF1 (Pre-Canning aquifer) from adjacent 3-D model areas (Table 20.2 for all hydrostratigraphic correlations; Bajc and Shirota 2007; Burt 2018) and was screened in a Regional Municipality of Waterloo monitoring well. Muddy and thick rhythmically bedded sandy glaciolacustrine sediments with detrital plants remains, tentatively correlated with pre-Catfish Creek Till aquifer AFD1, complete the bedrock valley fill sequence.

Although not yet assigned to specific hydrostratigraphic units, sediments within the upper portion of borehole BH02-G-02024 and the lower portion of borehole BH03-G-2024 are likely correlative. Stony,

sandy to silty tills, possibly Catfish Creek Till, were observed at depth in both boreholes, overlain by thick (borehole BH02-G-2024) and thin (borehole BH03-G-2024) gravel interpreted as glaciofluvial deposits. Interbedded gravel, diamicton and muddy glaciolacustrine deposits with debris observed in borehole BH02-G-2024 suggest deposition in ice marginal and glaciolacustrine settings as the ice front fluctuated. Thick stony silty sandy till (possibly Upper till aquifer ATB1 Port Stanley Till) overlain with finer textured tills and finally muddy glaciolacustrine (borehole BH02-G-2024) and Elmira Moraine sandy subaquatic fan sediments (borehole BH03-G-2024) deposited as the ice retreated complete the observed succession.

Central Guelph Area

Boreholes in the central portion of the Guelph area are shallower, but still contain a complex record of long-term ice sheet fluctuations. Sand and gravel overlies bedrock in geographically related boreholes BH04-G-2024, BH07-G-2024 and BH06-G-2024 and are likely part of the same deposit. Borehole BH01-G-2024 intersected a stony diamicton on top of bedrock, and the gravel (glaciofluvial?) and diamicton may be part of the same event. Similarly, the thin, muddy and, in places, organic-rich (borehole BH01-G-2024) glaciolacustrine deposits observed in most boreholes in this area are also likely correlative and predate the last glacial maximum. Beds of diamicton and other debris within the glaciolacustrine deposits, overlain by diamicton, sand and gravel with interbedded fines records the readvance of ice across the area. Based on stratigraphic position, the overlying variably thin to thick, stony, silty sandy diamicton is tentatively identified as the last glacial maximum Catfish Creek Till (ATC1). Textural variations and intervals of stratified sediments within a predominantly silty sandy diamicton package were observed in this area, as well as adjacent 3-D project areas (Bajc and Shirota 2007; Burt and Dodge 2016; Burt 2018). The top of this package is marked by a dashed line on Figure 20.3.

Interbedded diamicton and sand in borehole BH07-G-2024 and muddy glaciolacustrine sediments interbedded with variably fine- and coarse-textured diamicton observed in all centrally located boreholes were likely deposited within an interlobate glacial lake formed as the regional last glacial maximum ice sheet broke up into distinct lobes flowing out of the Huron–Georgian Bay and Erie–Ontario lake basins. These deposits are thickest in the west, becoming thinner to the east, possibly reflecting a combination of duration of sediment deposition and available accommodation space related to the position of the retreating ice front. The subsequent re-advance of the Erie–Ontario ice lobe is recorded by deposition of a thin package of sand (eastern borehole) and gravel (western boreholes) overlain by silty to sandy diamicton tentatively identified as Port Stanley Till (Upper till aquitard ATB1). The stratified deposits overlying Catfish Creek Till are thicker and the surface diamicton (Port Stanley Till) is thinner in areas underlain by mega-scale glacial lineations—features that suggest a zone of relatively rapid ice flow (ice stream) compared to adjacent areas underlain by thinner stratified deposits and thicker surface diamicton within the Guelph drumlin field to the east (borehole BH01-G-2024). This is just one of many trends that will be explored as the project evolves.

Paris–Galt Moraine Area

The youngest sediments drilled as part of this study are from the Paris–Galt Moraine belt located in the eastern part of the area. A stony, silty sandy diamicton interbedded with thin gravel and sand overlying bedrock was observed in boreholes BH10-G-2024 and BH09-G-2024 and is tentatively identified as Catfish Creek Till (ATC1). As observed in central zone boreholes BH06-G-2024 and BH07-G-2024, gravel and gravel with fines overlying the till likely records break up and retreat of the ice (identified as Lower Erie Phase aquifer AFB3 deposits in adjacent 3-D model areas; Bajc and Shirota 2007; Burt and Dodge 2016). Upward, relatively thick beds of sand and silt with thin clayey laminations observed in boreholes BH10-G-2024 and BH08-G-2024 are interpretated as a subaquatic fan deposited in meltwater

ponded against the retreating ice margin. It is logical to identify this as is the same glacial lake interpreted from sediments overlying Catfish Creek Till within the central zone, despite occurring at a lower elevation. These sandy sediments were not observed in southeasternmost borehole BH09-G-2025; however, thin glaciolacustrine silts and clays may be contemporaneous deposits.

The upper portion of this cluster of boreholes is dominated by stony, silty sandy diamicton, coarse gravel, sand and gravel with some fines and interbedded gravel and diamicton. At first glance, it is tempting to lump these deposits into units representing a single depositional event; however, careful consideration of both the surrounding landforms and their relative position across the moraine belt suggests a more intricate story. Located at the most distal (western) position of the moraine belt and surrounded by subtle but long (over 2 km) northwest-trending streamlined bedforms draped with hummocky stratified deposits, the gravel over till observed in upper portion of borehole BH10-G-2024 is tentatively interpreted as ice-contact stratified deposits overlying Port Stanley Till (Upper till aquitard ATB1). Located to the southeast, borehole BH08-G-2024 was drilled within a hummocky portion of the moraine belt and the upper portion of the borehole is dominated by gravel interbedded with diamicton. These deposits are consistent with observations from other boreholes drilled in hummocky moraine settings (Burt and Dodge 2016; Arnaud et al. 2018). A thin bed of stony, silty sandy diamicton observed at the top of the borehole may be Wentworth Till (Wentworth aquitard ATA1). Borehole BH09-G-2024 was drilled in an ice-proximal position at the transition between hummocky moraine and the characteristically small northwest-trending (<1 km long and 30 m high) drumlins of the Wentworth drumlin field (Burt and Hagedorn 2022). Stony, silty sandy diamicton, tentatively identified as Wentworth Till (Wentworth aquitard ATA1), was observed in this borehole.

It is anticipated that laboratory grain size and carbonate content analysis and clast lithology counts will confirm these correlations and ice-flow directions. A data release comprising detailed borehole descriptions, graphic logs, analytical results and core photographs is planned as an interim product. This will be followed by a 3-D model of Quaternary sediments after further drilling is completed.

ACKNOWLEDGMENTS

The author would like to thank Six Nations of the Grand River and Mississaugas of the Credit First Nation for allowing the Ontario Geological Survey to map their traditional land-use area. The Chiefs and Councils are thanked for their interest and support of this project.

The expertise and professionalism of driller and lead technical advisor Don Grant (Aardvark Drilling Inc.), mud engineer John Tatarnic, and helper Nate made this project a success. Assistants S. Lilley and W. Grant and volunteer M. Burt sorted and prepared samples for laboratory submission. K.H. Yeung and J.E. Chartrand provided much needed technical support, J. Bonin drafted figures and R.P.M. Mulligan provided helpful comments on this summary report.

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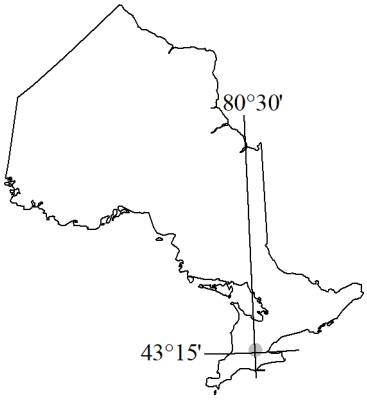
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21. Project SO-25-004. What's Under the Regional Municipality of Waterloo?



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INTRODUCTION

In 2007, the Ontario Geological Survey (OGS) released a three-dimensional (3-D) model of Quaternary sediments within the Regional Municipality of Waterloo (hereafter referred to as "the Region"; Bajc and Shirota 2007). Centred over the Late Wisconsin interlobate zone that extends southwest from the city of Orangeville toward London, this groundbreaking project established both the first regional-scale hydrostratigraphy of southwestern Ontario (Table 21.1) and 3-D modelling workflows at the OGS. High-quality, continuously cored boreholes were used to interpret geotechnical engineering and water well records and a total of 19 (18 sediment and 1 bedrock) hydrostratigraphic units were modelled. Several of these units form important producing aquifers for the Region's expanding population, and so understanding the stratigraphic context and characteristics of the sediments remains a priority.

A recent drilling and monitoring well installation program by the Region provided an opportunity for the OGS to obtain high-quality core that can provide contextual information for ongoing 3-D mapping projects and augment existing publicly available data sets. The program focussed on 2 sand and gravel aquifers in southwest Kitchener, Ontario. Following the hydrostratigraphy established by Bajc and Shirota (2007), these 2 aquifers are Pre-Catfish Creek Till coarse-textured glaciofluvial and glaciolacustrine sediments which underlie the regionally significant last glacial maximum Catfish Creek Till aquitard and middle Waterloo Moraine stratified sediments and equivalents (*see* Table 21.1: AFB2) deposited in an interlobate glacial lake as the ice thinned and retreated from its maximum position (*see* Table 21.1). Muddy glaciolacustrine sediments and fine-grained tills, referred to collectively as Maryhill Drift, were also deposited within the interlobate zone and are found under, within, and overlying sand and gravel moraine deposits.

FIELD ACTIVITIES

Three PQ (8.5 cm inner diameter) continuously cored mud-rotary boreholes, penetrating the Quaternary sediments and upper metre of bedrock, were drilled between December 2024 and March 2025 (Figures 21.1 and 21.2). The boreholes range from 54.25 to 101.96 m in depth, with a combined drill length of 240.03 m. The core was logged on site by consulting geoscientists, then wrapped and donated to the OGS. After coring was complete, the holes were converted into monitoring wells using 51 mm inside diameter threaded, flush-joint polyvinyl chloride (PVC) with 1.3 to 3.1 m long slotted screens.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.21-1 to 21-8.

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Table 21.1. Comparison of the hydrostratigraphic units in the Regional Municipality of Waterloo, Brantford–Woodstock and Orangeville–Fergus 3-D project area (Bajc and Shirota 2007; Bajc and Dodge 2011; Burt and Dodge 2016).

Relative Age	Hydrostratigraphic Unit	Regional Municipality of Waterloo	Brantford–Woodstock	Orangeville–Fergus
Younger	Regressive aquifer	—	AFA0	—
	Whittlesey aquitard	ATA1	ATA1	—
	Whittlesey/Wentworth aquifer	AFA1	AFA1	AFA1
	Wentworth aquitard	ATA2	ATA2	ATA2
	Caledon–Grand River Outwash aquifer	AFA2	AFA2	AFA2
	Grand River aquitard	ATA3	ATA3	—
	Upper till/Port Bruce phase aquitard	ATB1	ATB1	ATB1
	Upper Waterloo/Orangeville moraine aquifer	AFB1	AFB1	AFB1
	Upper Maryhill drift/Erie Phase aquitard	ATB2	ATB2	—
to	Middle Waterloo Moraine/Erie Phase aquifer	AFB2	AFB2	—
	Lower Maryhill drift/Erie Phase aquitard	ATB3	ATB3	ATB3
	Lower Waterloo/Orangeville moraine/Erie Phase aquifer	AFB3	AFB3	AFB3
	Upper Catfish Creek Till aquitard	ATC1	ATC1	ATC1
	Catfish Creek aquifer	AFC1	AFC1	AFC1
	Lower Catfish Creek Till aquitard	ATC2	ATC2	ATC2
	Pre-Catfish Creek Till aquifer	AFD1	AFD1	AFD1
	Canning aquitard	ATE1	ATE1	ATE1
	Pre-Canning aquifer	AFF1	AFF1	AFF1
Older	Pre-Canning aquitard	ATG1	ATG1	ATG1
	Contact aquifer	—	—	AFH1
Oldest	Bedrock	BR	BR	BR

During the summer of 2025, the stored core was logged in detail, photographed at 0.25 m increments and representative samples were taken from each major sediment interval. Samples were collected for particle size analysis (diamicton and stratified sediments), heavy mineral analysis (diamicton), carbonate content (diamicton and fine-textured stratified sediments) and clast lithology counts (diamicton and gravelly stratified sediments). The borehole locations, bedrock and borehole depths are listed in Table 21.2.

PRELIMINARY OBSERVATIONS

Preliminary graphic borehole logs and hydrostratigraphic correlations for boreholes BH01-W-2025 (ND-OW1-24-A, Stantec Consulting Ltd. 2025), BH02-W-2025 (K-MW-OW1-25-A, Stantec Consulting Ltd. 2025) and BH03-W-2025 (ND-OW1-25-A, Stantec Consulting Ltd. 2025) are presented in Figure 21.3. Hydrostratigraphic units modelled within the Region of Waterloo and adjacent Orangeville–Fergus and Brantford–Woodstock project areas are listed in Table 21.1. Missing intervals reflect surficial zones removed by hydro-excavation, missing core and drilling losses. Preliminary observations and interpretations are as follows:

- Salina Group shale bedrock was intersected in boreholes BH01-W-2025 and BH02-W-2025. Borehole BH03-W-2025 was terminated before reaching bedrock because of ground conditions. The core was frost shattered during storage and so it is not possible to determine if there are naturally occurring fractures that may host an interface aquifer.

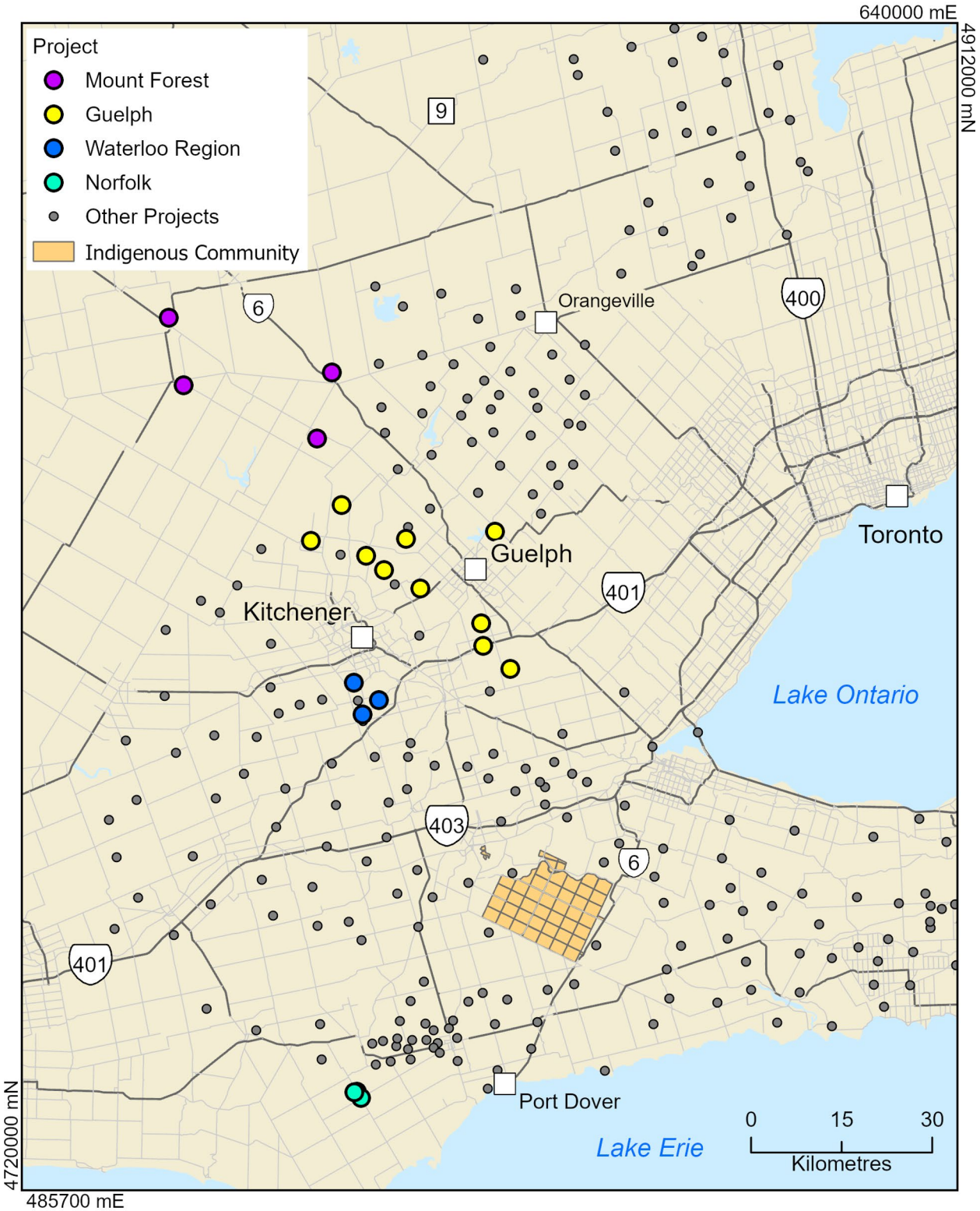


Figure 21.1. Locations of cored boreholes in southwestern Ontario. New boreholes drilled in the Region of Waterloo (this study) are shown as blue-filled circles. New boreholes drilled in the Mount Forest–Elmira project area (*see* Burt, Strynatka and Baxter, this volume, Article 19) are shown as purple-filled circles, in the Guelph 3-D project area (*see* Burt, this volume, Article 20) are shown as yellow-filled circles, and in Norfolk County (*see* Burt, this volume, Article 22) are shown as teal-filled circles.

- Approximately 20 m of variably coarse- and fine-textured tills—grouped into 2 packages separated by fine sand, silt and clay glaciolacustrine sediments, and collectively referred to as older deposits (*see* Figure 21.3)—were observed in borehole BH02-W-2025. These deposits likely encompass hydrostratigraphic units ATG1 Pre-Canning aquitard coarse-textured till overlying bedrock and ATE1 Canning aquitard till and associated fine-textured glaciolacustrine sediments (Bajc and Shirota 2007; Burt and Dodge 2016). In borehole BH01-W-2025, the older deposits are only 6 m thick and are characterized by coarse-textured till with beds of sand and gravel (ATG1) overlain by a thin package of fine sand, silt and clay glaciolacustrine sediments (ATE1).

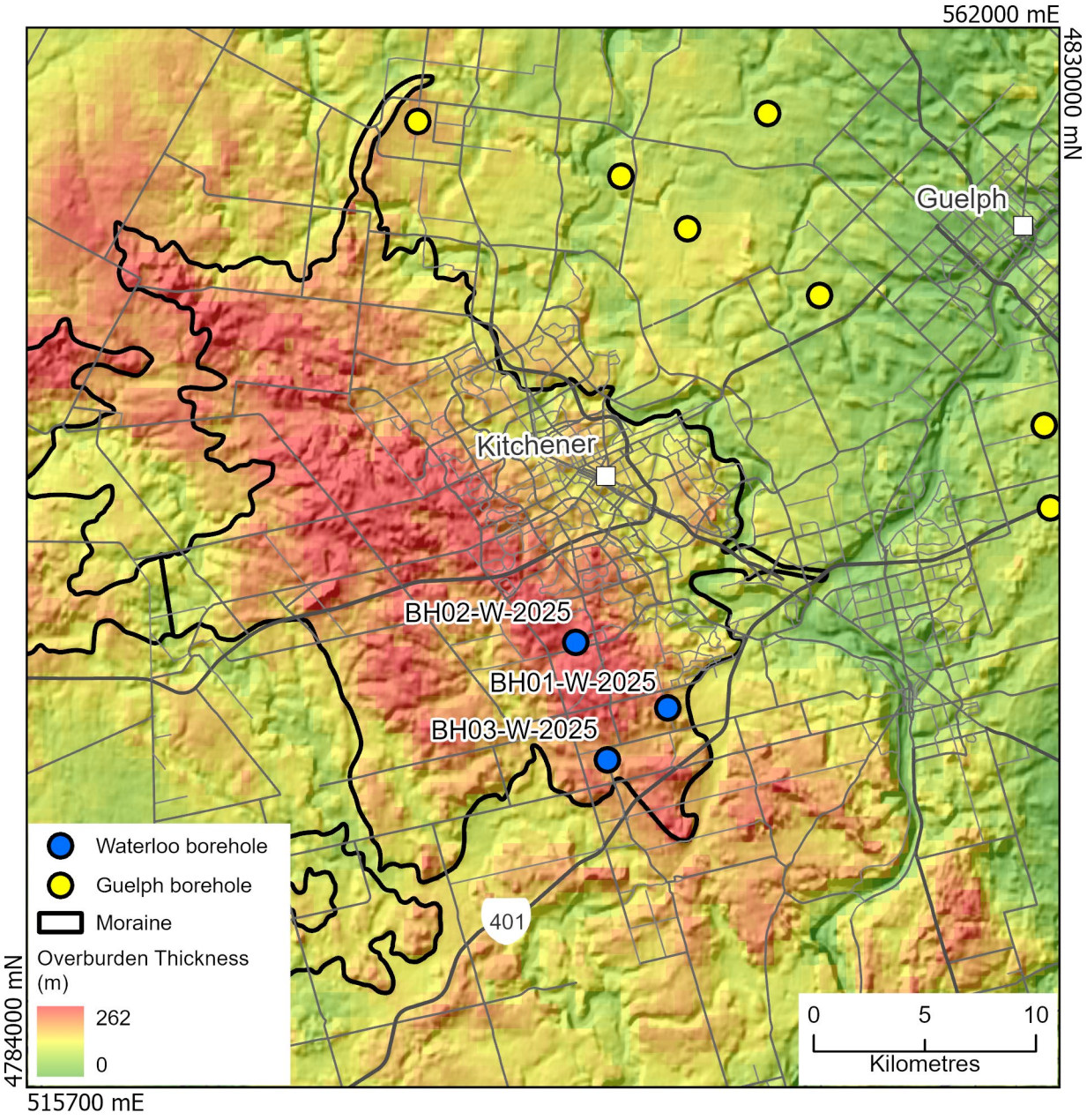


Figure 21.2. High-resolution lidar-derived digital terrain model draped over a hillshade revealing a hummocky topographic high (red) corresponding with the interlobate Waterloo Moraine (Ministry of Natural Resources 2025). The approximate boundary of the moraine is outlined (geology *from* Ontario Geological Survey 2010). New boreholes drilled in the Region of Waterloo (this study) are shown as blue-filled circles and in the Guelph 3-D project area (*see* Burt, this volume, Article 20) are shown as yellow-filled circles. Data are projected using North American Datum 1983 (NAD83) Universal Transverse Mercator (UTM) in Zone 17N.

Table 21.2. Borehole and well identification numbers, location, depth to bedrock and depth of hole.

OGS Borehole ID	Consultant Well ID	Easting[1] (m)	Northing[1] (m)	Surface Elevation (m asl)	Depth to Competent Bedrock (m)	Depth of Hole (m)
BH01-W-2025	ND-OW1-24-A	544605	4800511	334.25	82.15	83.82
BH02-W-2025	K-MW-OW1-25-A	540460	4803455	348.71	101.65	101.96
BH03-W-2025	ND-OW1-25-A	541897	4798161	318.59	—	54.25

[1]*Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 17.*

- In borehole BH02-W-2025, the glaciolacustrine sediments coarsen upward into rhythmically bedded sands and silts overlain by coarser sand and gravel. This coarse-textured sediment package is approximately 18 m thick and is identified as hydrostratigraphic unit AFD1 Pre-Catfish Creek Till aquifer consisting of coarse-textured glaciofluvial and glaciolacustrine deposits. This package was also observed in boreholes BH01-W-2025 and BH03-W-2025, the latter of which is dominated by thick beds of coarse gravel and cobbles. Hydrostratigraphic unit AFD1 is a producing aquifer for the Region and this interval was screened in all 3 boreholes.
- In all 3 boreholes, aquifer AFD1 is overlain by stony sandy silt till with thin sand beds. This is identified as Catfish Creek Till deposited by southwest-flowing ice during the last glacial maximum. The till is a regional marker bed and has been modelled as hydrostratigraphic unit ATC1 Catfish Creek Till aquitard in the Waterloo Region, Orangeville–Fergus and Brantford–Woodstock 3D mapping project areas.
- The upper portion of all 3 boreholes is dominated by thick gravels with beds of sand and gravelly sand. In boreholes BH01-W-2025 and BH02-W-2025, 7 to 8 m of fine-textured glaciolacustrine sediments, including laminated silt and clay, and rhythmically bedded fine sand and silts were observed. These deposits encompass hydrostratigraphic units AFB1 Upper Waterloo Moraine aquifer, ATB2 Upper Maryhill drift aquitard, AFB2 Middle Waterloo Moraine aquifer, ATB3 Lower Maryhill Drift aquitard and AFB3 Lower Waterloo Moraine aquifer. The coarse- and fine-textured packages observed in the core have not yet been assigned to these units.
- Hydraulic conductivity testing and water quality sampling of each of the monitoring wells occurred in early 2025. Hydraulic conductivities ranged from 2×10^{-5} to 2×10^{-4} m/s. These measured hydraulic conductivities are lower than expected given the observations during drilling, both by the drilling contractor and by the Region, based on material recovered in the PQ core. In comparison to literature values, these measured hydraulic conductivities are within the lower range for well-sorted sand or gravel-rich glacial outwash of 1×10^{-5} m/s to 1×10^{-3} m/s (Fetter 1994) and mid-range for sand deposits of 1×10^{-6} m/s to 1×10^{-2} m/s (Freeze and Cherry 1979). The measured hydraulic conductivities may be an indicator that the formation has a higher proportion of sandy matrix and/or a less well sorted matrix than anticipated from the PQ coring. The water quality analyses included those for general chemistry, nutrients and metals. Results were compared against the Ontario drinking water quality standards (ODWS), and no exceedances were found of the maximum acceptable concentration (MAC). The Region is undergoing further drilling and investigative work at BH02-W-2025 (K-MW-OW1-25-A) and BH03-W-2025 (ND-OW1-25-A) as part of a larger groundwater exploration project.

It is anticipated that laboratory data on grain size, carbonate content and clast lithology will refine these correlations and provide information for inferring ice-flow directions. For example, observations from cored boreholes in the adjacent Orangeville–Fergus 3-D study area have shown that Catfish Creek Till typically has a higher proportion of clasts from Precambrian bedrock compared to other tills (Burt and Dodge 2016). A visual comparison of clasts lithologies from some units in borehole BH02-W-2025 indicates considerable downhole variability and this may help resolve till provenance and, hence, ice-flow directions (Photo 21.1). A data release comprising detailed borehole descriptions, graphic logs, analytical results and core photographs is planned.

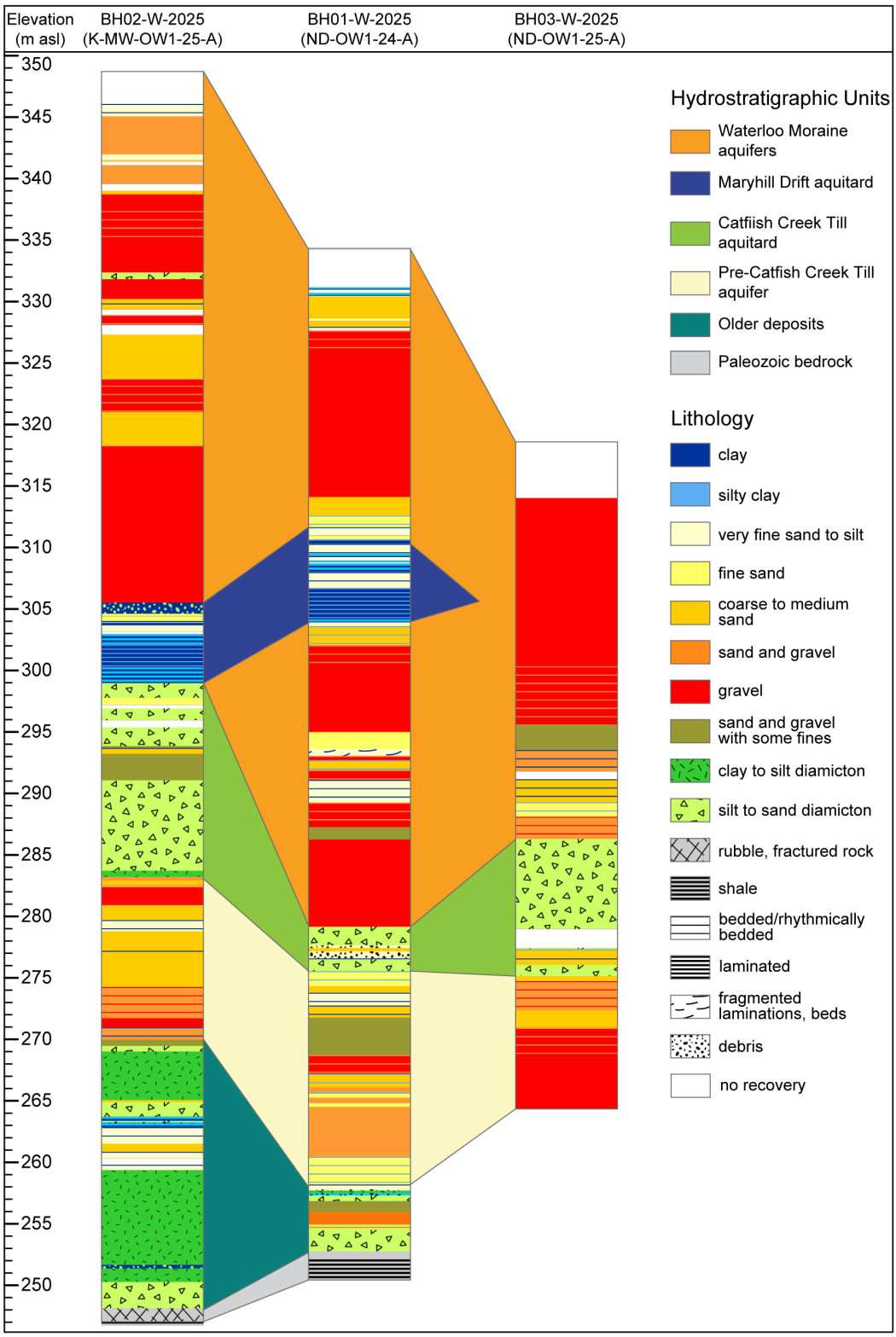


Figure 21.3. Preliminary graphic borehole logs and tentative correlations for Region of Waterloo boreholes drilled in 2024 and 2025. Logs are shown in metres above sea level (m asl). Hydrostratigraphic units correspond with regional-scale 3-D model layers from the Region of Waterloo (Bajc and Shirota 2007) and adjacent Orangeville–Fergus (Burt and Dodge 2016) project areas. Standard hydrostratigraphy and lithology legends have been used in articles presenting preliminary borehole information (*see* this volume, Articles 19 to 22). Note that both OGS borehole and Region of Waterloo monitoring well names are shown.

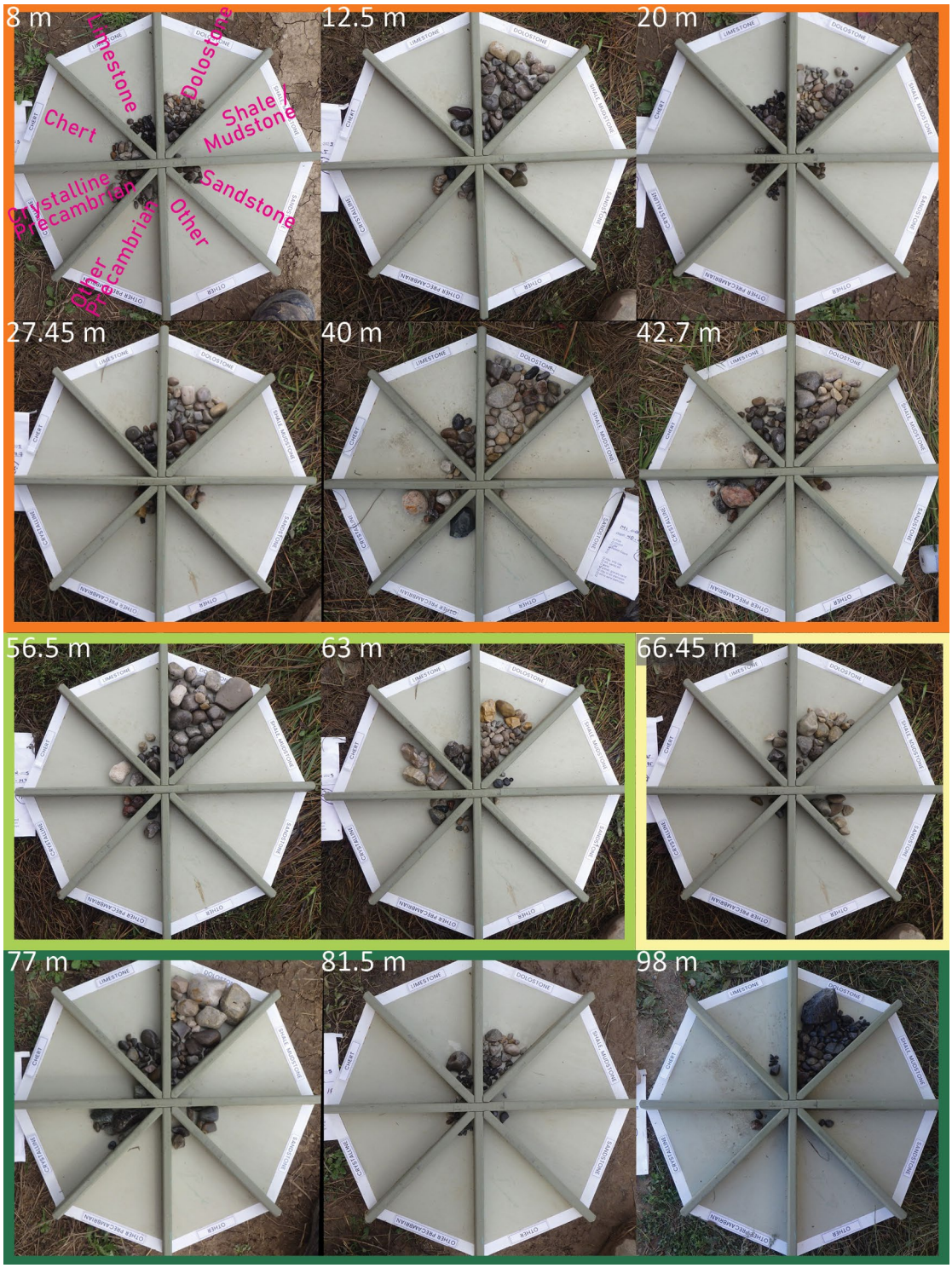


Photo 21.1. Examples of downhole variations in clast lithology for borehole BH02-W-2025. Samples from the Waterloo Moraine aquifer (first 2 rows) are outlined in orange, the Catfish Creek Till aquitard (left and middle in second last row) are outlined in light green, the Pre-Catfish Creek Till aquifer (on right in second last row) are outlined in yellow and older deposits (last row) are outlined in dark green. Sorted clasts are displayed in separate octants; in the top left image, clockwise from the top, these are labelled as 1) dolostone, 2) shale to mudstone, 3) sandstone, 4) other, 5) other Precambrian, 6) crystalline Precambrian, 7) chert and 8) limestone. For example, note the change in older deposit dolostone clasts from light and dark to dark colours with depth, reflecting different source formations and the sharp decrease in limestone clasts. This information may help refine interpreted ice-flow directions. Clasts greater than 2 mm were counted and measurements refer to depth (metres) below ground surface.

ACKNOWLEDGMENTS

The authors thank L. Veale and the Stantec hydrogeological team (Stantec Consulting Ltd.) for facilitating the transfer of core to the OGS and providing insight and clarification on hydrostratigraphic correlations. Eric Brown and his team (Aardvark Drilling Inc.) are thanked for working diligently throughout a difficult winter drilling program. Assistants S. Lilley and W. Grant and volunteer M. Burt assisted with transporting, sorting and logging core, preparing samples, and providing administrative support. P. Murray shared her rock identification expertise and helped wade through dozens of pebble counts. J. Bonin drafted figures and C. Gao provided helpful comments on this article.

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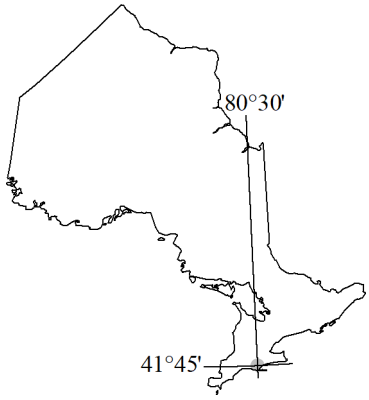
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22. Project SO-25-003. Collaborative Core Logging in Norfolk County



A.K. Burt[1]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey

INTRODUCTION

Older abandoned gas wells have been linked to high concentrations of naturally occurring methane and sulphur in groundwater in parts of southwestern Ontario and beyond (Colgrove and Hamilton 2018; Hamilton 2021). Gas escaping the rock portion of these wells can accumulate in groundwater within confined overburden aquifers and, if the aquifers are under pressure, methane- and sulphur-rich water may discharge at surface. Thick packages of coarse- and fine-grained sediments resulting from a complex late glacial history of ice advance and retreat means that groundwater can migrate laterally for considerable distances before discharging. If metal well casings are no long present because of corrosion or the abandonment practices of the time, locating and plugging the rock portion of the well can be problematic.

In 2025, a series of 6 cored boreholes were drilled by Montrose Environmental Solutions Canada Inc. acting for Norfolk County to investigate the Quaternary stratigraphy at a site along Big Creek Valley in Norfolk County where there is artesian flow of methane- and sulphur-rich water to surface (Figures 22.1 and 22.2). The boreholes were then converted to monitoring wells equipped with pressure transducers and these, along with 7 micro-piezometers, will provide information required to update numerical groundwater flow models. Cores from 3 boreholes drilled to bedrock were retained and donated to the Ontario Geological Survey (OGS) for detailed logging and sampling.

REGIONAL SETTING

Norfolk County is underlain by southwest-dipping Silurian and Devonian bedrock formations. The Upper Silurian Salina Group consisting of calcareous shale, dolostone and evaporites occurs north of the Onondaga Escarpment in the northern part of the county (Armstrong and Dodge 2007). The Onondaga Escarpment, with a local relief of 15 to 20 m, is formed by Upper Silurian Bertie–Bass Islands and Lower Devonian Bois Blanc formations consisting of dolostone and cherty limestone, respectively. Bituminous, bioclastic and fossiliferous dolostone and limestone of the overlying Amherstburg Formation, cherty fossiliferous Onondaga Formation and laminated dolostone and limestone of the Lucas Formation subcrop south of the escarpment. The Dundee Formation, consisting of a locally cherty, fossiliferous limestone with bituminous partings and oil staining, is found across the central portion of the county, whereas the Marcellus Formation shale, the youngest bedrock in the area, subcrops along Lake Erie in the far south (Armstrong and Dodge 2007).

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.22-1 to 22-7.

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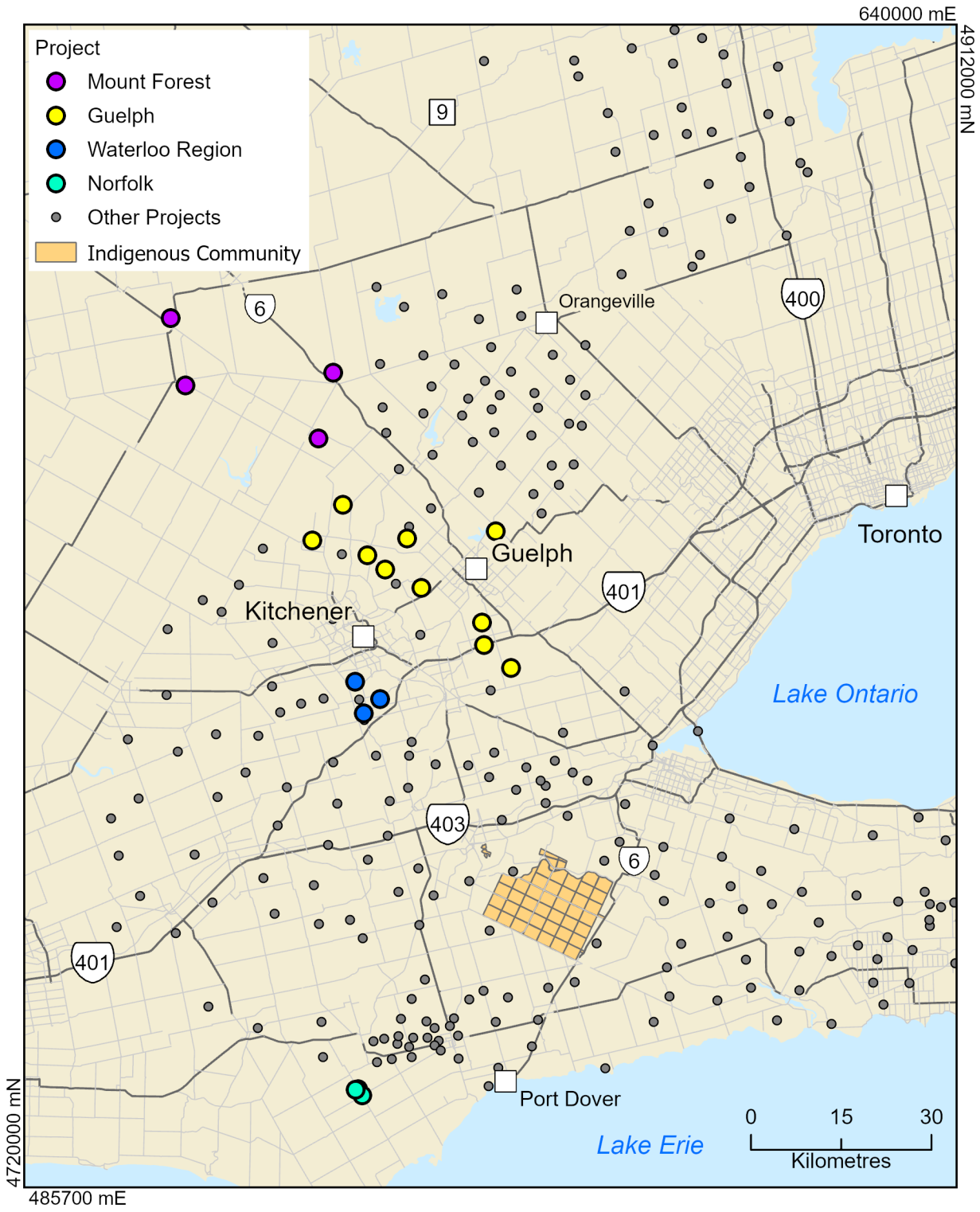


Figure 22.1. Locations of cored boreholes in southwestern Ontario. New boreholes drilled in Norfolk County (this study) are shown as teal-filled circles. New boreholes drilled in the Mount Forest–Elmira project area (*see* Burt, Strynatka and Baxter, this volume, Article 19) are shown as purple-filled circles, in the Guelph 3-D project area (*see* Burt, this volume, Article 20) are shown as yellow-filled circles, and in the Region of Waterloo (*see* Burt and McKie, this volume, Article 21) are shown as blue-filled circles.

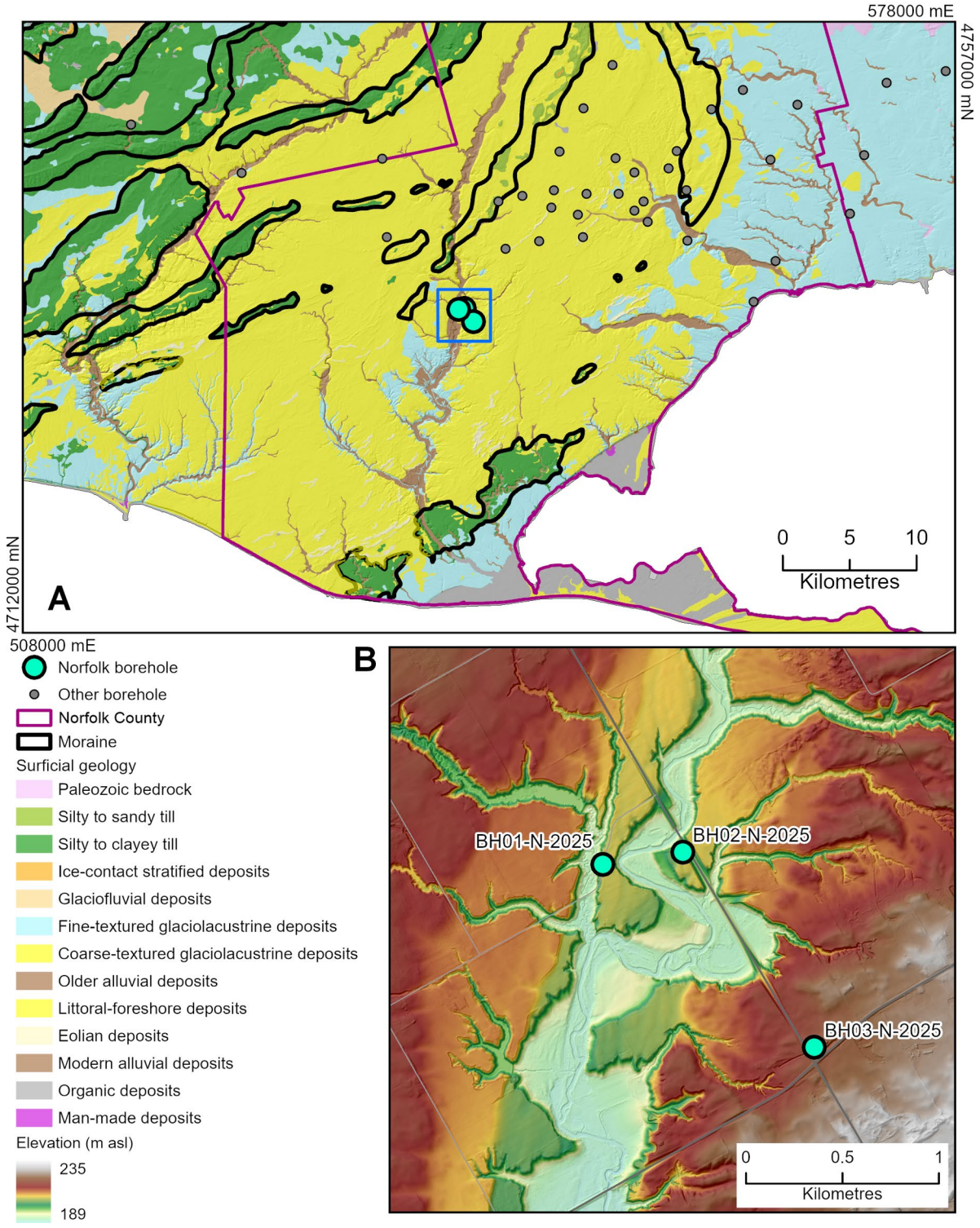


Figure 22.2. A) Study site and surficial geology of Norfolk County and surrounding area. The surficial geology map (*from* Ontario Geological Survey 2010) overlies a lidar-derived digital terrain model hillshade (Ministry of Natural Resources 2025). Till-cored end moraines are outlined in black. New boreholes described in this article are shown as teal-filled circles. Boxed area is enlarged in B. **B)** High-resolution lidar-derived digital terrain model draped over a hillshade highlighting a broad shallow channel roughly outlined by orange to yellow and a series of progressively lower terraces (light and dark green) developed through river incision as lake levels dropped (Ministry of Natural Resources 2025). Data are projected using North American Datum 1983 (NAD83) Universal Transverse Mercator (UTM) in Zone 17N.

Table 22.1. Borehole and well identification numbers, location, depth to bedrock and depth of hole.

OGS Borehole ID	Consultant Well ID	Easting[1] (m)	Northing[1] (m)	Surface Elevation (m asl)	Depth to Competent Bedrock (m)	Depth of Hole (m)
BH01-N-2025	MW25-01D	540520	4735711	206	42.6	43.6
BH02-N-2025	MW25-02D	540935	4735776	207	42.4	43.6
BH03-N-2025	MW25-03D	541618	4734763	221	53.73	55.8

[1]*Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 17.*

The Quaternary sediment cover in Norfolk County is thickest in the south, approaching 100 m thick in some locations, and thins northward pinching out along the Onondaga Escarpment. Previous drilling in central Norfolk County and eastward across the Niagara Peninsula (Burt 2020; Marich 2014) indicates last glacial maximum silty to sandy Catfish Creek Till, often observed overlying bedrock, is the oldest Quaternary deposit reported in the area. During retreat, ice blocked drainage routes and meltwater ponded within the Lake Erie basin allowing deposition of sandy and muddy glaciolacustrine sediments which dominate the Quaternary sediment cover and form both confined and unconfined aquifers (Burt 2020). Late glacial readvances of the Erie–Ontario ice lobe deposited older muddy Port Stanley Till in the west and younger muddy to sandy Wentworth Till in the southern and eastern portions of the county (Ontario Geological Survey 2010). These tills are exposed along a series of generally southwest-trending end moraines (*see* Figure 22.2A) and have been observed at depth in boreholes between the moraines (Bajc and Dodge 2011; Marich 2014). Glaciolacustrine silt and sand dominates the surficial geology across the county with some muddy deposits at exposures at lower elevations near Lake Erie and along creeks and rivers. High-resolution digital elevation models reveal an early river system consisting of a succession of broad shallow channels cutting across the landscape, which transitioned to more deeply incised meandering streams as glacial lake levels dropped (*see* Figure 22.2B). The current study site straddles one of these incised streams (*see* Figure 22.2).

FIELD ACTIVITIES

A series of 3 rotosonic cores penetrating the Quaternary sediment cover and upper few metres of bedrock were drilled to further characterize the Quaternary deposits and subsurface hydrostratigraphic units during the winter of 2025 (*see* Figure 22.2; Montrose Environmental Solutions Canada Inc. 2025). The boreholes range from 43.6 to 55.8 m in depth, and have a combined drill length of 143 m. The core was logged and sampled in the field prior to being wrapped and donated to the OGS for detailed investigation. During the summer of 2025, the stored core was relogged, photographed at 0.25 m increments and representative samples were taken from each major sediment interval. Samples were collected for particle size analysis (diamicton and stratified sediments), heavy mineral analysis (diamicton), carbonate content (diamicton and fine-textured stratified sediments) and clast lithology counts (diamicton and gravelly stratified sediments). The borehole locations, bedrock and borehole depths are listed in Table 22.1. Descriptions of the drilling program, monitoring well installation and groundwater sampling are available in the publicly accessible consultant report (Montrose Environmental Solutions Canada Inc. 2025).

PRELIMINARY RESULTS

Preliminary graphic borehole logs and tentative hydrostratigraphic correlations for boreholes BH01-N-2025 (Montrose Environmental Solutions Inc. monitoring well MW25-01D), BH02-N-2025 (Montrose Environmental Solutions Inc. monitoring well MW25-02D) and BH03-N-2025 (Montrose Environmental Solutions Inc. monitoring well MW25-03D) are presented in Figure 22.3. Missing intervals in the core logs reflect both drilling losses and previous sampling. Although confirming in general the work by Montrose Environmental Solutions Canada Inc. (2025), the detailed logging of the

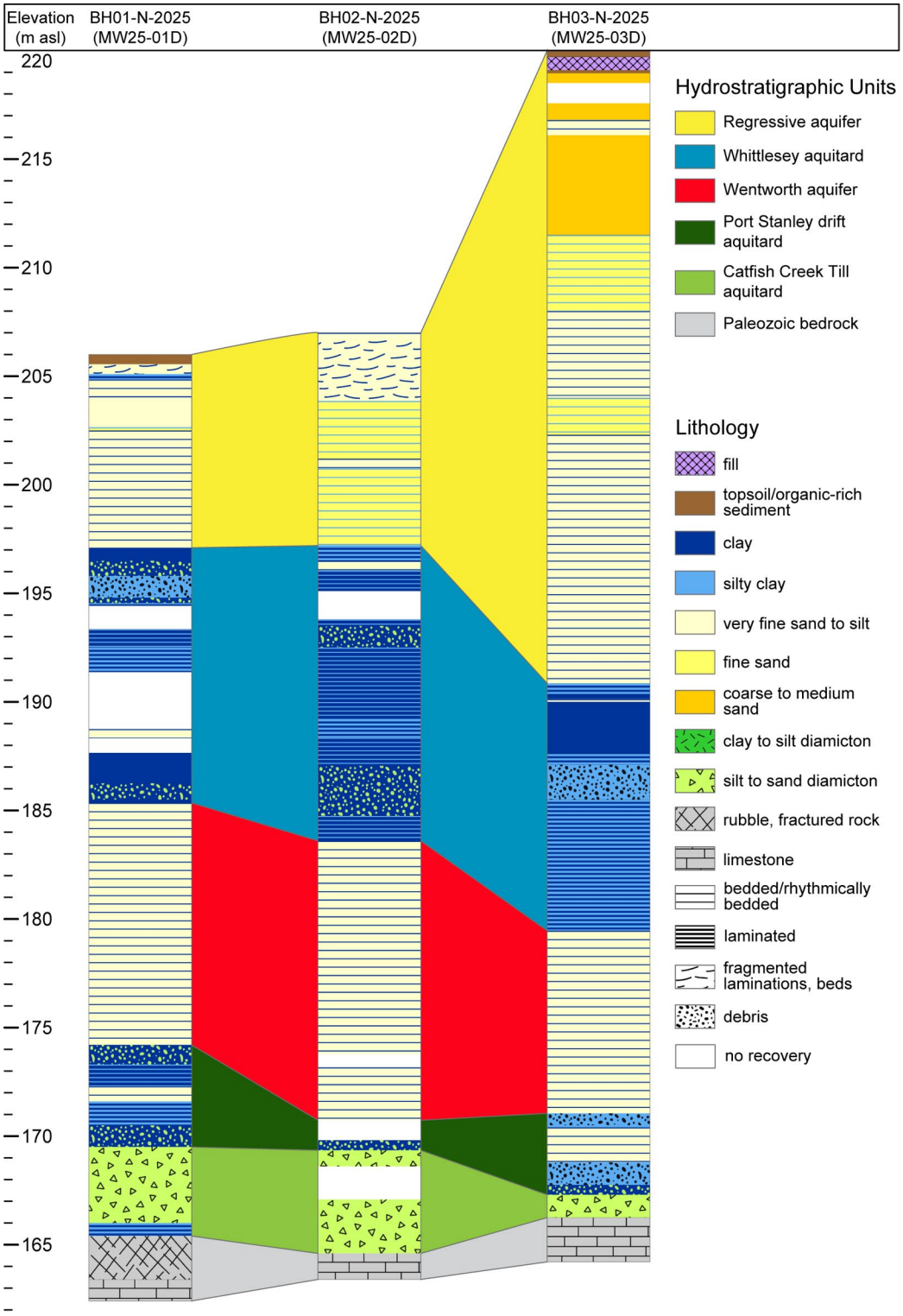


Figure 22.3. Preliminary graphic borehole logs and tentative correlations for Norfolk County boreholes drilled in 2025. Logs are shown in metres above sea level (m asl). Hydrostratigraphic units correspond with regional-scale 3-D model layers from the adjacent Brantford–Woodstock (Bajc and Dodge 2011) and Niagara Peninsula (Burt 2020) project areas. Unit depths are approximate as the drilling method resulted in "stretching" of clayey intervals so that a 10-foot drilled interval resulted in up to 15 feet of core. A standard hydrostratigraphy and lithology legend has been used in articles presenting preliminary borehole information (*see* this volume, Articles 19 to 22). Note that both OGS borehole (BH) and consultant monitoring well names (MW25) are shown.

cores has refined the previous observations. It should be noted that many of the cores were partially dried out and this revealed additional sedimentary structures. Early observations are as follows:

- Bedrock was intersected at depths generally consistent with provincial-scale sediment thickness and bedrock topography mapping (Gao et al. 2006). Cherty, fossiliferous limestone with a strong hydrocarbon odour, consistent with the Dundee Formation, was intersected in all 3 boreholes.
- Laminated clay-rich glaciolacustrine sediments were observed overlying bedrock in BH01-N-2025, which may reflect deposition in a glacial lake formed as advancing ice blocked drainage. These sediments have been grouped with overlying tills into the Catfish Creek Till aquitard.
- Up to 5 m of stony, silty to sandy Catfish Creek Till was observed overlying bedrock (BH02-N-2025 and BH03-N-2025) and older glaciolacustrine sediments (BH01-N-2025) and likely confines groundwater at the overburden–bedrock interface.
- Typically laminated to thinly bedded, silt- and clay-rich sediments, with some beds of ice-rafted debris including characteristically fine gravel clasts and intervals with diamicton, overlying the Catfish Creek Till aquitard, reflect deposition in a glacial lake and are correlated with the Port Stanley drift aquitard (Burt 2020; Marich 2014).
- A thick package of rhythmically bedded very fine sand to silt and laminated to thinly bedded clay reflects deposition in a glaciolacustrine setting with relatively high sediment loads. This package is correlated to the Wentworth aquifer mapped in adjacent 3-D model areas (Bajc and Dodge 2011; Burt 2020).
- Higher water levels and lower sediment loads are recorded in a thick package of laminated silt and clay, laminated clay, and silty clay to clay with no apparent structure. In boreholes BH01-N-2025 and BH02-N-2025, there are 2 distinct intervals with ice-rafted debris. The debris may be related to minor fluctuations along the margin of Erie–Ontario ice lobe and is tentatively correlated with Wentworth Till and/or Halton Till mapped in moraines and observed in boreholes to the east (Burt 2020).
- The uppermost regressive aquifer hydrostratigraphic unit includes glaciolacustrine rhythmically bedded fine sand and very fine sand to silt and laminated to very thinly bedded clay, which was observed in all 3 boreholes. In borehole BH03-N-2025, this fine sand with silty clay laminations coarsens upward into medium to coarse sand package. This coarser sand was likely eroded during incision of Big Creek and, therefore, it is missing from BH01-N-2025 and BH02-N-2025.

It is anticipated that laboratory data on grain size, carbonate content and clast lithology will refine these correlations and provide information for inferring ice-flow directions. A digital data release comprising detailed borehole descriptions, graphic logs, analytical results and core photographs is planned.

ACKNOWLEDGMENTS

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Geoscience Laboratories

23. Analysis of Halogens by Ion-Selective Electrode and Wavelength Dispersive X-ray Fluorescence at the Geoscience Laboratories



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INTRODUCTION

Fluorine- and chlorine-bearing hydrothermal fluids are commonly invoked in ore deposit formation to explain mobilization of elements, particularly those considered generally immobile (e.g., high-field strength elements (HFSE), rare earth elements (REE) and platinum group elements (PGE); Pan and Fleet 1996; Castillo 2022; Payne, Gysi and Hurtig 2023; Mountain and Wood 1988). This has been demonstrated through mineralogical and experimental studies correlating higher fluorine and chlorine concentrations with greater element mobility (Liu et al. 2024). However, whole rock geochemical data for fluorine and chlorine are generally lacking in ore deposit research.

To assist in the generation of geochemical data for fluorine and chlorine in mineralized systems, methods for the analysis of fluorine and/or chlorine have been set up at the Geoscience Laboratories ("Geo Labs"), using either a sodium carbonate fusion (method code SOL-FDI) followed by solution analysis by ion-selective electrode (method code ISE-R01) or wavelength dispersive X-ray fluorescence (XRF) on pressed powder pellets (method codes XRF-W01 and XRF-WAX). Whereas the ion selective electrode method is highly sensitive and able to provide accurate and precise data for fluorine concentrations as low as 100 ppm F, because of adverse reactions during the carbonate fusion procedure, its application has historically been limited to sulphide-poor samples (total sulphide sulphur contents <0.5 weight %). In contrast, although possibly less precise at low concentrations, the XRF-W01 method should be less affected by sample matrix and better able to tolerate the presence of sulphides. The provision of halogen data by alternate methods allows for analyses in a variety of ore-bearing matrices, permitting a greater understanding of how ore deposits form and the role of fluorine and chlorine in mobilizing critical elements.

BACKGROUND

Ion-Selective Electrode Analyses

The ISE-R01 method at the Geo Labs was initially developed in 2008 for the determination of total chlorine and fluorine in geological materials following a sodium carbonate fusion (method code SOL-FDI). For this method, 0.5 g of sample material is fused with 2 g of sodium carbonate flux at 900°C, the cooled samples dissolved in deionized water, and the solutions transferred to a centrifuge tube for analysis using a Mandel PC-Titrate Automated Analyzer. Solutions are introduced to the instrument at

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a 1:1 ratio with a total ionic strength adjustment buffer (TISAB) to reduce any interfering ions and a 10% w/v citric acid solution is added in small increments with constant stirring to achieve a pH between 5.5 and 6.5. The halide content of the solution is then measured using ion-selective electrodes (ISE) immersed in the sample solution and the total halide concentrations calculated based on external calibrations.

The ability of the ISE-R01 method to analyze for fluorine in mineralized systems is limited by its low tolerance for sulphides as a result of their chemical incompatibility with the sodium carbonate flux. Samples that contain even low sulphide concentrations (≥0.5 weight % sulphide sulphur) can react violently during the high-temperature fusion, posing a health and safety risk, so are unsuitable for the sample preparation method.

As a result of the aggressive nature of the solution matrix, the sensing membrane of chloride electrodes are commonly found to rapidly degrade during analyses of the fused samples, impacting their performance. Until 2016, consistent and reliable results were achievable with the specific robust model that was in use. However, following a change in manufacturer, replacement electrodes obtained after this date failed within a few sample analyses and no other electrodes available at the time were found to be sufficiently robust for the analysis. In 2017, the analysis for total chlorine was therefore removed from the ISE-R01 method, leaving fluorine as the only analyte.

Following the observation of discrepancies in the data obtained for routine quality-control materials in 2022 and with the increase in the potential analysis of high total fluorine contents associated with fluorite mineralization, between 2023 and 2025, the ISE-R01 method was re-evaluated to determine the effect of sample mineralogy and/or analytical conditions on fluorine recovery, to confirm the theoretical upper reporting limit of 11 weight % F that was established during the 2014 method validation, and to determine whether and how higher concentrations might be reportable, in particular, in fluorite-mineralized samples. This article summarizes the results of the re-evaluation and presents revised working limits for the method.

X-ray Fluorescence Analyses

In 2016, in response to the failure of the ISE-R01 method to obtain chlorine data on submitted samples, the Geo Labs initiated the creation of a halogen application (method code XRF-W01) to analyze chlorine, sulphur and fluorine on wax pressed pellets using one of the Geo Labs Axios® wavelength-dispersive X-ray fluorescence (WD-XRF) spectrometers and data reduction using fundamental parameters algorithms (*after* Willis and Duncan 2008). Wax pressed pellets were preferred for sample preparation because the binder is dry and halogen free, so neither reacts with halide minerals nor imparts halogens to the sample. Although the XRF-W01 method was included in the 2017 brochure, only data for chlorine were initially reported.

With the increased interest in whole-rock halogen data, as well as the inclusion of fluorspar on Ontario's Critical Minerals list, when, in 2020, the Axios® spectrometers were replaced with Malvern Panalytical® Zetium® spectrometers, the XRF-W01 method was re-examined during its transfer to the new instrument. During the re-examination, it was determined that, although the quantification of sulphur on pressed pellets was not feasible because of peak shifts associated with sulphur's oxidation state, with an appropriate choice of background positions and overlap corrections, accurate data for fluorine concentrations of up to 1 weight % could be obtained, allowing it to be added to the XRF-W01 method.

This article presents a summary of the work done to transfer the application and generate the new calibrations for the XRF-W01 analytical application and the figures of merit for the expanded test method based on those calibrations.

ANALYTICAL WORK

Ion-Selective Electrode Analyses

Initial testing focussed on the 3 most influential parameters during the sample fusions, using the basaltic in-house material MRB-29 as the test material: sample-to-flux ratio (1:6 versus the historic 1:4 by weight), fusion duration (60 minutes versus the historic 30 minutes) and temperature during the dissolution phase (150°C until the cake became a slurry versus 50°C overnight). Although marginally higher recoveries were observed when higher sample-to-flux ratios were combined with slow dry downs, the results were inconclusive, and no change was made to the fusion method.

Additional testing explored the impact of the flux ratio on recoveries from different sample matrices, employing a range of in-house quality-control materials and inter-laboratory reference materials with compositions similar to those routinely seen in submitted samples (e.g., in-house: QS-1 MRB-7, MRB-8, MRB-14, MRB-16, MRB-17, MRB-18, MRB-29 and MRB-40; inter-laboratory: BCR-2, BHVO-2, AGV-2, BIR-1a, AC-E, G-A, GH, JG-1, JG-2, and MA-N with a maximum fluorine content of 1.7 weight % F), the accuracy of TISAB and citric acid addition, and the use of alternate fluoride ion-selective electrodes. Once again, whereas the analytical conditions (sample-to-flux ratio and buffer solution addition) had minimal impact on analytical results, a change to the ion-selective electrode considerably improved the accuracy of results. The alternate electrode was used for all subsequent testing and production analyses. The results obtained for the reference materials using the original SOL-FDI method but utilizing the new ion-selective electrode, along with data subsequently obtained for additional quality-control materials and proficiency test samples (Table 23.1; Figure 23.1), were used to obtain a revised estimate of the accuracy and precision of the SOL-FDI/ISE-R01 method.

To estimate the lower limit of detection (LLoD) and to provide a second estimate of the precision of analyses, 66 duplicate pairs of samples and reference materials were also analyzed, mostly between November 2024 and August 2025, and the results processed according to the method proposed by Thompson and Howarth (1976) (*see* Figure 23.1). To minimize the effect of the highest concentration groups on the regression and the uncertainty in the calculated LLoDs, only the lowest 63 duplicate pairs (7 groups of 9 samples) were used in the calculation.

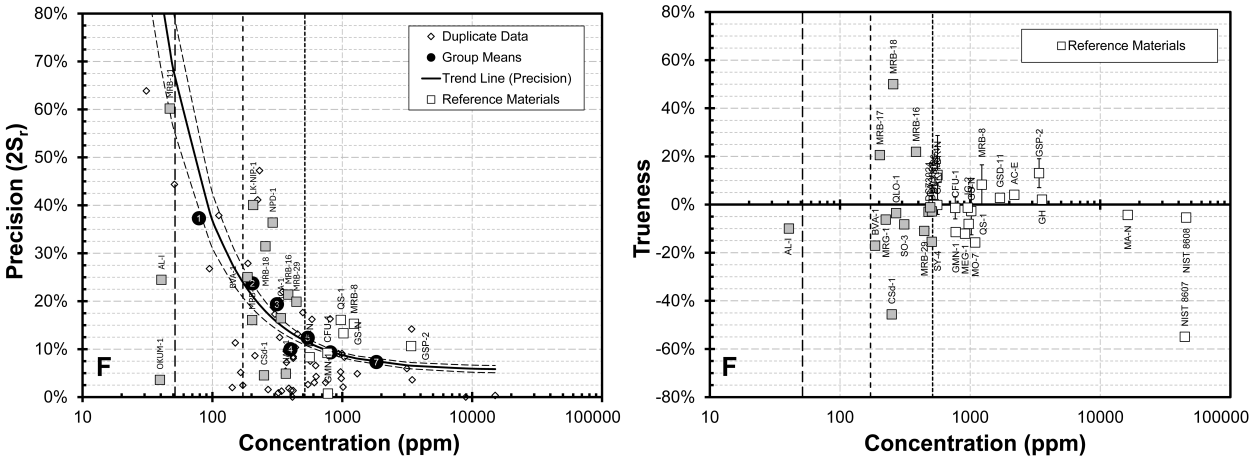


Figure 23.1. Plots summarizing the data used for the estimation of LLoD, 2σ precision, and trueness as a function of concentration for fluorine (F) and chlorine (Cl) analyses using test method code ISE-R01. The most reliable estimate of the LLoD and the estimate of the precision of the method were obtained using all 7 of the interval concentration groups. Only reference materials with concentrations greater than 3× LoQ were used in calculation of trueness and precision (open squares). Long dashed lines, lower limit of detection (LLoD); medium dashed lines, lower limit of quantification (LoQ); short dashed lines, 3× LoQ. NIST 8607 is calcium-enriched (33 weight % CaO) and is excluded from the statistics for undiluted samples.

Table 23.1. Summary of data obtained for reference materials analyzed during the validation of the ISE-R01 and XRF-W01 methods for the analysis of halogens.

Material	F (ppm)					Cl (ppm)		
	Assigned Value	ISE-R01 Average	n	XRF-W01 Average	n	Assigned Value	XRF-W01 Average	n
AC-E	2100 ± 200	2185	1	1885.7 ± 16.1	10	180	299.50 ± 1.64	10
AL-I	45 ± 7	40.5 ± 4.9	2	21.0 ± 7.6	11	110	176.50 ± 1.74	11
BCS-353				980.4 ± 8.1	5		176.5 ± 14.4	5
BCSS-1				469.5 ± 24.5	13	11,200 ± 500	12,565 ± 52	13
BE-N	1000 ± 60			789 ± 35	14	200	229.6 ± 9.5	14
BHVO-2	370			424.7 ± 20.9	12		343.4 ± 6.8	12
BVA-1	225‡	186.5 ± 23.3	2	307 ± 0	2	285‡	339.5 ± 9.2	2
CFU-1	780‡	769 ± 35	2	−418 ± 34†	2		287.5 ± 17.7	2
CSd-1	460‡	250.0 ± 5.7	2	410.5 ± 7.8	2	47‡	70.00 ± 2.83	2
DC73024	495 ± 40	480	1	681	1	7800 ± 500	8890	1
DC73026	524 ± 30	509	1	583	1	40,000 ± 3000	39,900	1
DC73030	524 ± 40	525	1	741	1	4800 ± 300	5360	1
DR-N	500 ± 70	561.5 ± 23.3	2			400		
EMS-1	1310‡			1268.0 ± 14.1	2	90‡	121.0 ± 15.6	2
GA	500 ± 50	494	1			250		
GAK-1	560‡	559	1	551.5 ± 10.6	2		338.50 ± 0.71	2
GH	3500 ± 200	3570	1	3440	1	100	107	1
GMN-1	875‡	775.0 ± 2.8	2	1017 ± 65	2	120‡	171 ± 34	2
GSD-11	1650 ± 128	1696	1	1901.4 ± 21.8	20	290 ± 32	327.6 ± 3.08	20
GS-N	1050 ± 80	1021 ± 70	17	1047.5 ± 27.8	23	450	436.8 ± 23.1	23
GSP-2	3000	3391 ± 180	13	3853.3 ± 13.7	12		373.4 ± 1.8	12
GSR-1	2350 ± 200			2802.6 ± 16.3	10	127 ± 19	130.0 ± 7.4	10
GSR-3	700 ± 68			732 ± 34	10	114 ± 26	150.0 ± 6.6	10
GSR-5	1290 ± 100			1281.1 ± 24.2	9	40 ± 18	60.0 ± 5.3	9
GSR-6	406 ± 44			547.7 ± 28.7	9	83 ± 25	99.1 ± 5.2	9
JG-1	498	553	1			58.1		
JG-1A		459	1					
JG-2	972	959	1					
LDI-2				103	1		150	1
LK-NIP-1		206 ± 41	8	178 ± 50	6		477.7 ± 25.9	6
MA-N	17,000 ± 800	16,260	1	14,859 ± 141	9	140	179.9 ± 11.8	9
MEG-1	1040‡	914	1	949 ± 50	2	77‡	97 ± 49	2
MMTe-1				476	1		189	1
MO-7	1300	1095	1	821 ± 35	10		727.5 ± 7.8	10
MRB-8	1137 [a]	1231 ± 94	2	1664	1		114	1
MRB-11		47.0 ± 14.1	2	64	1		151	1
MRB-16	315 [a]	384 ± 41	2	111	1		109	1
MRB-17	168 [a]	202.5 ± 16.3	2	95	1		106	1
MRB-18	171 [a]	257 ± 40	2	195	1		212	1
MRB-29	499 [a]	444 ± 44	15	562 ± 127	3		97 ± 35	3
MRG-1	240 ± 40	225	1	352.9 ± 26.8	15	170 ± 30	173.2 ± 5.1	15

‡ *Median of reported data for International Association of Geoanalysts (IAG) GeoPT proficiency test data.*

† *XRF-W01 data overcorrected for Fe interference.*

[a] *Richardson (1995).*

[b] *Schnetger, Muramatsu and Yoshida (1998).*

[c] *Gladney and Roelandts (1989).*

Table 23.1, *continued*.

Material	F (ppm)					Cl (ppm)		
	Assigned Value	ISE-R01 Average	n	XRF-W01 Average	n	Assigned Value	XRF-W01 Average	n
NAS-1		368.0 ± 8.9	5	348.2 ± 30.0	5		161.0 ± 7.3	5
NIM-L	4400			4471 ± 51	10	1200	1172.9 ± 12.2	10
NIST 2710				1464.8 ± 25.0	6		352.58 ± 1.34	6
NIST 8607	99,100 ± 3100	44,632	1	66,242 ± 1068	5		56.5 ± 7.3	5
NIST 8608	48,400 ± 1200	45,778	1					
NPD-1		291.5 ± 53	2					
ODL-1				487.5 ± 14.8	2		702.0 ± 2.8	2
OKUM-1		39.50 ± 0.71	2	195.6 ± 25.3	13		115.5 ± 9.3	13
OPEG-1				261	1		60	1
ORCA-1		336.4 ± 27.6	12	219.6 ± 20.2	24		62.5 ± 20.4	24
OREAS 753				259	1		98	1
OU-6				344.7 ± 18.5	3		40.3 ± 17.9	3
PACS-1	350 ±10 [b]			279.1 ± 6.2	10	23,900 ± 900	23,717 ± 17	10
PJV-2				295 ± 37	8		68.6 ± 23.7	8
QLO-1	280 ± 20	270	1	116.4 ± 21.5	9	220 ± 18	230.1 ± 9.5	9
QS-1	1060 ± 16	975 ± 78	7	1022 ± 56	16		111.1 ± 16.3	16
REE-1				403	1		162	1
RV-1	101			158	1	126	138	1
SMB-1	420‡			614.0 ± 17.3	4	143‡	198.0 ± 17.3	4
SO-3	340 ± 90 [c]	312	1	455.1 ± 31.1	9	210 [c]	439.1 ± 2.1	9
SY-3	6600			6448 ± 101	11		150.8 ± 6.3	11
SY-4	600 ± 100	507	1	497.6 ± 26.4	13	4500 ± 1500	4670.1 ± 11.8	13
TDB-1	400			356 ± 81	2	1050	1013 ± 49	2
TLB-1	440‡			417.5 ± 21.9	2		283.0 ± 7.1	2
TRHB	9200			11,090	1		66	1
TRM-2	18,900 ± 100			11,380	1		290	1
UB-N	95			144.1 ± 19.5	15	800 ± 200	838.9 ± 9.2	15

‡*Median of reported data for International Association of Geoanalysts (IAG) GeoPT proficiency test data.*

† *XRF-W01 data overcorrected for Fe interference.*

[b] *Schnetger, Muramatsu and Yoshida (1998).*

[c] *Gladney and Roelandts (1989).*

The upper reporting limits for routine fluorine analyses by the ISE-R01 method was set at 110% of the higher of the highest concentration used in the calibration or the highest reference material that gave a satisfactory result (MA-N at 1.7 weight % F).

A summary of the figures of merit obtained for the ISE-R01 method is given in Table 23.2.

X-ray Fluorescence Analyses

The revised XRF-W01 method, including Cl and F as analytes, was transferred to the Zetium® spectrometers, using similar parameters to those employed in the previous versions of the analytical application. A total of 100 certified reference materials (CRMs) and 59 synthetic materials were used to calibrate the spectrometer for the transferred application. All reference materials were freshly prepared using the same preparation method and dilution to that used for samples. The calibration and sample analysis results are expressed as “as submitted” using the spectrometer control software (SuperQ: Malvern-PANalytical 2020).

Table 23.2. Summary of figures of merit obtained for XRF-W01 and ISE-R01 test methods from the analysis of certified reference materials.

	Cl (XRF-W01)	F (XRF-W01)	F (ISE-R01)
Limit of Reporting (LLoR, ppm)	25	75	51
Limit of Quantification (LoQ, ppm)	46	250	171
Upper Limit of Validated Range [a] (UL, ppm)	26 000	10 000	53 000
Relative Standard Deviation [b] (S_r, %)	2.5	2.7	5.3
Relative Measurement Precision (%)	± 5.0	± 5.4	± 10.6
Method Bias [c] (Weighted Regression, %)	4.4	0.8	0.4
Method Trueness [d] (Mean Absolute Trueness, %)	± 14.0	± 13.9	± 6.5

[a] ***Validated Range:*** *Defined as the working range in which the method has been validated (Limit of Reporting to maximum concentration used in validation statistics or calibration regression). Minimum and maximum values of reference materials used.*

[b] ***Relative Standard Deviation (S_r):*** *Defined as the average of the relative standard deviations of all measurements greater than 3× LoQ (Richardson and Morrison 1995).*

[c] ***Method Bias (Weighted Regression):*** *Calculated from the gradient of the linear regression of the measured concentrations against the certified concentrations of the reference materials, with points weighted according to the square root of their variance (Reed 1989; Richardson and Morrison 1995). Bias = (Gradient – 1) × 100 (result in percent).*

[d] ***Method Trueness (Mean Absolute Trueness):*** *Defined as the average absolute trueness (Richardson and Morrison 1995) of the suite of reference materials. Only samples with measured concentrations greater than 3× LoQ.*

$$Absolute\ Trueness = \left|\left(\left(\frac{Mean\ Measured\ Value}{Certified\ Value}\right) - 1\right)\right| \times 100$$

To maximize sensitivity for fluorine without compromising resolution, collimators with a medium spacing were selected for its analysis, leading to broad peaks in the part of the spectrum where fluorine is analyzed. To avoid large background factors, a background position as close as possible to the F K_α peak was selected. Although this improves the accuracy of the background correction and the quality of data at low fluorine concentrations, peak broadening and tailing of the F K_α peak onto the background position at elevated fluorine concentrations restricts the operating range of the method to approximately 1 weight % F, above which the behaviour becomes unpredictable. Initial experiments showed that marginally higher fluorine concentrations (up to at least 2 weight % F) could be accommodated by diluting the sample with a non-fluorine (non-chlorine) bearing material, such as silica flour, provided the sample and diluent were mixed by grinding. Further testing showed that even higher fluorine contents could be accommodated in this way (see below) provided the final fluorine content was brought within the routine operating range.

In addition to applying a fundamental parameters approach to matrix correction, during data processing for the XRF-W01 method, a number of overlap corrections are applicable. For fluorine, overlap corrections include

- oxygen (O K_α) on the background. With the greater sensitivity of the new Zetium® spectrometers in the region of the fluorine K_α peak came a greater sensitivity to the oxygen content of rocks and a tailing of the oxygen K_α peak onto the background position. It was possible to minimize, but not eliminate, this effect in oxygen-rich samples (generally samples that contain high concentrations of light elements, in particular silicon and aluminum), leading to a loss of precision and accuracy for low-level analyses in silica-rich samples. This issue will be addressed in future developments of the method by either the direct measurement of the oxygen K_α line (not currently measured) and appropriate correction or the possible relocation of the fluorine background position to avoid the oxygen peak tailing.
- iron (Fe L_α) on the F K_α peak. This is successfully corrected up to 20 weight % Fe_2O_3.
- manganese (Mn L_α and L_β), chromium (Cr L_α and L_β) and barium (Ba M lines) on the background. These are successfully corrected up to 2 weight % MnO, 2 weight % Cr_2O_3 and 1.5 weight % BaO.

Although, in theory, first-order Co L lines, second-order As or Ge L_α or L_β lines, and third-order Zr or Rb L_α or L_β lines could interfere with F K_α, no correction is applied for these emissions and no effects are seen up to 500 ppm Co, 16,400 ppm As, 1000 ppm Ge, 11000 ppm Zr or 9000 ppm Rb.

Because chlorine is in a much cleaner part of the spectrum, only a handful of possible overlaps could occur (e.g., first-order Pb M_α lines, second-order Nd, Ce, or Cs L_α, L_β or L_γ lines, or third-order Hf L_α lines) and no corrections appear to be needed. No effects are seen in samples containing up to 56,000 ppm Pb (5.6 weight %) or 1000 ppm Cs, Nd, Ce or Hf.

The accuracy and precision of the new application were verified through multiple analyses of a suite of certified reference materials that were independent of those used for the calibration regressions and prepared using the same preparation method as that used for samples (AC-E, AL-I, BCS-353, BCSS-1, BE-N, BHVO-2, GS-N, GSD-11, GSP-2, GSR-1, GSR-3, GSR-5, GSR-6, MA-N, MO-7, MRG-1, NIM-L, NIST 2710, NIST 8607, OKUM-1, ORCA-1, PACS-1, QLO-1, QS-1, SO-3, SY-3, SY-4 and UB-N). Analyses took place between December 2024 and March 2025. The results are summarized in Table 23.1 and Figure 23.2.

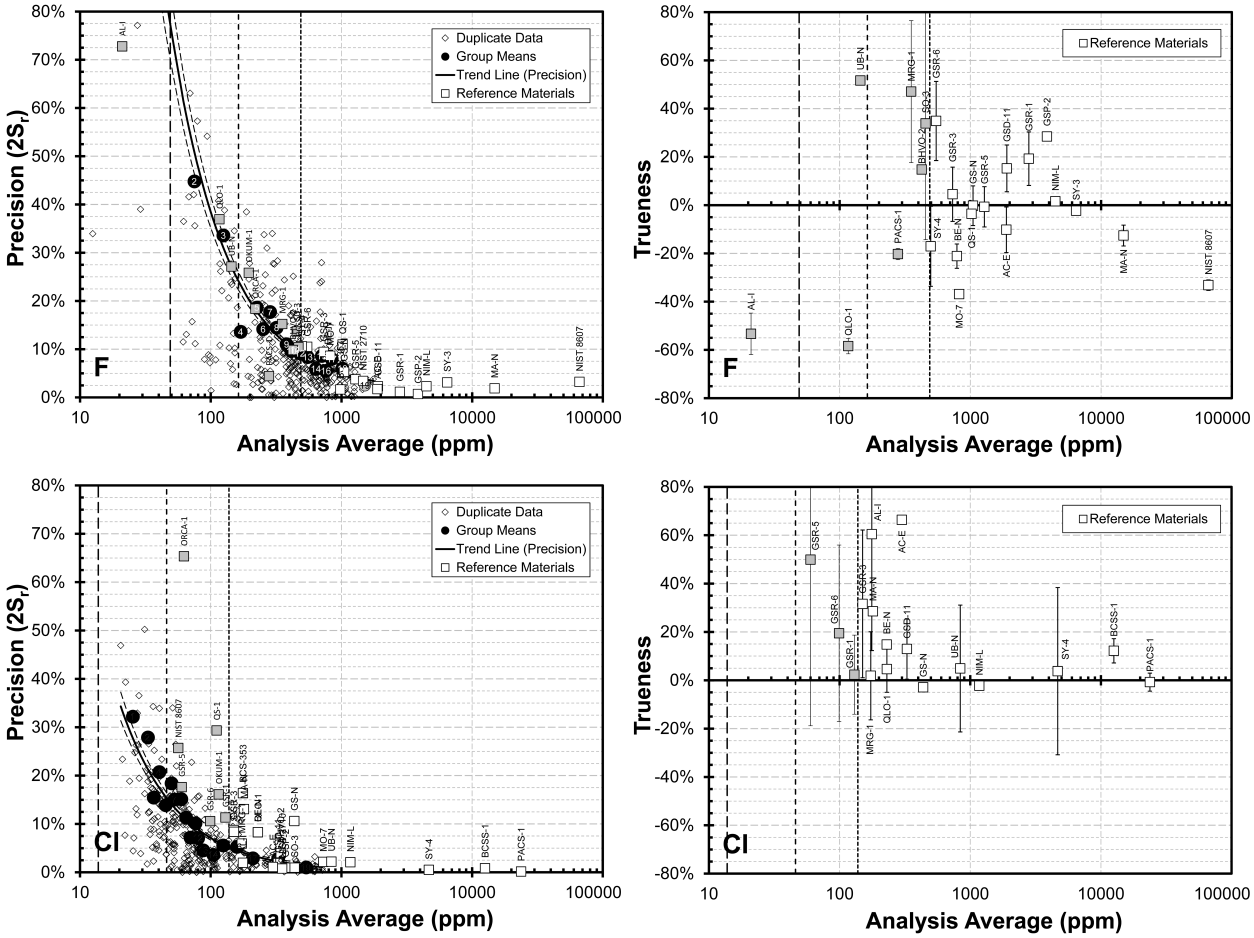


Figure 23.2. Plots summarizing the data used for the estimation of LLoD, 2σ precision, and trueness as a function of concentration for fluorine (F) and chlorine (Cl) analyses using test method code XRF-W01. The most reliable estimate of the LLoD and the estimate of the precision of the method was obtained using all 19 of the interval concentration groups. Only reference materials with concentrations greater than 3× LoQ were used in calculation of trueness and precision (open squares). Long dashed lines, lower limit of detection (LLoD); medium dashed lines, lower limit of quantification (LoQ); short dashed lines, 3× LoQ. MA-N and NIST 8607 considered over-range for fluorine and excluded from statistics. AL-I and AC-E excluded from statistics for chlorine because of poorly constrained reference values.

To estimate the lower limit of detection (LLoD) and to provide a second estimate of the precision of analyses, 288 pressed pellets (144 duplicate pairs) of samples and reference materials were analyzed twice between December 2024 and March 2025, with a four-week separation between analyses and, like the duplicates for the ISE-R01 method, the results were processed according to the method proposed by Thompson and Howarth (1976) (*see* Figure 23.2). To minimize the effect of the highest concentration groups on the regression and the uncertainty in the calculated LLoDs, only the lowest concentration groups (points closest to the LLoD) were used to calculate the LLoDs. For chlorine, 13 groups (195 sample pairs) were used in the calculation. For fluorine, 18 of the 19 groups (270 sample pairs) were used. To allow for degradation of the X-ray tube with time, leading to decreased sensitivity and increased signal-to-noise ratios, the lower reporting limits for the XRF-W01 method were set at 150% of the LLoD determined from the duplicate analyses.

The upper reporting limits for routine fluorine and chlorine by the XRF-W01 method were set at 110% of the higher of the highest concentration used in the calibration or the highest reference material that gave a satisfactory result. Based on the recalculated LLoD for chlorine and the successful analysis of the NRC marine sediment reference material PACS-1 (2.37 weight % Cl), the reporting range for chlorine by the XRF-W01 method was expanded to 25–26,000 ppm Cl. The reporting range for fluorine was set at 75–10,000 ppm, with the upper reporting limit constrained by the successful analysis of the Mongolian REE ore reference material TRHB (assigned value: 9200 ppm F), but the observation of 13% low results for the French granite reference material MA-N (assigned value: 17,000 ppm F).

A summary of the figures of merit obtained for the revised XRF-W01 is given in Table 23.2.

EXPANDING ANALYTICAL RANGES

Having obtained satisfactory results for the range of fluorine concentrations routinely seen in samples submitted for the ISE-R01 and XRF-W01 methods, additional testing using a suite of fluorine-rich reference materials with a variety of matrices and total fluorine contents up to 47 weight % F was carried out to determine how and whether each method could handle the more elevated fluorine contents expected in fluorite-mineralized samples. For the ISE-R01 method, the fluorine-rich test materials were either fused and analyzed as normal or were diluted with ultrapure silica prior to fusion and the diluted materials fused and analyzed. For the XRF-W01 method, given the poor results obtained for samples containing in excess of method's upper reporting limit of 1 weight % F, all samples were diluted with silica to bring their fluorine contents below this limit and only the diluted test materials were analyzed. The results of these experiments are shown in Table 23.3 and Figure 23.3.

Ion-Selective Electrode Analyses

Despite the estimation of an upper reporting limit of 11 weight % F, based on the linear working range of the electrode during the initial development of the ISE-R01 method in 2008, initial inspection of the results of the extension tests suggested that the method struggles during the analysis of samples containing more than 2 weight % F, with low results obtained for the basic slag reference material BCS 382, phosphate rock reference material NIST 120c and fluorite-bearing tungsten ore reference material NIST 8607 (all with 1–10 weight % F), and very low results obtained for the fluorspar reference materials HJ and BCS 392, with 35 to 47 weight % F. Whereas dilution with silica before fusion appeared to improve the accuracy of results somewhat, the results for all 5 reference materials remained low and dilution of the solutions did not appear to improve recoveries, suggesting that the issue relates to the fusion rather than the solution analysis stage.

Given the reasonable recovery of fluorine from the calcium-poor tungsten ore NIST 8608 (4.17 weight % CaO and 4.84 weight % F, recovery 94.6%), the dramatically poor recoveries of fluorine from the most calcium-rich reference materials (NIST 120c, HJ and BCS 392 with 48 to 70 weight % CaO; *see* Table 23.3) and the improvement in the fluorine recovery with sample dilution before fusion, the cause of the low recovery is inferred to be the precipitation or non-dissolution of calcium fluoride during the carbonate fusion. Based on the current analyses, it appears that a reduction of calcium contents to less than 10 weight % CaO by dilution of samples with silica before fusion may be necessary to quantitatively put or retain fluorine in solution and achieve adequate recoveries of fluorine by the ISE-R01 method. At only a five-fold dilution, the calcium concentrations in reference materials HJ and BCS 392 (10–14 weight % CaO) remained too high for successful analysis (*see* Table 23.3; *see* Figure 23.3).

Table 23.3. Summary of fluorine concentrations obtained for reference materials analyzed during the experiments to extend the working ranges of the ISE-R01 and XRF-W01 methods.

Reference Material	Dilution Factor	Assigned Values		ISE-R01		XRF-W01	
		CaO (wt %)	F (wt %)	Average (wt %)	n	Average (wt %)	n
BCS 382	1	33.02	1.61 ± 0.06	1.24	1	1.13 ± 0.01	2
BCS 392	1	70.33	47.29 ± 0.15	6.95	1		
	5			35.06	1		
	50					45.55 ± 0.87	2
HJ	1	52.22	34.89 ± 0.19	17.87	1		
	5			26.96	1		
	50					38.35 ± 0.77	2
NIST 120c	1	48.02	3.82 ± 0.02	1.504 ± 0.003	2		
	10					2.85 ± 0.13	2
NIST 8607	10	37.73	9.91 ± 0.26	8.97	1	9.01 ± 0.23	3
	15			8.04	1	10.49 ± 0.12	2
NIST 8608	15	4.17	4.84 ± 0.12	4.56	1	4.28 ± 0.10	2
OshBo	1	0.39	1.13 ± 0.16	1.23	1	1.16 ± 0.05	2
Silica Blank	1	0	0	0.01 ± 0.01	2	−0.01 ± 0.00	2

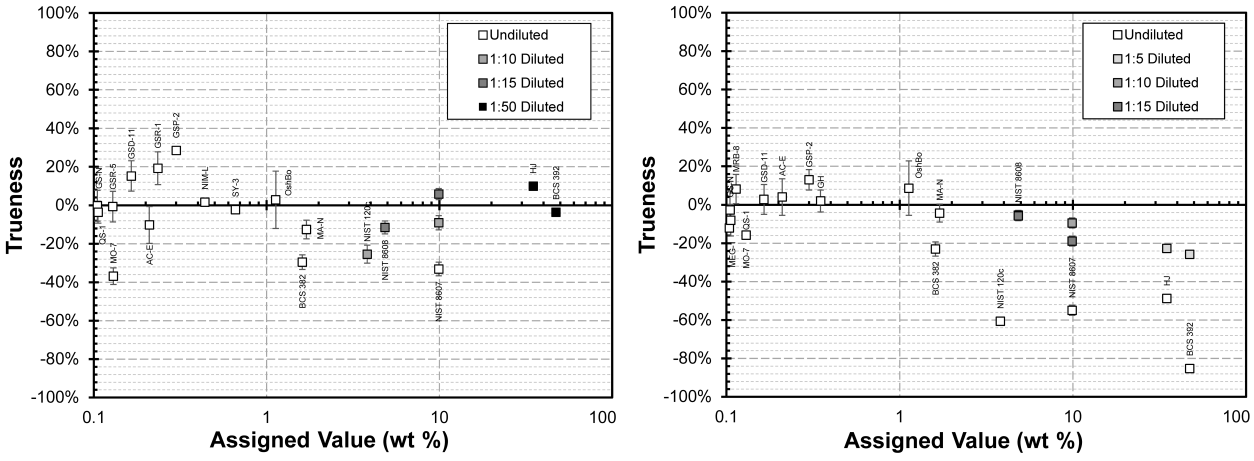


Figure 23.3. Plots summarizing the trueness as a function of concentration for the analysis of fluorine at elevated concentrations by method codes XRF-W01 (left) and ISE-R01 (right), using solid-phase dilution of samples before pressed pellet or carbonate fusion preparation (*see* Table 23.3). Additional data for sample containing greater than 1000 ppm F taken from Table 23.1.

Further work to expand the reporting range for the ISE-R01 method will focus on the application of silica dilution to reduce sample calcium contents before fusion, focussing on the most calcium-rich and, coincidentally, most fluorine-rich reference materials. This work will be assisted by the participation in the characterization of 2 new Ore Research & Exploration (OREAS) fluorite reference materials (OREAS 780 with around 5 weight % F and 8 weight % CaO, and OREAS 782 with around 16 weight % F and 23 weight % CaO), analyzing the materials with and without silica dilution.

X-ray Fluorescence Analyses

In general, provided the fluoride concentration in the pressed pellet is less than the approximately 1 weight % F upper reporting limit of the routine method and the grain size of the sample is similar to that of the silica diluent, the XRF-W01 appears to be able to analyze fluorine up to the highest concentrations that could be expected in mineralized samples:

- Repeated analyses of 1:50 blends of the Central Mongolian Laboratory and British Analytical Standards fluorspar reference materials HJ and BCS 392, which contain 34.89 ± 0.19 weight % F and 47.29 ± 0.15 weight % F (0.698 weight % F and 0.946 weight % F after dilution), respectively, yielded concentrations of 38.35 ± 0.77 weight % F and 45.55 ± 0.87 weight % F (*see* Table 23.3), both of which are within±10% of the assigned values.
- For the fluorite-bearing tungsten ore NIST 8607, as the dilution factor increases from undiluted to 1:10 and 1:15 blends with silica (and the fluorine contents decrease from 9.91 weight % F to 0.991 weight % F and 0.661 weight % F), the measured fluorine concentrations increase from 6.62 weight % F (33% low) through 9.01 weight % F (9.1% low) to 10.49 weight % F (5.8% high), consistent with the achievement of satisfactory results at 1 weight % F and less in the pressed pellet.
- Analysis of the fluorite-bearing tungsten ore NIST 8608 (4.84 ± 0.12 weight % F) at 1:15 dilution (0.323 weight % F in the pressed pellet) yielded a concentration of 4.282 ± 0.099 weight % F (11.5 ± 3.4 % low).

It is unclear why the Florida phosphate rock reference material NIST 120c (3.82 ± 0.02 weight % F) yielded low results, even when diluted 1:10 with silica.

To better characterize the XRF-W01 method's capabilities at elevated F concentrations, the preparation and analysis of NIST 120c at different dilutions will be repeated, along with analyses of the basic slag BCS 382 and granite MA-N after 1:10 dilution, and the 2 new OREAS fluorite ores will be analyzed after suitable dilution with silica.

SUMMARY

Two methods have been set up and verified for the analysis of total fluoride and/or chloride at the Geo Labs: sodium carbonate fusions followed by ion-selective electrode analysis (method codes SOL-FDI and ISE-R01) and wavelength dispersive analysis of pressed powder pellets (method codes XRF-WAX and XRF-W01).

Analysis of certified reference materials and sample duplicates suggests that, of the 2 methods, analysis by ion-selective electrode (method code ISE-R01) is the more sensitive and accurate, with a revised lower reporting limit of around 50 ppm F and an upper reporting limit of over 5 weight % F in calcium-poor samples. However, as the calcium content increases, fluorine recovery appears to decrease, presumably resulting from the insolubility of calcium fluoride in solution. Although dilution of calcium-rich samples prior to fusion appears to improve recovery, further work is required to determine the optimum dilution factors for fluorite-rich samples.

Although the working range of fluorine analyses by wavelength-dispersive XRF on pressed powder pellets (without dilution) is smaller than that of the ISE-R01 method, the XRF-W01 method appears to be more robust, being unaffected by either the presence of sulphides or the insolubility of fusion products. These features, and the provision of complimentary data for total chlorine in samples containing up to 2.6 weight % Cl, make it the more applicable method for the analysis of sulphide-bearing samples associated with base or precious metal mineralization. With suitable sample dilution prior to the pellet creation, it appears to be able to handle fluoride concentrations up to almost 50 weight % F, representing almost pure fluorite, giving it the potential to analyse a range of fluorite-mineralized samples.

Further testing is underway to investigate the scope of solid sample dilution to tackle high calcium matrices and elevated halide concentrations and the establishment of revised operating ranges ahead of the release of the 2026 "*Schedule of Fees and Services*".

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The authors would like to thank Nathan Guitard and Sydney Thompson, Sample Preparation Technologists, for making the blends used in the dilution tests, Natalie Chrétien and Margaret Leigh, XRF Technologists, for making pressed pellets, and Evan Hastie for his help filling in the geological context of halogen analyses.

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24. Summary of Quality Control Data for the Geoscience Laboratories Methods GFA-PBG, XRF-M01, XRF-M02, XRF-T04, XRF-T05 and XRF-W01



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INTRODUCTION

This article summarizes the results of analyses for quality-control samples for the Geoscience Laboratories' GFA-PBG, XRF-M01, XRF-M02, XRF-T04, XRF-T05 and XRF-W01 test methods. The GFA-PBG test method is used to determine gold (Au) in geological samples using lead fire-assay with gravimetric finish. The X-ray fluorescence (XRF) method XRF-M01 (Keating 2023) is designed for analysis of major elements in geological samples after fusion to produce glass beads. Method XRF-M02 is a complementary XRF test method and an add-on to the XRF-M01, providing data for the trace elements cobalt, copper, lead, nickel, strontium, vanadium, zinc and zirconium (Co, Cu, Pb, Ni, Sr, V, Zn and Zr) in the glass beads. The XRF-T04 and XRF-T05 test methods are XRF methods for the analysis of trace elements in pressed powder pellets prepared from geological samples using a micropowder wax binder. The XRF-T04 method provides results for silver (Ag) and cadmium (Cd). The XRF-T05 (Keating 2022) method provides results for arsenic, barium, bromine, cerium, cobalt, chromium, cesium, copper, gallium, lanthanum, manganese, molybdenum, niobium, nickel, lead, rubidium, scandium, strontium, thorium, titanium, uranium, vanadium, yttrium, zinc and zirconium (As, Ba, Br, Ce, Co, Cr, Cs, Cu, Ga, La, Mn, Mo, Nb, Ni, Pb, Rb, Sc, Sr, Th, Ti, U, V, Y, Zn and Zr). The XRF-W01 test method is an XRF method for the analysis of chlorine (Cl) and fluorine (F) in pressed pellets prepared from geological samples using a micropowder wax binder. Fluorine was added to the method following its transfer to new instrumentation in 2020. The updated method became available to clients April 1, 2025, with the release of the Geo Labs *2025 Schedule of Fees and Services* (Ontario Geological Survey 2025).

The quality-control data for the GFA-PBG method are summarized for March 3, 2020, to July 10, 2025, and capture results obtained since a summary was last published (Hargreaves and Burnham 2020) (Table 24.1). The quality-control data for the XRF-M01 (Table 24.2) and XRF-M02 (Table 24.3) test methods are summarized from June 28, 2022, to July 10, 2025; the XRF-T04 (Table 24.5), from April 7, 2022, to July 10, 2025; the XRF-T05 (Table 24.4) test method, from January 21, 2022, to July 10, 2025; and the XRF-W01 (Table 24.6), from March 27, 2025, to July 10, 2025. These data capture results obtained since the methods' transfer to new wavelength dispersive X-ray fluorescence (WD-XRF) instrumentation.

In Tables 24.2 to 24.6, data are presented for both in-house and certified (inter-laboratory) reference materials. Whereas both types of reference material are prepared from fresh aliquots during lead fire-assay analysis (GFA-PBG), to preserve the limited supply of many of the inter-laboratory reference materials used during the XRF analysis, only in-house reference materials are freshly prepared for analyses;

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Ontario Geological Survey, Open File Report 6421, p.24-1 to 24-14.

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Table 24.1. Summary of results obtained by the GFA-PBG test method for routine in-house and certified reference materials from March 3, 2020, to July 10, 2025.

Material	Provider	Description	Au (oz gold/ton)
In-House Reference Materials			
PJV-2	In-house	Rock Powder	0.271 ± 0.010 (101)
Certified Reference Materials			
OREAS 247	OREAS	Gold Ore	1.227 ± 0.029 (19)
Certificate‡			*1.25 ±0.026*
			(42.96 ± 0.900 µg/g)
SQ88	Rocklabs	Synthetic Rock Blend	1.153 ± 0.019 (103)
Certificate†			*1.16 ± 0.01*
			(39.72 ± 0.29 µg/g)

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
‡ Certificate value is average ± 1 standard deviation of the mean.
† Certificate value is average ± 95% confidence interval on the inter-laboratory mean.
Abbreviation: *OREAS = Ore Research & Exploration Pty Ltd.*

analyses of inter-laboratory reference materials by these methods are performed on existing glass beads and pressed pellets. As a result, the variations shown for both types of reference material analyzed by method GFA-PBG and the in-house reference materials analyzed by the XRF methods represent the total variability of the method (including preparation reproducibility), but those shown for the certified reference materials by the XRF methods represent variability resulting from instrument performance alone.

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Table 24.2. Summary of results obtained by the XRF-M01 test method for routine in-house and certified reference materials from June 28, 2022, to July 10, 2025.

Material	Provider	Description	Al_2O_3 (wt %)	BaO (wt %)	CaO (wt %)	Cr_2O_3 (wt %)	$Fe_2O_3^{Total}$ (wt %)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	15.31 ± 0.08 (116)	0.0153 ± 0.0014 (116)	10.17 ± 0.04 (116)	0.0226 ± 0.0022 (116)	13.52 ± 0.09 (116)
ODL-1	In-house	Dolomitic Limestone	2.252 ± 0.011 (39)	0.0054 ± 0.0010 (39)	26.18 ± 0.14 (39)	<0.002 (39)	2.691 ± 0.013 (39)
OPEG-1	In-house	Evolved Pegmatite	14.23 ± 0.07 (36)	0.0078 ± 0.0015 (36)	0.5061 ± 0.0030 (36)	0.0228 ± 0.0008 (36)	0.412 ± 0.007 (36)
ORCA-1	In-house	Rhyolite	12.59 ± 0.07 (147)	0.0406 ± 0.0014 (147)	1.134 ± 0.005 (147)	0.0099 ± 0.0015 (147)	2.889 ± 0.031 (147)
QS-1	In-house	Calcareous Shale	14.20 ± 0.08 (51)	0.0395 ± 0.0012 (51)	7.97 ± 0.04 (51)	0.0101 ± 0.0007 (51)	6.41 ± 0.04 (51)
RV-1	In-house	Melagabbro	15.71 ± 0.09 (108)	0.0234 ± 0.0013 (108)	8.86 ± 0.03 (108)	0.0327 ± 0.0010 (108)	10.27 ± 0.06 (108)
Certified reference materials							
AGV-2	USGS	Andesite	17.04 ± 0.07 (160)	0.1250 ± 0.0015 (160)	5.148 ± 0.014 (160)	0.0024 ± 0.0007 (160)	6.73 ± 0.03 (160)
Certificate‡			*16.91 ± 0.21*	*0.127 ± 0.004*	*5.20 ± 0.13*	*0.0025 ± 0.0003*	*6.69 ± 0.1*
BCS-353	BAS	Portland Cement	3.807 ± 0.008 (7)	0.0316 ± 0.0019 (7)	64.67 ± 0.20 (7)	0.0179 ± 0.0006 (7)	4.751 ± 0.007 (7)
Certificate			*3.77 ± 0.07*	*NA*	*64.8 ± 0.2*	*NA*	*4.82 ± 0.06*
BHVO-2	USGS	Basalt	13.70 ± 0.06 (152)	0.0157 ± 0.0016 (152)	11.40 ± 0.03 (152)	0.0413 ± 0.0006 (152)	12.44 ± 0.06 (152)
Certificate‡			*13.5 ± 0.2*	*0.0145 ± 0.0015*	*11.4 ± 0.2*	*0.0409 ± 0.0028*	*12.3 ± 0.2*
GSP-2	USGS	Granodiorite	15.05 ± 0.07 (164)	0.1496 ± 0.0017 (164)	2.083 ± 0.005 (164)	0.0030 ± 0.0006 (164)	4.945 ± 0.027 (164)
Certificate‡			*14.9 ± 0.2*	*0.150 ± 0.005*	*2.1 ± 0.06*	*0.0029 ± 0.0009*	*4.9 ± 0.16*
IF-G	GIT-IWG	Iron Formation	0.166 ± 0.014 (9)	<0.004 (9)	1.547 ± 0.006 (9)	<0.002 (9)	55.8 ± 0.5 (9)
Certificate†			*0.15 ± 0.02*	*0.00017 ± 0.00005*	*1.55 ± 0.03*	*0.00058 ± 0.00015*	*55.85 ± 0.22*
OKUM-1	IAG	Ultramafic Komatiite	7.97 ± 0.04 (102)	<0.004 (102)	7.791 ± 0.028 (102)	0.3478 ± 0.0028 (102)	11.84 ± 0.07 (102)
Certificate‡			*7.97 ± 0.04*	*NA*	*7.85 ± 0.06*	*0.3595 ± 0.0045*	*11.81 ± 0.05*
SARM-40	MINTEK	Carbonatite	0.410 ± 0.008 (23)	0.0504 ± 0.0010 (23)	49.95 ± 0.21 (23)	0.0079 ± 0.0005 (23)	2.662 ± 0.014 (23)
Certificate [1] ‡			*0.410 ± 0.085*	*0.035 ± 0.014*	*49.77 ± 1.65*	*0.0051**	*2.75 ± 0.14*
SY-4	CANMET	Diorite Gneiss	20.90 ± 0.09 (18)	0.0370 ± 0.0013 (18)	8.003 ± 0.027 (18)	<0.002 (18)	6.250 ± 0.029 (18)
Certificate†			*20.69 ± 0.08*	*0.0380 ± 0.0006*	*8.05 ± 0.04*	*0.00175 ± 0.00015*	*6.21 ± 0.03*
UB-N	ANRT	Serpentine	2.917 ± 0.017 (57)	<0.004 (57)	1.2103 ± 0.0028 (57)	0.3346 ± 0.0016 (57)	8.31 ± 0.04 (57)
Certificate†			*2.90 ± 0.08*	*0.0030 ± 0.0003*	*1.20 ± 0.03*	*0.336 ± 0.015*	*8.34 ± 0.10*

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements). OKUM is routinely prepared and reported "as is"; data do not include a correction for the approximate 0.2% loss on drying.*

†Certificate value is the recommended working value ± 95% confidence interval; ‡Certificate value is the average ± 1 standard deviation of the laboratory means.

*ǂCertificate value is average ± 95% confidence interval on the population mean; *Provisional or indicative values; NA: data not available.*

References: *[1]Ring (1993).*

Abbreviations: *ANRT = Association National de la Recherche Technique; BAS = Bureau of Analysed Samples Ltd.; CANMET = Canadian Centre for Mineral and Energy Technology; GIT-IWG = Group International de Travail – International Working group; IAG = International Association of Geoanalysts; MINTEK = Council for Mineral Technology, South Africa; USGS = United States Geological Survey.*

Table 24.2, ***continued.***

Material	Provider	Description	K_2O (wt %)	MgO (wt %)	MnO (wt %)	Na_2O (wt %)	Nitrogen LOI 105 (wt %)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	0.465 ± 0.009 (116)	7.34 ± 0.04 (116)	0.1821 ± 0.0023 (116)	2.458 ± 0.020 (116)	0.18 ± 0.04 (116)
ODL-1	In-house	Dolomitic Limestone	0.68 ± 0.04 (39)	17.64 ± 0.07 (39)	0.1717 ± 0.0014 (39)	0.082 ± 0.019 (39)	0.26 ± 0.10 (39)
OPEG-1	In-house	Evolved Pegmatite	2.98 ± 0.04 (36)	0.079 ± 0.007 (36)	0.0294 ± 0.0021 (36)	4.52 ± 0.04 (36)	0.08 ± 0.04 (36)
ORCA-1	In-house	Rhyolite	2.080 ± 0.022 (147)	0.465 ± 0.008 (147)	0.0546 ± 0.0017 (147)	4.70 ± 0.04 (147)	0.08 ± 0.04 (147)
QS-1	In-house	Calcareous Shale	4.268 ± 0.027 (51)	3.639 ± 0.019 (51)	0.0966 ± 0.0015 (51)	0.154 ± 0.014 (51)	0.88 ± 0.23 (51)
RV-1	In-house	Melagabbro	0.668 ± 0.008 (108)	9.13 ± 0.04 (108)	0.1609 ± 0.0021 (108)	2.193 ± 0.023 (108)	0.15 ± 0.04 (108)
Certified reference materials							
AGV-2	USGS	Andesite	2.823 ± 0.009 (160)	1.794 ± 0.006 (160)	0.0977 ± 0.0017 (160)	4.35 ± 0.03 (160)	0.7125 ± 0.0000 (160)
Certificate‡			*2.88 ± 0.11*	*1.79 ± 0.03*	*0.099 ± 0.003*	*4.19 ± 0.13*	*NA*
BCS-353	BAS	Portland Cement	0.4105 ± 0.0009 (7)	2.444 ± 0.006 (7)	0.2008 ± 0.0013 (7)	0.075 ± 0.005 (7)	<0.05 (7)
Certificate			*0.49 ± 0.02*	*2.42 ± 0.05*	*NA*	*0.10 ± 0.01*	*NA*
BHVO-2	USGS	Basalt	0.5101 ± 0.0023 (152)	7.389 ± 0.016 (152)	0.1672 ± 0.0019 (152)	2.310 ± 0.021 (152)	<0.05 (152)
Certificate‡			*0.52 ± 0.01*	*7.23 ± 0.12*	*0.1666 ± 0.0052*	*2.22 ± 0.08*	*NA*
GSP-2	USGS	Granodiorite	5.279 ± 0.014 (164)	0.977 ± 0.008 (164)	0.0514 ± 0.0016 (164)	2.895 ± 0.026 (164)	0.125 ± 0.006 (164)
Certificate‡			*5.38 ± 0.14*	*0.96 ± 0.03*	*0.0413 ± 0.0026*	*2.78 ± 0.09*	*NA*
IF-G	GIT-IWG	Iron Formation	0.0135 ± 0.0003 (9)	1.941 ± 0.009 (9)	0.0393 ± 0.0017 (9)	0.055 ± 0.020 (9)	<0.05 (9)
Certificate†			*0.012 ± 0.008*	*1.89 ± 0.04*	*0.042 ± 0.003*	*0.032 ± 0.01*	*NA*
OKUM-1	IAG	Ultramafic Komatiite	0.059 ± 0.007 (102)	21.55 ± 0.11 (102)	0.1733 ± 0.0019 (102)	1.176 ± 0.014 (102)	0.23 ± 0.05 (102)
Certificate‡			*0.044 ± 0.002*	*21.29 ± 0.10*	*0.1813 ± 0.0027*	*1.136 ± 0.022*	*NA*
SARM-40	MINTEK	Carbonatite	0.0146 ± 0.0004 (23)	1.907 ± 0.012 (23)	0.1799 ± 0.0016 (23)	0.030 ± 0.012 (23)	<0.05 (23)
Certificate [1]*‡*			*0.030 ± 0.026**	*1.97 ± 0.29*	*0.18 ± 0.01*	*0.05 ± 0.21**	*NA*
SY-4	CANMET	Diorite Gneiss	1.577 ± 0.016 (18)	0.525 ± 0.008 (18)	0.1072 ± 0.0018 (18)	7.31 ± 0.08 (18)	0.097 ± 0.010 (18)
Certificate†			*1.66 ± 0.02*	*0.54 ± 0.01*	*0.108 ± 0.001*	*7.1 ± 0.05*	*NA*
UB-N	ANRT	Serpentine	0.0223 ± 0.0005 (57)	35.80 ± 0.07 (57)	0.1184 ± 0.0013 (57)	0.143 ± 0.007 (57)	1.6087 ± 5.0375 (57)
Certificate†			*0.02 ± 0.01*	*35.21 ± 0.18*	*0.12 ± 0.01*	*0.10 ± 0.04*	*NA*

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements). OKUM is routinely prepared and reported "as is"; data do not include a correction for the approximate 0.2% loss on drying.*

†Certificate value is the recommended working value ± 95% confidence interval; ‡Certificate value is the average ± 1 standard deviation of the laboratory means.

*ǂCertificate value is average ± 95% confidence interval on the population mean; *Provisional or indicative values; NA: data not available.*

References: *[1]Ring (1993).*

Abbreviations: *ANRT = Association National de la Recherche Technique; BAS = Bureau of Analysed Samples Ltd.; CANMET = Canadian Centre for Mineral and Energy Technology; GIT-IWG = Group International de Travail – International Working group; IAG = International Association of Geoanalysts; MINTEK = Council for Mineral Technology, South Africa; USGS = United States Geological Survey.*

Table 24.2, ***continued.***

Material	Provider	Description	P_2O_5 (wt %)	SiO_2 (wt %)	TiO_2 (wt %)	Total (wt %)	Total LOI (wt %)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	0.1085 ± 0.0026 (116)	49.08 ± 0.26 (116)	1.144 ± 0.010 (116)	99.9 ± 0.4 (116)	0.12 ± 0.04 (116)
ODL-1	In-house	Dolomitic Limestone	0.0343 ± 0.0006 (39)	8.88 ± 0.05 (39)	0.101 ± 0.006 (39)	98.91 ± 0.19 (39)	40.19 ± 0.07 (39)
OPEG-1	In-house	Evolved Pegmatite	0.0391 ± 0.0022 (36)	75.7 ± 0.4 (36)	0.017 ± 0.013 (36)	99.2 ± 0.4 (36)	0.666 ± 0.027 (36)
ORCA-1	In-house	Rhyolite	0.0531 ± 0.0023 (147)	74.7 ± 0.4 (147)	0.290 ± 0.021 (147)	99.7 ± 0.5 (147)	0.774 ± 0.030 (147)
QS-1	In-house	Calcareous Shale	0.1467 ± 0.0028 (51)	50.44 ± 0.27 (51)	0.752 ± 0.007 (51)	99.4 ± 0.4 (51)	11.32 ± 0.23 (51)
RV-1	In-house	Melagabbro	0.0154 ± 0.0020 (108)	49.88 ± 0.26 (108)	0.204 ± 0.008 (108)	99.4 ± 0.4 (108)	2.21 ± 0.04 (108)
Certified reference materials							
AGV-2	USGS	Andesite	0.465 ± 0.005 (160)	59.46 ± 0.23 (160)	1.039 ± 0.007 (160)	100.22 ± 0.27 (160)	1.1496 ± 0.0000 (160)
Certificate‡			*0.48 ± 0.02*	*59.3 ± 0.7*	*1.05 ± 0.22*	*NA*	*NA*
BCS-353	BAS	Portland Cement	0.0786 ± 0.0025 (7)	20.55 ± 0.04 (7)	0.150 ± 0.011 (7)	97.19 ± 0.16 (7)	0.0069 ± 0.0000 (7)
Certificate			*0.077 ± 0.004*	*20.5 ± 0.2*	*NA*	*NA*	*NA*
BHVO-2	USGS	Basalt	0.263 ± 0.003 (152)	50.20 ± 0.15 (152)	2.751 ± 0.013 (152)	100.50 ± 0.18 (152)	−0.683 ± 0.016 (152)
Certificate‡			*0.27 ± 0.02*	*49.9 ± 0.6*	*2.73 ± 0.04*	*NA*	*NA*
GSP-2	USGS	Granodiorite	0.283 ± 0.004 (164)	66.95 ± 0.21 (164)	0.678 ± 0.004 (164)	100.11 ± 0.23 (164)	0.762 ± 0.005 (164)
Certificate‡			*0.29 ± 0.02*	*66.6 ± 0.8*	*0.66 ± 0.02*	*NA*	*NA*
IF-G	GIT-IWG	Iron Formation	0.0662 ± 0.0019 (9)	41.22 ± 0.30 (9)	<0.01 (9)	99.7 ± 0.4 (9)	−1.2278 ± 0.0000 (9)
Certificate†			*0.063 ± 0.014*	*41.20 ± 0.15*	*0.014 ± 0.008*	*NA*	*1.1**
OKUM-1	IAG	Ultramafic Komatiite	0.0235 ± 0.0020 (102)	44.02 ± 0.20 (102)	0.378 ± 0.007 (102)	100.1 ± 0.4 (102)	4.76 ± 0.06 (102)
Certificate‡			*0.0266 ± 0.0023*	*44.14 ± 0.14*	*0.380 ± 0.004*	*NA*	*4.49 ± 0.14**
SARM-40	MINTEK	Carbonatite	1.852 ± 0.021 (23)	3.14 ± 0.07 (23)	0.024 ± 0.006 (23)	99.28 ± 0.19 (23)	39.053 ± 0.000 (23)
Certificate [1]‡			*2.05 ± 0.08*	*3.08 ± 0.18*	*0.05 ± 0.01*	*NA*	*NA*
SY-4	CANMET	Diorite Gneiss	0.128 ± 0.004 (18)	50.11 ± 0.23 (18)	0.289 ± 0.006 (18)	99.6 ± 0.3 (18)	4.380 ± 0.025 (18)
Certificate†			*0.131 ± 0.004*	*49.9 ± 0.1*	*0.287 ± 0.003*		*4.56 ± 0.07*
UB-N	ANRT	Serpentine	0.0116 ± 0.0013 (57)	39.70 ± 0.13 (57)	0.103 ± 0.005 (57)	100.71 ± 0.18 (57)	12.0397 ± 0.0000 (57)
Certificate†			*0.04 ± 0.02*	*39.43 ± 0.15*	*0.11 ± 0.01*	*NA*	*12.06**

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements). OKUM is routinely prepared and reported "as is"; data do not include a correction for the approximate 0.2% loss on drying.*

†Certificate value is the recommended working value ± 95% confidence interval; ‡Certificate value is the average ± 1 standard deviation of the laboratory means.

*ǂCertificate value is average ± 95% confidence interval on the population mean; *Provisional, information or indicative values; NA: data not available.*

References: *[1]Ring (1993).*

Abbreviations: *ANRT = Association National de la Recherche Technique; BAS = Bureau of Analysed Samples Ltd.; CANMET = Canadian Centre for Mineral and Energy Technology; GIT-IWG = Group International de Travail – International Working group; IAG = International Association of Geoanalysts; MINTEK = Council for Mineral Technology, South Africa; USGS = United States Geological Survey.*

Table 24.3. Summary of results obtained by the XRF-M02 test method for routine in-house and certified reference materials from June 28, 2022, to July 10, 2025.

Material	Provider	Description	Co (ppm)	Cu (ppm)	Ni (ppm)	Pb (ppm)
In-house reference materials						
LK NIP-1	In-house	Diabase Sill	59 ± 4 (32)	167 ± 16 (32)	146 ± 3 (32)	<35 (32)
ODL-1	In-house	Dolomitic Limestone	<12 (27)	<60 (27)	<30 (27)	<35 (27)
OPEG-1	In-house	Evolved Pegmatite	<12 (4)	<60 (4)	<30 (4)	<35 (4)
ORCA-1	In-house	Rhyolite	<12 (31)	<60 (31)	<30 (31)	<35 (31)
QS-1	In-house	Calcareous Shale	17.3 ± 3.2 (13)	<60 (13)	40 ± 4 (13)	<35 (13)
RV-1	In-house	Melagabbro	73 ± 4 (34)	2031 ± 70 (34)	559 ± 13 (34)	<35 (34)
Certified reference materials						
AGV-2	USGS	Andesite	17 ± 4 (40)	<60 (40)	<30 (40)	<35 (40)
Certificate‡			*16 ± 1*	*53 ± 4*	*19 ± 3*	*13 ± 1*
BCS-353	BAS	Portland Cement	<12 (5)	<60 (5)	72.0 ± 1.3 (5)	<35 (5)
Certificate			*NA*	*NA*	*NA*	*NA*
BHVO-2	USGS	Basalt	46 ± 5 (48)	123 ± 3 (48)	119.9 ± 2.1 (48)	<35 (48)
Certificate‡			*45 ± 3*	*127 ± 7*	*119 ± 7*	*NA*
GSP-2	USGS	Granodiorite	<12 (43)	<60 (43)	<30 (43)	43.4 ± 2.9 (43)
Certificate‡			*7.3 ± 0.8*	*43 ± 4*	*17 ± 2*	*42 ± 3*
OKUM-1	IAG	Ultramafic Komatiite	92 ± 5 (46)	54 ± 10 (46)	879 ± 13 (46)	0.9 ± 2.4 (46)
Certificate⸸			*88.9 ± 1.5*	*43.5 ± 1.2*	*886 ± 10*	*0.26 ± 0.2**
SARM-40	MINTEK	Carbonatite	15.0 ± 2.7 (17)	<60 (17)	<30 (17)	<35 (17)
Certificate [1]‡			*20.0 ± 11.5**	*10.0 ± 3.5**	*25 ± 34**	*20 ± 22**
SY-4	CANMET	Diorite Gneiss	<12 (9)	<60 (9)	<30 (9)	<35 (9)
Certificate†			*2.8 ± 0.2*	*7 ± 1*	*9 ± 1*	*10 ± 1*
UB-N	ANRT	Serpentine	104 ± 3 (24)	90.3 ± 2.9 (24)	1939 ± 24 (24)	<35 (24)
Certificate†			*100 ± 12*	*28 ± 3*	*2000 ± 80*	*13 ± 3*

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements). OKUM is routinely prepared and reported "as is"; data do not include a correction for the approximate 0.2% loss on drying.*

†Certificate value is the recommended working value ± 95% confidence interval; ‡Certificate value is the average ± 1 standard deviation of the laboratory means.

*⸸Certificate value is average ± 95% confidence interval on the population mean; *Provisional, information or indicative values; NA: data not available.*

References: *[1]Ring (1993).*

Abbreviations: *ANRT = Association National de la Recherche Technique; BAS = Bureau of Analysed Samples Ltd.; CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; MINTEK = Council for Mineral Technology, South Africa; USGS = United States Geological Survey.*

Table 24.3, ***continued.***

Material	Provider	Description	Sr (ppm)	V (ppm)	Zn (ppm)	Zr (ppm)
In-house reference materials						
LK NIP-1	In-house	Diabase Sill	160.7 ± 1.5 (32)	286 ± 7 (32)	96.3 ± 2.7 (32)	81.8 ± 2.0 (32)
ODL-1	In-house	Dolomitic Limestone	66.7 ± 0.8 (27)	17 ± 4 (27)	55.3 ± 1.0 (27)	26.9 ± 1.0 (27)
OPEG-1	In-house	Evolved Pegmatite	41.73 ± 0.26 (4)	<8 (4)	<40 (4)	<10 (4)
ORCA-1	In-house	Rhyolite	70.7 ± 1.1 (31)	<8 (31)	44 ± 4 (31)	243.4 ± 2.8 (31)
QS-1	In-house	Calcareous Shale	110.4 ± 1.5 (13)	104 ± 5 (13)	69.5 ± 2.0 (13)	154.4 ± 2.3 (13)
RV-1	In-house	Melagabbro	332.1 ± 2.7 (34)	101 ± 5 (34)	95 ± 4 (34)	18.0 ± 1.9 (34)
Certified reference materials						
AGV-2	USGS	Andesite	646.7 ± 2.9 (40)	112 ± 5 (40)	86.7 ± 1.4 (40)	229.0 ± 1.5 (40)
Certificate‡			*658 ± 17*	*120 ± 5*	*86 ± 8*	*230 ± 4*
BCS-353	BAS	Portland Cement	1838 ± 4 (5)	52.4 ± 1.5 (5)	191.4 ± 1.0 (5)	74.2 ± 2.1 (5)
Certificate			*NA*	*NA*	*NA*	*NA*
BHVO-2	USGS	Basalt	385.4 ± 2.2 (48)	337 ± 8 (48)	101.2 ± 1.5 (48)	167.1 ± 1.6 (48)
Certificate‡			*389 ± 23*	*317 ± 11*	*103 ± 6*	*172 ± 11*
GSP-2	USGS	Granodiorite	235.7 ± 1.7 (43)	44.4 ± 2.8 (43)	112.9 ± 1.4 (43)	564 ± 6 (43)
Certificate‡			*240 ± 10*	*52 ± 4*	*120 ± 10*	*550 ± 30*
OKUM-1	IAG	Ultramafic Komatiite	15.0 ± 1.4 (46)	168 ± 4 (46)	61 ± 4 (46)	16.7 ± 1.5 (46)
Certificate‡			*16.1 ± 1.0*	*167.8 ± 3.1*	*61.2 ± 1.9*	*17.0 ± 1.4*
SARM-40	MINTEK	Carbonatite	1613 ± 6 (17)	30.9 ± 1.7 (17)	<40 (17)	117 ± 7 (17)
Certificate [1]*‡*			*1600 ± 150*	*27 ± 5.5*	*25 ± 7*	*87 ± 16*
SY-4	CANMET	Diorite Gneiss	1189 ± 4 (9)	<8 (9)	91.7 ± 2.5 (9)	573 ± 7 (9)
Certificate†			*1191 ± 12*	*8 ± 1.6*	*93 ± 2*	*517 ± 16*
UB-N	ANRT	Serpentine	8.3 ± 0.9 (24)	58 ± 4 (24)	77.5 ± 0.9 (24)	<10 (24)
Certificate†			*9.00 ± 1.85*	*75 ± 9*	*85 ± 7*	*4 ± 1*

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements). OKUM is routinely prepared and reported "as is"; data do not include a correction for the approximate 0.2% loss on drying.*

†Certificate value is the recommended working value ± 95% confidence interval; ‡Certificate value is the average ± 1 standard deviation of the laboratory means.

*ǂCertificate value is average ± 95% confidence interval on the population mean; *Provisional, information or indicative values; NA: data not available.*

References: *[1]Ring (1993).*

Abbreviations: *ANRT = Association National de la Recherche Technique; BAS = Bureau of Analysed Samples Ltd.; CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; MINTEK = Council for Mineral Technology, South Africa; USGS = United States Geological Survey.*

Table 24.4. Summary of results obtained by the XRF-T05 test method for routine in-house and certified reference materials from January 21, 2022, to July 10, 2025.

Material	Provider	Description	As (ppm)	Ba (ppm)	Br (ppm)	Ce (ppm)	Co (ppm)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	<4 (93)	145 ± 5 (93)	0.9 ± 0.4 (93)	23 ± 5 (93)	54.8 ± 1.1 (93)
MMTe-1**	In-house	Gold Ore	25.7 ± 0.4 (4)	3352 ± 18 (3)	2.73 ± 0.10 (3)	133.8 ± 2.7 (3)	7.3 ± 0.7 (3)
ODL-1	In-house	Dolomitic Limestone	53.5 ± 2.3 (8)	52.0 ± 2.4 (8)	8.2 ± 0.7 (8)	31 ± 4 (8)	9.9 ± 0.4 (8)
OPEG-1	In-house	Evolved Pegmatite	26 ± 4 (32)	17.7 ± 3.1 (32)	<0.8 (32)	<18 (32)	<1.8 (32)
ORCA-1	In-house	Rhyolite	<4 (113)	337 ± 4 (113)	<0.8 (113)	50 ± 3 (113)	3.6 ± 1.5 (113)
PJV-2	In-house	Rock Powder	54.4 ± 0.8 (7)	127 ± 4 (7)	<0.8 (7)	<18 (7)	47.8 ± 0.6 (7)
QS-1	In-house	Calcareous Shale	8.1 ± 2.1 (30)	353 ± 6 (30)	<0.8 (30)	83 ± 5 (30)	16.0 ± 0.5 (30)
RV-1	In-house	Melagabbro	<4 (68)	213 ± 4 (68)	<0.8 (68)	<18 (68)	66.0 ± 0.8 (68)
SPC-1	In-house	Portland Cement	10.9 ± 1.6 (4)	469 ± 6 (4)	<0.8 (4)	52 ± 7 (4)	7.25 ± 0.21 (4)
Certified reference materials							
AGV-2	USGS	Andesite	5.3 ± 2.1 (133)	1196 ± 31 (133)	<0.8 (133)	80 ± 5 (133)	16.1 ± 0.6 (133)
Certificate‡			*0.67 ± 0.12* [1]	*1140 ± 32*	*0.13* [1]	*68 ± 3*	*16 ± 1*
BHVO-2	USGS	Basalt	<4 (111)	147 ± 11 (111)	<0.8 (111)	47 ± 5 (111)	45.6 ± 1.1 (111)
Certificate‡			*0.70 ± 0.14* [1]	*130 ± 13*	*0.30 ± 0.01* [1]	*38 ± 2*	*45 ± 3*
GSP-2	USGS	Granodiorite	7.5 ± 2.4 (130)	1347 ± 23 (130)	<0.8 (130)	415 ± 10 (130)	7.2 ± 0.5 (130)
Certificate‡			*NA*	*1340 ± 44*	*NA*	*410 ± 30*	*7.3 ± 0.8*
OKUM-1	IAG	Ultramafic Komatiite	<4 (53)	<12 (53)	<0.8 (53)	<18 (53)	84.7 ± 0.7 (53)
Certificate¥			*NA*	*6.2 ± 0.5**	*NA*	*1.27 ± 0.03*	*88.9 ± 1.5*
STSD-2	CANMET	Stream Sediment	42.8 ± 2.5 (10)	532 ± 19 (10)	3.1 ± 0.7 (10)	94 ± 8 (10)	21.2 ± 0.5 (10)
Certificate [2,3]			*42 ± 3*	*540 ± 43*	*4 ± 1*	*93 ± 10*	*19 ± 2*
TDB-1	CANMET	Diabase	4.7 ± 0.6 (8)	269 ± 3 (8)	2.51 ± 0.09 (8)	47 ± 4 (8)	45.1 ± 0.7 (8)
Certificate†			*2.5 ± 0.5**	*241 ± 13*	*NA*	*41 ± 4*	*47 ± 4**

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements).*
‡Certificate value is the average ± 1 standard deviation of the laboratory means.
¥Certificate value is average ± 95% confidence interval on the population mean.
†Certificate value is the recommended working value ± 95% confidence interval.
**Provisional, information or indicative values; NA: data not available.*
***In-house characterization of MMTe-1 detailed in Burnham and Hastie (2023).*
References: *[1]Jochum et al. (2016); [2]Lynch (1990); [3]Lynch (1999).*
Abbreviations: *CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; USGS = United States Geological Survey.*

Table 24.4, ***continued.***

Material	Provider	Description	Cr (ppm)	Cs (ppm)	Cu (ppm)	Ga (ppm)	La (ppm)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	157 ± 4 (93)	<8 (93)	156.0 ± 2.3 (93)	19.3 ± 0.3 (93)	<9 (93)
MMTe-1**	In-house	Gold Ore	60.5 ± 1.5 (3)	12.5 ± 0.8 (3)	283.7 ± 1.5 (3)	16.0 ± 0.3 (3)	70.7 ± 2.7 (3)
ODL-1	In-house	Dolomitic Limestone	15.4 ± 1.0 (8)	<8 (8)	33.71 ± 0.29 (8)	2.85 ± 0.22 (8)	14.7 ± 1.9 (8)
OPEG-1	In-house	Evolved Pegmatite	152 ± 4 (32)	141.9 ± 2.3 (32)	2.2 ± 0.6 (32)	30.96 ± 0.29 (32)	<9 (32)
ORCA-1	In-house	Rhyolite	56.8 ± 2.8 (113)	<8 (113)	10.7 ± 0.5 (113)	15.15 ± 0.27 (113)	22.7 ± 1.7 (113)
PJV-2	In-house	Rock Powder	233 ± 5 (7)	<8 (7)	182.4 ± 3.1 (7)	16.86 ± 0.32 (7)	<9 (7)
QS-1	In-house	Calcareous Shale	71.6 ± 2.7 (30)	<8 (30)	11.3 ± 0.6 (30)	18.9 ± 0.4 (30)	38.4 ± 2.0 (30)
RV-1	In-house	Melagabbro	235 ± 6 (68)	<8 (68)	1684 ± 24 (68)	14.73 ± 0.28 (68)	<9 (68)
SPC-1	In-house	Portland Cement	37.2 ± 2.8 (4)	<8 (4)	24.8 ± 0.5 (4)	7.6 ± 0.6 (4)	20 ± 4 (4)
Certified reference materials							
AGV-2	USGS	Andesite	13.3 ± 2.1 (133)	<8 (133)	56.9 ± 1.1 (133)	21.3 ± 0.4 (133)	43.0 ± 2.6 (133)
Certificate‡			*17 ± 2*	*1.16 ± 0.08**	*53 ± 4*	*20 ± 1*	*38 ± 1*
BHVO-2	USGS	Basalt	299 ± 11 (111)	<8 (111)	136.0 ± 1.5 (111)	21.7 ± 0.4 (111)	14.1 ± 2.7 (111)
Certificate‡			*280 ± 19*	*0.099 ± 0.010* [1]	*127 ± 7*	*21.7 ± 0.9*	*15 ± 1*
GSP-2	USGS	Granodiorite	14.1 ± 1.8 (130)	<8 (130)	43.8 ± 0.8 (130)	22.7 ± 0.4 (130)	177 ± 7 (130)
Certificate‡			*20 ± 6*	*1.2 ± 0.1**	*43 ± 4*	*22 ± 2*	*180 ± 12*
OKUM-1	IAG	Ultramafic Komatiite	2396 ± 55 (53)	<8 (53)	43.4 ± 0.8 (53)	8.75 ± 0.29 (53)	<9 (53)
*Certificate*ǂ			*2460 ± 31*	*0.184 ± 0.003*	*43.5 ± 1.2*	*8.79 ± 0.16*	*0.412 ± 0.017*
STSD-2	CANMET	Stream Sediment	109 ± 4 (10)	12.4 ± 2.8 (10)	52.5 ± 0.8 (10)	22.15 ± 0.30 (10)	54.2 ± 2.3 (10)
Certificate [2,3]			*116 ± 13*	*12 ± 1.4*	*47 ± 5*	*24 ± 4*	*59 ± 6*
TDB-1	CANMET	Diabase	246.6 ± 1.6 (8)	<8 (8)	316.6 ± 1.4 (8)	22.19 ± 0.25 (8)	15.4 ± 2.9 (8)
Certificate†			*251 ± 13*	*NA*	*323 ± 15*	*21 ± 2**	*17 ± 2**

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements).*
‡Certificate value is the average ± 1 standard deviation of the laboratory means.
ǂCertificate value is average ± 95% confidence interval on the population mean.
†Certificate value is the recommended working value ± 95% confidence interval.
**Provisional, information or indicative values; NA: data not available.*
***In-house characterization of MMTe-1 detailed in Burnham and Hastie (2023).*
References: *[1]Jochum et al. (2016); [2]Lynch (1990); [3]Lynch (1999).*
Abbreviations: *CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; USGS = United States Geological Survey.*

Table 24.4, ***continued.***

Material	Provider	Description	Mn (ppm)	Mo (ppm)	Nb (ppm)	Ni (ppm)	Pb (ppm)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	1426 ± 7 (93)	1.10 ± 0.28 (93)	4.09 ± 0.21 (93)	143.3 ± 1.9 (93)	3.2 ± 0.9 (93)
MMTe-1**	In-house	Gold Ore	490.0 ± 2.3 (3)	1284 ± 3 (3)	8.90 ± 0.26 (3)	18.25 ± 0.19 (3)	127.1 ± 1.3 (3)
ODL-1	In-house	Dolomitic Limestone	1387 ± 5 (8)	<0.9 (8)	2.01 ± 0.20 (8)	9.1 ± 0.3 (8)	17.2 ± 1.0 (8)
OPEG-1	In-house	Evolved Pegmatite	222 ± 5 (32)	0.96 ± 0.30 (32)	58.6 ± 1.8 (32)	3.92 ± 0.30 (32)	10.2 ± 1.0 (32)
ORCA-1	In-house	Rhyolite	424 ± 3 (113)	3.53 ± 0.27 (113)	11.02 ± 0.21 (113)	2.9 ± 0.4 (113)	5.4 ± 0.9 (113)
PJV-2	In-house	Rock Powder	2071 ± 5 (7)	1.06 ± 0.17 (7)	2.03 ± 0.24 (7)	77.2 ± 1.1 (7)	4.1 ± 0.5 (7)
QS-1	In-house	Calcareous Shale	752 ± 4 (30)	1.03 ± 0.27 (30)	13.69 ± 0.29 (30)	38.5 ± 0.7 (30)	9.2 ± 1.0 (30)
RV-1	In-house	Melagabbro	1297 ± 7 (68)	<0.9 (68)	<0.8 (68)	516 ± 6 (68)	5.5 ± 0.9 (68)
SPC-1	In-house	Portland Cement	430.6 ± 2.3 (4)	6.63 ± 0.24 (4)	5.93 ± 0.26 (4)	43.6 ± 1.0 (4)	12.1 ± 0.6 (4)
Certified reference materials							
AGV-2	USGS	Andesite	823 ± 13 (133)	1.76 ± 0.30 (133)	13.94 ± 0.21 (133)	19.4 ± 0.7 (133)	14.9 ± 0.8 (133)
Certificate‡			*770 ± 20*	*NA*	*15 ± 1*	*19 ± 3*	*13 ± 1*
BHVO-2	USGS	Basalt	1363 ± 22 (111)	3.9 ± 0.4 (111)	17.78 ± 0.25 (111)	127.4 ± 2.8 (111)	2.3 ± 0.9 (111)
Certificate‡			*1290 ± 40*	*4.07 ± 0.44* [1]	*18 ± 2**	*119 ± 7*	*1.65 ± 0.05* [1]
GSP-2	USGS	Granodiorite	317 ± 5 (130)	2.2 ± 0.4 (130)	25.8 ± 0.4 (130)	16.3 ± 0.6 (130)	42.8 ± 1.1 (130)
Certificate‡			*NA*	*2.1 ± 0.6**	*27 ± 2*	*17 ± 2*	*42 ± 3*
OKUM-1	IAG	Ultramafic Komatiite	1349 ± 8 (53)	<0.9 (53)	<0.8 (53)	911 ± 12 (53)	<2.0 (53)
Certificate‡			*1404 ± 21*	*NA*	*0.37 ± 0.06*	*886 ± 10*	*0.26 ± 0.02*
STSD-2	CANMET	Stream Sediment	1118 ± 22 (10)	13.5 ± 0.4 (10)	21.4 ± 0.4 (10)	64.1 ± 1.4 (10)	78.5 ± 0.9 (10)
Certificate [2,3]			*1060 ± 60*	*13 ± 2*	*20 ± 3*	*53 ± 6*	*66 ± 4*
TDB-1	CANMET	Diabase	1500 ± 6 (8)	<0.9 (8)	11.24 ± 0.24 (8)	91.5 ± 1.5 (8)	16.0 ± 0.3 (8)
Certificate†			*1577 ± 76**	*1.6 ± 0.7**	*NA*	*92 ± 6*	*17 ± 3**

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements).*
‡Certificate value is the average ± 1 standard deviation of the laboratory means.
ǂCertificate value is average ± 95% confidence interval on the population mean.
†Certificate value is the recommended working value ± 95% confidence interval.
**Provisional, information or indicative values; NA: data not available.*
***In-house characterization of MMTe-1 detailed in Burnham and Hastie (2023).*
References: *[1]Jochum et al. (2016); [2]Lynch (1990); [3]Lynch (1999).*
Abbreviations: *CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; USGS = United States Geological Survey.*

Table 24.4, ***continued.***

Material	Provider	Description	Rb (ppm)	Sc (ppm)	Sr (ppm)	Th (ppm)	Ti (ppm)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	12.59 ± 0.26 (93)	29.7 ± 1.3 (93)	159.1 ± 1.7 (93)	<1.9 (93)	6809 ± 84 (93)
MMTe-1**	In-house	Gold Ore	187.4 ± 1.3 (3)	4.1 ± 0.5 (3)	1505 ± 6 (3)	12.7 ± 0.8 (3)	2428 ± 21 (3)
ODL-1	In-house	Dolomitic Limestone	22.90 ± 0.21 (8)	8.9 ± 0.9 (8)	64.5 ± 0.7 (8)	<1.9 (8)	733 ± 10 (8)
OPEG-1	In-house	Evolved Pegmatite	3542 ± 10 (32)	<4 (32)	45.9 ± 0.3 (32)	3.4 ± 0.6 (32)	62.1 ± 3.0 (32)
ORCA-1	In-house	Rhyolite	52.09 ± 0.27 (113)	5.1 ± 0.8 (113)	69.0 ± 0.6 (113)	4.4 ± 0.5 (113)	1407 ± 17 (113)
PJV-2	In-house	Rock Powder	34.94 ± 0.23 (7)	46.0 ± 1.0 (7)	79.41 ± 0.23 (7)	<1.9 (7)	4865 ± 26 (7)
QS-1	In-house	Calcareous Shale	130.6 ± 0.6 (30)	14.7 ± 1.0 (30)	106.6 ± 1.4 (30)	10.4 ± 0.5 (30)	4668 ± 48 (30)
RV-1	In-house	Melagabbro	19.2 ± 0.3 (68)	25.4 ± 1.2 (68)	324 ± 5 (68)	<1.9 (68)	1240 ± 19 (68)
SPC-1	In-house	Portland Cement	17.55 ± 0.10 (4)	8.5 ± 1.9 (4)	436.9 ± 0.9 (4)	4.13 ± 0.28 (4)	1574 ± 10 (4)
Certified reference materials							
AGV-2	USGS	Andesite	71.8 ± 1.0 (133)	14.0 ± 0.8 (133)	674 ± 8 (133)	6.5 ± 0.5 (133)	6542 ± 149 (133)
Certificate‡			*68.6 ± 2.3*	*13 ± 1*	*658 ± 17*	*6.1 ± 0.6*	*6295 ± 1319*
BHVO-2	USGS	Basalt	9.96 ± 0.31 (111)	30.7 ± 1.2 (111)	391 ± 5 (111)	<1.9 (111)	17 530 ± 340 (111)
Certificate‡			*9.8 ± 1.0*	*32 ± 1*	*389 ± 23*	*1.2 ± 0.3**	*16 366 ± 240*
GSP-2	USGS	Granodiorite	247.8 ± 2.9 (130)	6.2 ± 0.8 (130)	239 ± 4 (130)	106.0 ± 2.4 (130)	4068 ± 67 (130)
Certificate‡			*245 ± 7*	*6.3 ± 0.7*	*240 ± 10*	*105 ± 8*	*3957 ± 120*
OKUM-1	IAG	Ultramafic Komatiite	0.94 ± 0.19 (53)	25.9 ± 1.0 (53)	14.51 ± 0.21 (53)	<1.9 (53)	2248 ± 27 (53)
Certificate‡			*0.96 ± 0.06*	*27.9 ± 1.5*	*16.1 ± 1.0*	*0.031 ± 0.004*	*2278 ± 24*
STSD-2	CANMET	Stream Sediment	103.4 ± 1.2 (10)	14.8 ± 0.8 (10)	439 ± 5 (10)	15.2 ± 0.7 (10)	4805 ± 105 (10)
Certificate [2,3]			*104 ± 10*	*16 ± 2*	*400 ± 65*	*17.2 ± 1.3*	*4796**
TDB-1	CANMET	Diabase	21.13 ± 0.21 (8)	35.9 ± 0.9 (8)	227.3 ± 2.9 (8)	2.3 ± 0.8 (8)	13 705 ± 21 (8)
Certificate†			*23 ± 2**	*36 ± 3**	*230 ± 24**	*2.7 ± 0.3*	*8393 ± 600**

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements).*
‡Certificate value is the average ± 1 standard deviation of the laboratory means.
ǂCertificate value is average ± 95% confidence interval on the population mean.
†Certificate value is the recommended working value ± 95% confidence interval.
**Provisional, information or indicative values; NA: data not available.*
***In-house characterization of MMTe-1 detailed in Burnham and Hastie (2023).*
References: *[2]Lynch (1990); [3]Lynch (1999).*
Abbreviations: *CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; USGS = United States Geological Survey.*

Table 24.4, ***continued.***

Material	Provider	Description	U (ppm)	V (ppm)	Y (ppm)	Zn (ppm)	Zr (ppm)
In-house reference materials							
LK NIP-1	In-house	Diabase Sill	<1.3 (93)	272.4 ± 2.6 (93)	20.8 ± 0.6 (93)	96.2 ± 0.7 (93)	76.7 ± 1.2 (93)
MMTe-1**	In-house	Gold Ore	3.7 ± 0.9 (3)	162.3 ± 1.3 (3)	12.8 ± 0.3 (3)	31.40 ± 0.23 (3)	222 ± 4 (3)
ODL-1	In-house	Dolomitic Limestone	<1.3 (8)	16.5 ± 0.9 (8)	11.4 ± 0.6 (8)	56.4 ± 0.6 (8)	23.7 ± 1.2 (8)
OPEG-1	In-house	Evolved Pegmatite	1.6 ± 1.0 (32)	3.0 ± 0.8 (32)	9 ± 8 (32)	17.4 ± 0.3 (32)	<1.6 (32)
ORCA-1	In-house	Rhyolite	<1.3 (113)	9.9 ± 0.7 (113)	71.2 ± 0.6 (113)	50.6 ± 0.6 (113)	251.5 ± 1.6 (113)
PJV-2	In-house	Rock Powder	<1.3 (7)	318.9 ± 1.1 (7)	19.5 ± 0.3 (7)	129.4 ± 1.0 (7)	53.4 ± 0.6 (7)
QS-1	In-house	Calcareous Shale	2.5 ± 0.5 (30)	111.2 ± 1.0 (30)	27.7 ± 0.5 (30)	74.9 ± 0.5 (30)	152.2 ± 1.6 (30)
RV-1	In-house	Melagabbro	<1.3 (68)	108.1 ± 1.3 (68)	4.9 ± 0.7 (68)	97.9 ± 0.8 (68)	14.2 ± 1.5 (68)
SPC-1	In-house	Portland Cement	3.4 ± 0.6 (4)	103.5 ± 0.9 (4)	15.60 ± 0.24 (4)	109.0 ± 0.4 (4)	71.85 ± 0.26 (4)
Certified reference materials							
AGV-2	USGS	Andesite	1.8 ± 0.6 (133)	117.1 ± 2.7 (133)	19.5 ± 0.6 (133)	90.5 ± 1.4 (133)	245 ± 4 (133)
Certificate‡			*1.88 ± 0.16*	*120 ± 5*	*20 ± 1*	*86 ± 8*	*230 ± 4*
BHVO-2	USGS	Basalt	<1.3 (111)	314 ± 6 (111)	25.1 ± 0.6 (111)	105.4 ± 1.4 (111)	173.4 ± 2.2 (111)
Certificate‡			*0.41 ± 0.03* [1]	*317 ± 11*	*26 ± 2*	*103 ± 6*	*172 ± 11*
GSP-2	USGS	Granodiorite	2.3 ± 0.5 (130)	50.5 ± 1.2 (130)	25.1 ± 0.6 (130)	118.1 ± 1.3 (130)	555 ± 5 (130)
Certificate‡			*2.40 ± 0.19*	*52 ± 4*	*28 ± 2*	*120 ± 10*	*550 ± 30*
OKUM-1	IAG	Ultramafic Komatiite	<1.3 (53)	168.2 ± 1.5 (53)	8.2 ± 0.7 (53)	63.1 ± 0.5 (53)	14.9 ± 1.2 (53)
Certificate‡			*0.012 ± 0.005*	*167.8 ± 3.1*	*9.08 ± 0.29*	*61.2 ± 1.9*	*17.0 ± 1.4*
STSD-2	CANMET	Stream Sediment	18.5 ± 0.9 (10)	104.2 ± 2.1 (10)	37.9 ± 0.6 (10)	262 ± 3 (10)	187.8 ± 2.3 (10)
Certificate [2,3]			*18.6 ± 1.0*	*101 ± 10*	*37 ± 6*	*246 ± 21*	*185 ± 9*
TDB-1	CANMET	Diabase	<1.3 (8)	446.4 ± 1.1 (8)	34.4 ± 0.3 (8)	137.3 ± 0.9 (8)	159.3 ± 0.8 (8)
Certificate†			*1.0 ± 0.1**	*471 ± 21**	*36 ± 4**	*155 ± 11*	*156 ± 20**

Notes: *Compiled data given as the mean ± 1 standard deviation of results (number of measurements).*
‡Certificate value is the average ± 1 standard deviation of the laboratory means.
ǂCertificate value is average ± 95% confidence interval on the population mean.
†Certificate value is the recommended working value ± 95% confidence interval.
**Provisional, information or indicative values; NA: data not available.*
***In-house characterization of MMTe-1 detailed in Burnham and Hastie (2023).*
References: *[1]Jochum et al. (2016); [2]Lynch (1990); [3]Lynch (1999).*
Abbreviations: *CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; USGS = United States Geological Survey.*
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Table 24.5. Summary of results obtained by the XRF-T04 test method for routine in-house and certified reference materials from April 7, 2022, to July 10, 2025.

Material	Provider	Description	Ag (ppm)	Cd (ppm)
In-house reference materials				
LK NIP-1	In-house	Diabase Sill	<1.5 (4)	<4 (4)
ORCA-1	In-house	Rhyolite	<1.5 (3)	<4 (3)
PJV-2	In-house	Rock Powder	<1.5 (66)	<4 (66)
XPB-2	In-house	Synthetic blend	5.4 ± 0.6 (9)	4.4 ± 0.5 (9)
Certified reference materials				
OREAS 600	OREAS	Ag-Cu-Au Ore	24.3 ± 0.6 (37)	<4 (37)
Certificate‡			*24.3 ± 0.9*	*3.37 ± 0.32*
OREAS 601	OREAS	Ag-Cu-Au Ore	50.1 ± 0.6 (12)	7.7 ± 0.7 (12)
Certificate‡			*49.4 ± 1.5*	*7.86 ± 0.53*
WPR-1a	CANMET	PGE-bearing Peridotite	<1.5 (40)	<4 (40)
Certificate‡			*1.02 ± 0.10*	*0.598 ± 0.086*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
‡Certificate value is average ± 1 standard deviation of the mean.
Abbreviation: *CANMET = Canadian Centre for Mineral and Energy Technology; OREAS = Ore Research & Exploration Pty Ltd.*

Table 24.6. Summary of results obtained by the XRF-W01 test method for routine in-house and certified reference materials from March 27, 2025, to July 10, 2025.

Material	Provider	Description	Cl (ppm)	F (ppm)
In-house reference materials				
LK NIP-1	In-house	Diabase Sill	464 ± 19 (24)	173 ± 41 (24)
MRB-29	In-house	Basalt	80 ± 32 (6)	483 ± 121 (6)
ODL-1	In-house	Dolomitic Limestone	707 ± 11 (3)	497 ± 20 (3)
OPEG-1	In-house	Evolved Pegmatite	58 ± 5 (4)	270 ± 7 (4)
ORCA-1	In-house	Rhyolite	63 ± 23 (30)	232 ± 25 (30)
QS-1	In-house	Calcareous Shale	109 ± 15 (14)	1049 ± 65 (14)
RV-1	In-house	Melagabbro	139.1 ± 2.5 (11)	213 ± 26 (11)
Certified reference materials				
GSD-11	IGGE	Stream Sediment	326.4 ± 2.5 (25)	1921 ± 24 (25)
Certificate†			*290 ± 64*	*1650 ± 256*
GS-N	ANRT	Granite	429 ± 5 (23)	1055 ± 36 (23)
Certificate‡			*450 ± 208.1*	*1050 ± 156*
GSP-2	USGS	Granodiorite	371.8 ± 2.4 (17)	3865 ± 30 (17)
Certificate‡			*NA*	*3000**
OKUM-1	IAG	Ultramafic Komatiite	111 ± 18 (7)	194 ± 20 (7)
Certificate¥			*NA*	*NA*
UB-N	ANRT	Serpentine	836 ± 4 (13)	149 ± 14 (13)
Certificate†			*800 ± 301*	*95 ± 138**

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
†Certificate value is average ± 95% confidence interval.
‡Certificate value is average ± 1 standard deviation of the mean.
¥Certificate value is average ± 95% confidence interval on the population mean.
**Provisional, information or indicative values; NA: data not available.*
Abbreviation: *ANRT = Association National de la Recherche Technique; IAG = International Association of Geoanalysts; IGGE = Institute of Geochemical and Geophysical Exploration; USGS = United States Geological Survey.*

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25. Revision of the Calibration for Silver and Cadmium Trace Analysis of Geological Samples by Wavelength Dispersive X-ray Fluorescence at the Geoscience Laboratories



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INTRODUCTION

In September 2020 and March 2021, the 2 Malvern Panalytical® Axios® wavelength dispersive X-ray fluorescence (WD-XRF) spectrometers used for major and trace element analysis at the Geoscience Laboratories ("Geo Labs") were replaced with Malvern Panalytical® Zetium® dual core (wavelength dispersive and energy dispersive) spectrometers. Because the existing instrumental application for the determination of silver and cadmium in geological samples by wavelength dispersive X-ray fluorescence spectrometry on pressed powder pellets (method code XRF-T04) could not be directly transferred to the new Zetium® instruments, a fresh build of the instrument application was required. Both spectrometers are identical in build (with the same accessories), so the method could have been built on either instrument. The method discussed here was built on Zetium® 2, the spectrometer installed in March 2021, and continues to use Compton scatter ratios for matrix correction.

Whereas the primary goal when rebuilding the application on the new instrument was, at a minimum, to match the previous performance for the XRF-T04 method (Keating 2018), the new build of the XRF-T04 application presented an opportunity to make improvements to both the instrument application (overlap corrections) and sample preparation technique:

- During measurement, indium, tin, antimony and tellurium were already measured to correct for overlaps on the cadmium peak and cadmium background (Willis, Feather and Turner 2014). During the rebuild, palladium was added to correct for an overlap on the silver peak and its background and molybdenum and niobium are now monitored, as they overlap with the rhodium $K_{\alpha\text{-}C}$ (primary Compton scatter peak) and silver K_{α} peaks, potentially leading to grossly biased results. If molybdenum or niobium are present at high concentrations (>1500 ppm or >3800 ppm, respectively), the method will fail to produce accurate results, but the samples will automatically be flagged by the application to ensure compromised data are not issued. Although unlikely in most samples received for analysis at Geo Labs, samples will be similarly flagged if palladium concentrations exceed 500 ppm Pd, above which the overlap correction is unreliable.
- The sample preparation of pressed pellets was modified by changing from a water-based binder, that can be reactive with certain types of samples, to a dry, non-hazardous and non-reactive amide wax binder. The same pressed pellet preparation can be used to analyze samples for most XRF trace element methods offered by the Geo Labs: XRF-T02 to XRF-T05 and XRF-W01. The dry binder is compatible with all types of geological samples, including hygroscopic minerals, and its use makes it more efficient and easier to prepare and analyze samples for multiple methods.

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With any change to a method, calibration or instrumentation, it is a Geo Labs' requirement to verify the performance of the method and update the statistics and limits before the method can be put into production. This article presents a summary of the work done to build and generate the calibrations and update the figures of merit for the method based on those calibrations.

ANALYTICAL WORK

The spectrometer measuring application was built based on parameters provided by the instrument manufacturer (Malvern Panalytical 2020) and those in use by Geo Labs in the previous version. Because the application uses the classic Compton scatter ratio method (Willis and Duncan 2008) for matrix correction, it is important that the ranges of matrices that could be present in samples are represented in the calibration reference material set. It should be noted that, whereas the Compton scatter ratio method will correct for X-ray absorption effects, it does not correct for enhancement. However, unless a sample is very unusual, with percent levels of elements of high atomic number (Z), in particular elements with Z = 49 to 56 (In to Ba), the enhancement is not usually an issue.

All of the measuring parameters were carefully optimized based on the types of samples historically received at the Geo Labs and the available natural and synthetic reference materials.

The spectrometer application was calibrated with 31 certified reference materials (CRM), along with 18 synthetic materials purchased from Malvern Panalytical® and 3 synthetic materials created in house. All CRMs were prepared in the same manner as for samples, with the same wax binder, to ensure infinite thickness and robust pressed pellets.

An independent validation set of CRMs (BHVO-2, GSD-11, NIST 2710, NIST 2710A, NIST 8607, OKUM-1, ORCA-1, OREAS 600, OREAS 601, PJV-2, PTC-1A, QS-1, RS-1, RS-2, SdAR-H1, SdAR-M2, SQ-88 and WPR-1A) with a wide range of bulk compositions and analyte concentrations was also prepared using the protocol that is applied to samples. These preparations were used to check the accuracy and precision of the calibration regressions for silver and cadmium over the range of analysis.

METHOD VERIFICATION

The lower limits of detection (LLoDs) were estimated from 59 client samples, 10 in-house materials (LK-NIP-1, MFC-1, ODL-1, OPEG-1, ORCA-1, PJV-2, QS-1, RV-1, XCB-1 and XPB-2) and 4 CRMs (GTS-2A, OKUM-1, OREAS 600 and SdAR-H1) that were prepared in duplicate in the Geo Labs between September 2020 and February 2023. By using duplicate analyses carried out on separate sample aliquots, with analyses on different days, it was possible to obtain an estimate of the overall "method" uncertainty as a function of concentration for each analyte that includes most of the major sources of variation (including those from sample preparation and within-run or between-run instrumental variations) and from which the method LLoDs can be calculated. The pairs were chosen to represent a broad range of rock types and to cover as broad a range of analyte concentrations as possible.

The LLoD and uncertainty calculations were based on the seminal article by Thompson and Howarth (1976). The data were grouped into 15 groups of 11 samples with the averages and relative differences calculated for each sample pair. For each group, the mean concentration, median difference, relative difference (%) and expected difference (95% relative uncertainty) were calculated. The LLoDs that are achievable by the method were estimated from the regression of the group median differences against the group means. To minimize the effect of the highest concentration groups on the regression and the uncertainty in the calculated LLoDs, only the lowest concentration groups (points closest to the LLoD within the range of the method) were chosen to calculate the LLoDs for most elements. In the case of silver, 12 groups (~132 sample pairs) were used for the LLoD calculation, excluding the top 3 groups.

Table 25.1. Summary of figures of merit obtained for the XRF-T04 method from the analysis of certified reference materials.

	Ag (ppm)	Cd (ppm)
Lower Limit of Reporting (LL)	1.5	4.0
Limit of Quantification (LoQ)	3.33	5
Upper Limit of Validated Range	360	28
Upper Limit for Reporting (UL)	1700	300
Relative Standard Deviation (S_r) (%)	1.8%	4.0%
Relative Measurement Precision (%)	± 3.6%	± 8.0%
Method Bias (Weighted Regression, %)	−0.2%	6.6%
Method Trueness (Mean Absolute Trueness, %)	± 3.6%	± 13.8%

Validated Working Range: *Defined as the working range in which the method has been validated (LoQ to maximum concentration used in the validation statistics or calibration regression).*

Relative Standard Deviation (S_r): *Defined as the average of the relative standard deviations of all measurements greater than 3× LoQ (Richardson and Morrison 1995).*

Method Bias (Weighted Regression): *Calculated from the gradient of the linear regression of the measured concentrations against the certified concentrations of the reference materials, with points weighted according to the square root of their variance (Reed 1989; Richardson and Morrison 1995). Bias = (Gradient – 1) × 100 (result in percent).*

Method Trueness (Mean Absolute Trueness): *Defined as the average absolute trueness (Richardson and Morrison 1995) of the suite of reference materials. Only samples with measured concentrations greater than 3× LoQ.*

$$Absolute\ Trueness = \left|\left(\left(\frac{Mean\ Measured\ Value}{Certified\ Value}\right) - 1\right)\right| \times 100$$

For cadmium, all 15 groups (~164 sample pairs) were used for the LLoD calculation. For the estimation of precision as a function of concentration, all 15 groups were used for both analytes.

To generate a robust lower limit of reporting, the calculated LLoD was multiplied by a factor of 1.5 and the value rounded up to compensate for normal instrument decay (loss of sensitivity) with time, since the calibration is expected to last for a minimum of 5 years. A typical set of plots (Ag) used to evaluate the LLoD statistics for the data is presented in Figure 25.1. The final lower reporting limits (LLs) for the XRF-T04 method analytes are listed in Table 25.1. Based on the calculated LLoDs, the lower reporting limits for the method would be 1.5 ppm for Ag and 2.25 ppm for Cd, both of which meet or exceed the previously published lower limits (1.5 ppm Ag, 4 ppm Cd), hence the lower reporting limits were not changed for either analyte.

The upper reporting limits (ULs) were estimated taking into consideration the calibration set of CRMs. The highest reasonable trace concentration successfully determined in the calibration set was chosen, with a +10% window for extrapolation applied (*see* Table 25.1 for a summary of the final values). The final ULs for silver and cadmium were set at 1700 ppm Ag and 300 ppm Cd, respectively.

Accuracy and precision were evaluated using 21 reference materials, analyzed repeatedly between October 2021 and February 2023. The limits of quantification (LoQ = ~3.33× LLoD), that is, the lowest concentrations at which an analyte can be reliably determined, for these elements are 3.3 ppm Ag and 5.0 ppm Cd. The Geo Labs target is for better than ±10% (2σ) accuracy and precision at concentrations greater than 3× LoQ (10× LLoD). In the case of silver, there are 10 materials with concentrations greater than 10 ppm, and the average trueness is better than ±5.0% (Figure 25.2). Based on the average between-analysis standard deviations for materials with silver greater than 3× LoQ, the overall relative precision of silver analyses is ±3.6%. In the case of cadmium, there are only 5 materials in the validation set with a concentration greater than 15 ppm Cd (3× LoQ). The trueness of its analysis is 13.8%, based on 4 materials (RS-2, NIST 2710, NIST 8607 and SdAR-H1, there being no assigned or literature values for cadmium in PTC-1a), with a relative precision of ±8.0%, indicating that the quality of the cadmium results are poorer than those for silver results, but may be acceptable depending on their purpose. A summary of the figures of merit obtained from the CRM analyses is provided in Table 25.1.

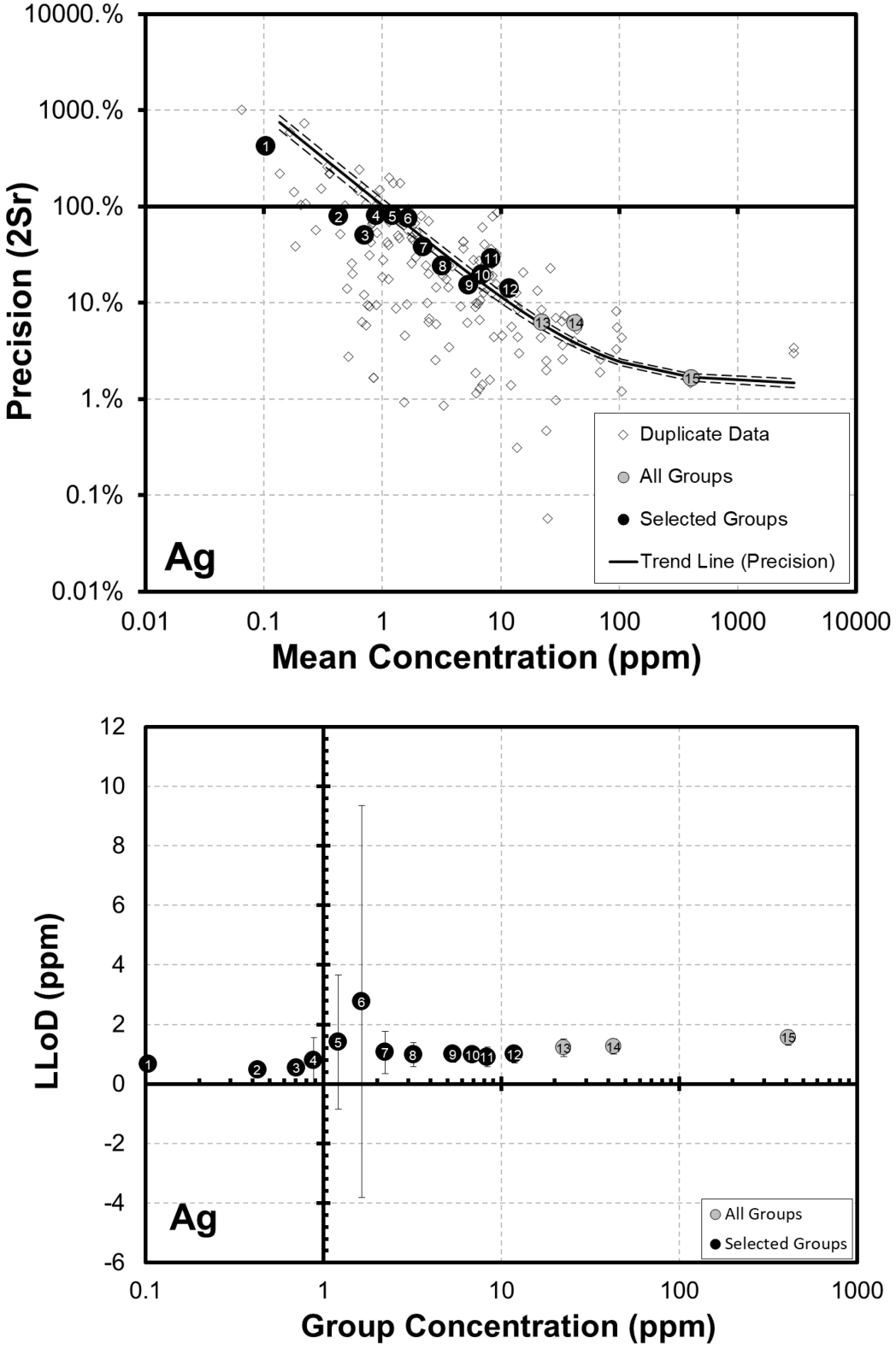
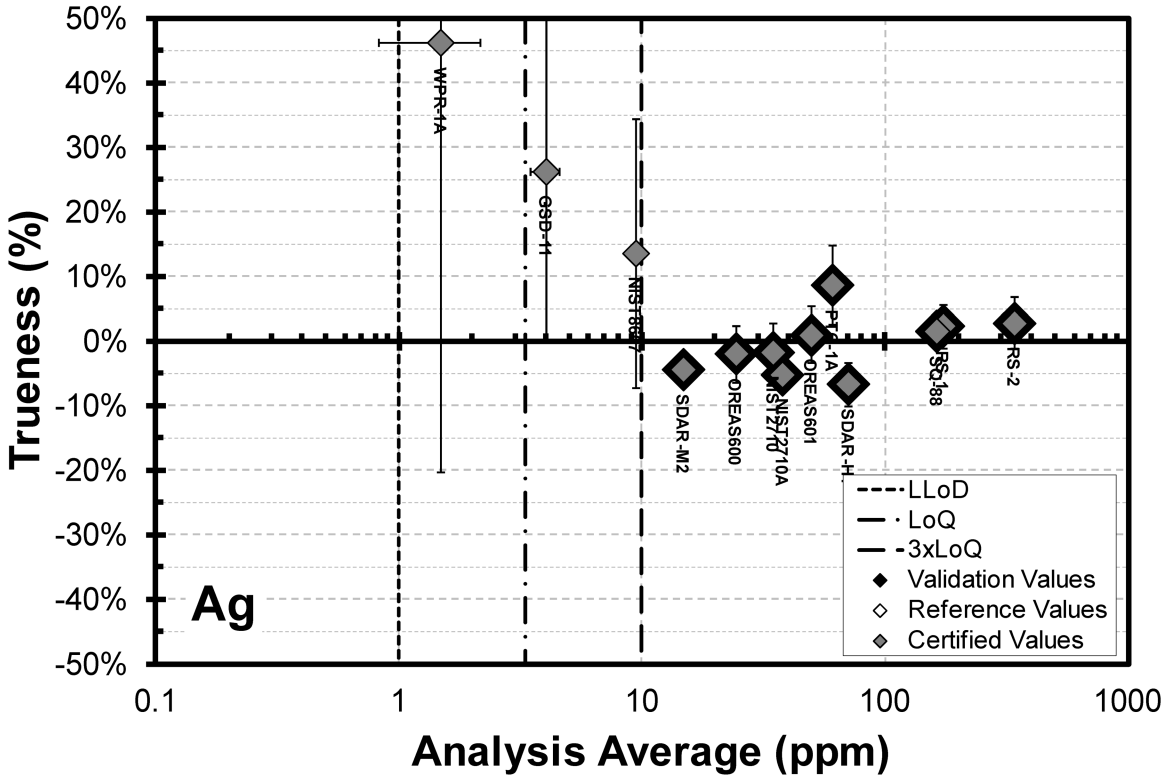


Figure 25.1. Plots summarizing the data used for the estimation of optimal precision (Max 2σ: 2σ at maximum concentration) and LLoD for silver analyses under method code XRF-T04. The most reliable estimate of the LLoD was obtained using the 12 lowest concentration groups, whereas the most reliable estimate of the precision of the method across the whole compositional range was obtained using the entire data set.



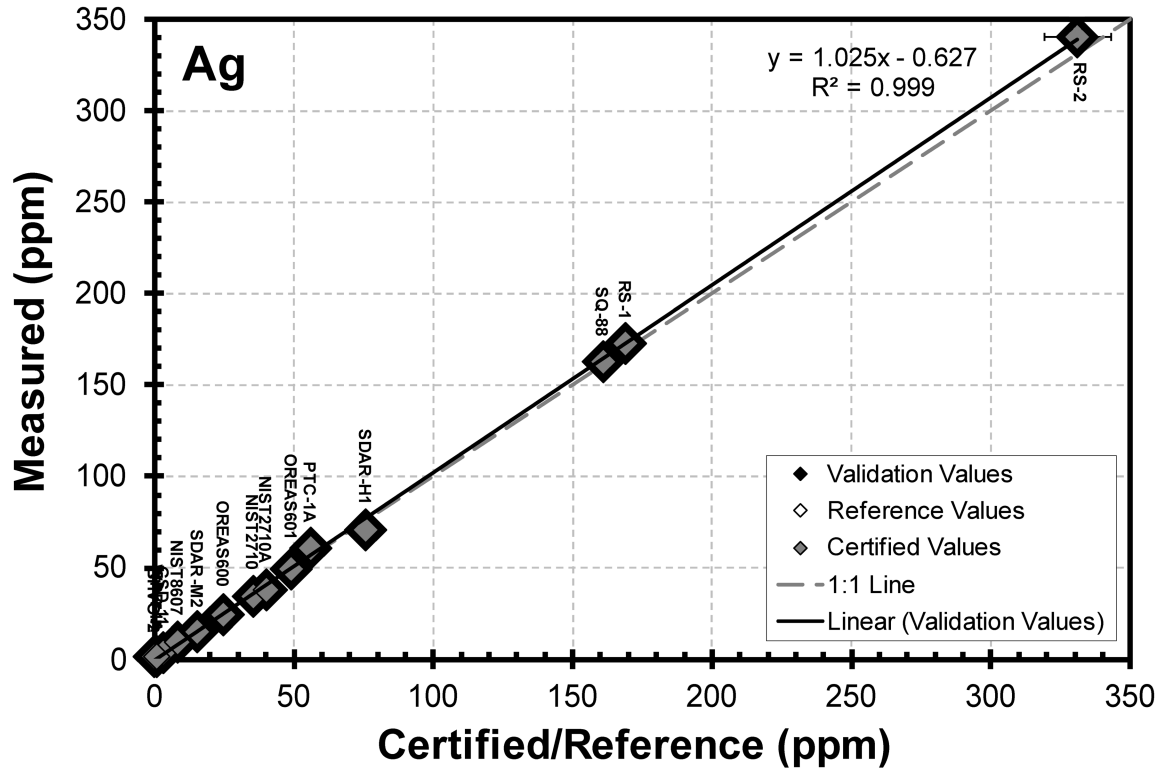


Figure 25.2. Plots summarizing the trueness and bias (unweighted regression) of silver analyses using method code XRF-T04. Outlined diamond symbols indicate the data used in the determination of the figures of merit (Table 25.1).

OBSERVATIONS AND SUMMARY

The transfer of the XRF-T04 method was informative and permitted a detailed analysis of its performance for routine and some atypical samples. Based on the analyses used to verify the technique, several conclusions and observations were noted:

- The method is accurate over a wide range of concentrations for both analytes and yields results that are within accepted published uncertainties for the suite of CRMs used during method validation.
- All figures of merit (upper and lower reporting limits, precision and accuracy) are now confirmed empirically for the total method, which includes the preparation of the pressed pellets.
- Both silver and cadmium can be successfully determined on pressed pellets when present at concentrations from low ppm levels to several hundred ppm.
- For cadmium analysis, there are some minor improvements that may need to be implemented to improve the accuracy and precision. These will be included in the next iteration of the application.
- When enriched in samples, molybdenum and niobium interfere with the measurement of the K_{α} line of silver and the rhodium $K_{\alpha\text{-}C}$ that is used to correct for mass absorption. Samples containing greater than 1500 ppm Mo or 3800 ppm Nb cannot be reliably analyzed using this method, but they can be identified, so compromised results will not be reported.
- Palladium can be a significant interferent for silver analysis. The range of the palladium overlap correction limits silver analysis to samples that contain less than 500 ppm Pd. Samples with higher palladium contents cannot be reliably analyzed using this method, but they can be identified, so compromised results will not be reported.
- Every attempt was made to expand the coverage of the reference materials used for the calibration and verification of the method, but it was not possible to add many more materials. Because of the lack of reference materials with suitably well-constrained silver and/or cadmium contents, it is difficult to verify the accuracy of the XRF-T04 method over some regions of its working range. This is particularly evident for cadmium, for which the number of well-characterized reference materials, with a wide range of bulk compositions, available to use in the calibration set is limited.
- The new Zetium® spectrometers perform as well as the previous Axios® spectrometers and were able to meet the previous reporting ranges for both analytes.

ACKNOWLEDGEMENTS

As always, such work does not take place in a vacuum. I would like to thank Natalie Chrétien, Marcus Burnham and Jennifer Hargreaves for providing support during this process.

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26. Inductively Coupled Plasma Atomic Emission Spectrometry Analysis of Major, Minor and Trace Elements in Water Samples: New Instrumentation and Analytical Methods



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INTRODUCTION

Technological advances in inductively coupled plasma atomic emission spectrometry (ICP–AES) over the last 30 years have improved detection capabilities and working ranges for most analytes. The initial industry emphasis for simultaneous analysis in both axial (looking along the plasma) and radial (looking across the plasma) views with a horizontal torch configuration allowed for lower limits of detection, but also caused lower tolerance for total dissolved solids (TDS). Whereas lower limits of detection improved, this lower tolerance had a noticeable impact on groundwater analysis for samples with elevated concentrations and required additional work through dilution and reanalysis to ensure accurate results of the more concentrated elements.

In 2017, the Spectro Arcos II ICP–AES (Multiview) was commissioned at the Geoscience Laboratories ("Geo Labs"). This instrument allows for fixed axial (horizontal) and fixed radial (vertical) torch configurations and allow the analysis of water samples according to the expected concentration ranges in the samples in various modes. Low TDS samples, such as lake waters, are recommended for analysis with the fixed axial torch configuration (Geo Labs method code IAW-100), whereas high TDS samples, such as groundwaters, are preferentially analyzed with the fixed radial torch configuration (Geo Labs method code IAW-101).

This article summarizes analytical method codes and statistics for ICP–AES analysis of water samples.

METHODOLOGY

Field-filtered samples, if not acidified by the client, are acidified at the Geo Labs to contain approximately 1% v/v ultrapure nitric acid. The sample containers sit under refrigerated conditions (4°C) for 1 week with occasional mixing to minimize element adhesion or absorption onto the container walls. The samples are transferred to an appropriate vial for analysis.

Both the IAW-100 and IAW-101 methods analyze water samples unattended using a 225-position capacity autosampler equipped with an Elemental Scientific (ESI) FAST valve system. An excess volume of sample solution is aspirated through a PFA loop system, using the overfill as an additional pre-wash.

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Ontario Geological Survey, Open File Report 6421, p.26-1 to 26-8.

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The sample solution is mixed at a ratio of 1:1 with internal standard solution and injected with a perfluoroalkoxy (PFA) concentric nebulizer into a cyclonic spray chamber with baffle. The fine droplets generated are pushed through a salting-resistant ceramic injector of a quartz torch and atomized and ionized in an argon gas plasma. The intensities of first-order elemental wavelengths are measured using argon-purged optics and elemental concentrations are derived from external calibration of the intensities against multi-point curves.

The main differences between the ICP–AES water methods are the torch configuration (IAW-100 analyses are carried out by viewing the axial, whereas IAW-101 analyses are carried out in radial mode), the flow rate of argon make-up gas used for gas dilution, the analysis of matrix correction solutions and the number of analytes. These differences benefit the purpose of each method, where

- greater sensitivity in axial view is ideal for low concentration samples. However, this increased sensitivity limits the upper limit of the method for analytes reaching saturation at lower concentrations than they would in radial view. Similarly, the lower sensitivity in the radial view configuration limits the number of detectable analytes.
- make-up gas flow acts as an additional dilution step increasing the tolerance for high TDS samples. However, an axial view plasma extinguishes at higher gas flows, further limiting tolerance in this configuration.
- the limited upper working range in axial view limits accurate measurement of high concentration of matrix elements. This prevents accurate mathematical correction of spectrum disturbances for samples with complex matrices.

Data are exported and processed with a Microsoft® Excel® VBA macro to standardize the output for evaluation and reporting.

Prior to March 2024, IAW-200 was the only method code available for water analysis by ICP–AES. To streamline the naming convention with other method codes in the wet chemistry section, the new method codes are

- IAW-100: axial view analysis. Recommended for low TDS water samples, such as lake waters.
- IAW-101: radial view analysis. Recommended for high TDS water samples, such as contaminated waters or groundwaters. This method is equivalent to the previous IAW-200 method code.

ANALYTICAL RESULTS

The IAW-100 and IAW-101 methods were evaluated for accuracy, precision and working range using certified reference materials, recent proficiency test samples from Environment and Climate Change Canada (ECCC) commercially available artificial reference materials and spiked samples of a selection of the preceding materials. Where required, these samples were acidified to matrix-match the 1% v/v nitric acid matrix and were analyzed in duplicate across a minimum of 7 separate analyses over a maximum of 3 months.

As a result of the different time frames for method development and validation and limited quantities of certain validation materials, only a few solutions used for the validation are in common between the 2 methods. The IAW-100 method was validated using 9 matrix-matched method blanks, 27 proficiency test materials with assigned values for major elements, 31 additional proficiency test materials with assigned values for trace elements, 2 in-house reference materials with inter-laboratory results and 12 certified reference materials. As the IAW-101 method was effectively a method transfer from previous

instrumentation, it was validated using fewer materials: 4 matrix-matched method blanks, 28 proficiency test materials with assigned values for major elements, 28 proficiency test materials with assigned values for trace elements, 2 in-house reference materials with inter-laboratory results and 2 certified reference materials.

Summaries of the method statistics and working ranges are presented in Table 26.1 for the IAW-100 and Table 26.2 for the IAW-101 method, with results from routine in-house materials in Table 26.3 and certified reference materials in Table 26.4.

Table 26.1. Summary of IAW-100 method statistics from method validation data.

	IAW-100						
	LLoD (ppb)	**LoQ (ppb)**	**UL (ppb)**	**Precision (±)**	**Method Bias**	**Method Trueness (±)**	**MU (±)**
Ag	1	3.6	20	6.8%	0.9%	2.5%	2.0%
Al	1.9	4.2	1760	7.4%	−2.3%	3.2%	17.9%
As	5.7	19	209	7.8%	−0.8%	2.8%	1.5%
B	2.6	7.1	330	6.6%	−1.1%	2.5%	9.6%
Ba	0.33	0.99	1760	7.0%	0.7%	2.5%	9.5%
Be	0.049	0.17	198	8.0%	3.4%	3.5%	4.2%
Bi	3.8	13	132	11.8%	9.7%	12.8%	5.7%
Ca	14	40	209,000	9.0%	2.2%	3.2%	12.5%
Cd	0.47	1.6	308	7.0%	0.6%	1.1%	3.1%
Cl	231	867	275,000	7.4%	−2.6%	4.7%	11.6%
Co	0.51	1.7	1980	6.4%	1.5%	2.8%	8.5%
Cr	0.47	1.4	1760	6.6%	2.3%	2.8%	7.4%
Cu	2.5	8.6	1980	5.4%	2.7%	4.4%	2.1%
Fe	5.4	14	1760	14.0%	1.2%	5.6%	11.3%
K	1.8	6.1	2700	9.6%	14.8%	8.5%	32.1%
Li	0.063	0.19	176	12.2%	2.3%	2.8%	19.9%
Mg	1.7	6.3	78,100	7.0%	0.1%	3.8%	12.4%
Mn	0.26	0.84	1870	7.4%	−1.9%	3.9%	15.4%
Mo	1.1	3.5	352	7.2%	6.0%	6.1%	4.0%
Na	5.5	20	102,300	7.4%	1.2%	4.9%	15.1%
Ni	1	3.7	1980	7.8%	−0.6%	1.8%	1.6%
P	4.5	15	594	6.6%	1.1%	5.9%	7.8%
Pb	2.2	7.2	1760	7.4%	1.2%	4.0%	2.3%
S	11	36	154,000	6.4%	−2.4%	3.2%	8.9%
Sb	5.3	19	154	9.8%	6.1%	4.5%	2.9%
Se	7.1	24	187	8.6%	1.2%	0.7%	3.3%
Si	6.2	19	12,100	7.2%	0.4%	3.3%	7.2%
Sn	1.3	4.6	341	8.8%	5.7%	5.7%	2.6%
Sr	0.13	0.47	15,400	4.8%	2.0%	4.6%	6.9%
Ti	0.22	0.63	143	7.0%	−4.9%	3.4%	12.3%
V	0.67	2.3	1760	6.6%	4.0%	4.1%	1.9%
Zn	0.44	1.4	1760	9.8%	2.6%	3.9%	15.5%

Abbreviations: *LLoD: lower limit of detection; LoQ: lower limit of quantification; MU: measurement uncertainty; UL: upper limit.*

Table 26.2. Summary IAW-101 method statistics from method validation data.

	IAW-101						
	LLoD (ppb)	**LoQ (ppb)**	**UL (ppb)**	**Precision (±)**	**Method Bias**	**Method Trueness (±)**	**MU (±)**
Al	3.6	13	1760	9.6%	6.7%	6.0%	19.6%
B	6.7	21	330	8.0%	−12.3%	13.3%	29.2%
Ba	1.1	3.7	1870	7.0%	−0.6%	2.4%	14.5%
Be	0.21	0.66	198	8.2%	6.5%	6.6%	21.3%
Ca	57	175	209,000	4.0%	2.7%	3.9%	2.4%
Cd	1.7	5.5	308	11.2%	1.1%	1.6%	31.5%
Cl	588	1620	275,000	10.6%	3.5%	6.1%	21.1%
Co	2.8	10	1760	8.4%	2.4%	3.0%	26.8%
Cr	4.4	14	1760	7.4%	−1.8%	3.1%	21.6%
Cu	3.9	14	1760	7.2%	−5.3%	5.3%	13.9%
Fe	4.1	13	1540	8.6%	−0.6%	3.7%	20.2%
K	306	1030	20,900	10.0%	3.1%	4.2%	32.1%
Li	13	43	176	10.4%	4.3%	5.2%	38.3%
Mg	4.1	12	78,100	7.8%	2.2%	3.5%	24.8%
Mn	0.76	2.6	1540	8.2%	−2.3%	3.1%	17.2%
Mo	2.9	9.6	352	9.4%	−4.6%	4.2%	13.5%
Na	124	400	275,000	7.4%	2.4%	4.2%	17.2%
Ni	5.2	17	1980	9.6%	−1.9%	1.4%	25.4%
P	3	11	50,000	7.4%	NA	NA	3.4%
Pb	13	42	1760	10.0%	−3.5%	2.8%	1.4%
S	15	51	143,000	8.8%	4.4%	5.8%	27.0%
Si	12	34	12,100	8.8%	−2.8%	2.7%	19.4%
Sr	0.87	2.6	15,400	7.6%	−1.6%	2.7%	17.7%
Ti	1.5	4.5	143	7.6%	−0.5%	1.4%	13.9%
V	4.4	15	1760	8.4%	4.0%	3.8%	22.1%
Zn	1.7	6.1	1980	7.2%	−3.1%	3.7%	38.4%

Abbreviations: *LLoD: lower limit of detection; LoQ: lower limit of quantification; MU: measurement uncertainty; NA: not available; UL: upper limit.*

Method Working Limits

The lower limits of detection (LLoD) and quantification (LoQ) for the IAW-100 and IAW-101 methods were estimated from a statistically screened data population of matrix-matched blanks analyzed during the validation study.

The upper reporting limits for each element were defined as 110% of the highest concentration successfully analyzed from validation test samples as part of the validation study.

Accuracy

The reference values of all validation materials were used to determine the overall accuracy of the analytes measured by the IAW-100 and IAW-101 methods. The accuracies were estimated from a weighted linear regression of measured values against reference values, weighted according to the uncertainties in the reference values (York 1996) to give an overall bias in the measurements, and from the average absolute deviation of the mean measured concentrations relative to the reference values, giving a measure of the average accuracy (trueness) at concentrations greater than 3 times the LoQ (3×LoQ).

Table 26.3. Summary of results obtained by the IAW-100 and IAW-101 for routine in-house materials analyzed during method validation. All concentrations in parts per billion (ppb, ng/mL).

Material Source Analyte	BULK-1-17 In-House Quality-Control Material			BULK-2-17 In-House Quality-Control Material		
	IAW-100	**IAW-101**	**Reference[1]**	**IAW-100**	**IAW-101**	**Reference[1]**
Ag	< 1		*NA*	< 1		*NA*
Al	153 ± 8.6	171 ± 6.3	*169 ± 10*	195 ± 10	220 ± 11	*218 ± 12*
As	< 5.7		*0.46 ± 0.15*	< 5.7		*0.11 ± 0.14*
B	1980 ± 68	1760 ± 60	*1736 ± 92*	67.2 ± 1.9	55.4 ± 3.7	*55.2 ± 4.3*
Ba	37.6 ± 1.2	41.2 ± 1.5	*40.7 ± 2.3*	45.2 ± 2.5	46.9 ± 1.6	*50.7 ± 3*
Be	< 0.049		*0.023 ± 0.031*	< 0.049		*0.028 ±*
Bi	< 3.8		*0.06 ± 0.41*	< 3.8		*0.044 ±*
Ca	14,700 ± 620	14,900 ± 340	*15,790 ± 410*	164,000 ± 6700	176,000 ± 4100	*171,800 ± 4200*
Cd	< 0.47		*0.181 ± 0.018*	< 0.47		*0.0211 ± 0.0042*
Cl	236,000 ± 7600	231,000 ± 11,000	*227,500 ± 2900*	7660 ± 310	7770 ± 430	*5780 ± 150*
Co	0.867 ± 0.19		*0.439 ± 0.02*	< 0.51		*0.05 ± 0.12*
Cr	< 0.47		*0.24 ± 0.15*	< 0.47		*0.148 ± 0.065*
Cu	27.8 ± 1.6	24.8 ± 1.3	*25.75 ± 1.03*	3.65 ± 1.6		*2.95 ± 0.7*
Fe	87.8 ± 3.2	89 ± 3.4	*94.2 ± 6.2*	153 ± 4.8	153 ± 5	*164.8 ± 9.6*
K	3670 ± 390	2450 ± 160	*2560 ± 110*	1210 ± 76	924 ± 76	*919 ± 47*
Li	70.4 ± 9.5	57.1 ± 6.1	*55.3 ± 2.1*	5.92 ± 0.51		*5.03 ± 0.26*
Mg	5540 ± 190	6120 ± 310	*5890 ± 310*	52,500 ± 2200	52,100 ± 2700	*53,400 ± 3700*
Mn	205 ± 9.1	232 ± 8.9	*227.5 ± 8.3*	4.72 ± 0.14	4.58 ± 0.32	*4.99 ± 0.23*
Mo	5.79 ± 0.35	5.83 ± 0.92	*5.67 ± 0.59*	3.43 ± 0.29	3.81 ± 0.83	*3.569 ± 0.068*
Na	190,000 ± 19,000	234,000 ± 8900	*224,500 ± 5000*	11,200 ± 790	9250 ± 320	*8560 ± 410*
Ni	1.44 ± 0.7		*1.064 ± 0.096*	1.43 ± 1.2		*1.12 ± 0.12*
P	16.5 ± 2.9	13.3 ± 1.6	*15.34 ± 1.08*[*]	16.9 ± 7.4	11.4 ± 2	*13.3 ± 0.7*[*]
Pb	< 2.2		*0.45 ± 0.11*	< 2.2		*0.237 ± 0.058*
S	21,800 ± 720	22,700 ± 1,100	*22,214 ± 334*	126,000 ± 3900	131,000 ± 5900	*128,279 ± 2203*
Sb	< 5.3		*0.012 ± 0.015*	< 5.3		*0.122 ± 0.023*
Se	< 7.1		*1.9*	< 7.1		*0.24 ± 0.1*
Si	3880 ± 140	3850 ± 180	*3680 ± 326*	4550 ± 150	4620 ± 170	*4346 ± 402*
Sn	< 1.3		*0.198 ± 0.018*	< 1.3		*0.03 ± 0.1*
Sr	587 ± 16	581 ± 24	*605 ± 16*	12,200 ± 310	12,0 ± 390	*12,986 ± 290*
Ti	4.54 ± 0.17	4.65 ± 0.31	*5.27 ± 0.86*	14.9 ± 0.53	16.6 ± 0.55	*16.05 ± 0.74*
V	< 0.67		*0.4 ± 2.6*	< 0.67		*0.367 ± 0.025*
Zn	7.23 ± 0.29	6.48 ± 0.39	*8.1 ± 0.71*	51.1 ± 1.5	48.5 ± 1.6	*49.2 ± 2.2*

[1]*Burnham et al. (2019).*
[*]*Information values obtained by ICP–MS analysis during IMW-100 method validation.*
Compiled data given as mean ± 1 standard deviation of results. Reference values are average ± 1 standard deviation of laboratory means. NA = not available.

Table 26.4. Summary of results obtained by the IAW-100 and IAW-101 for certified reference materials analyzed during method validation. All concentrations in parts per billion (ppb, ng/mL).

Material Source	HAMIL-20.2 ECCC Lake Water			TMDA-51.5 ECCC Trace-fortified Water		
Analyte	IAW-100	IAW-101	Reference[2]	IAW-100	IAW-101	Reference[3]
Ag	< 1		*NA*	12.6 ± 0.41		*12.1 ± 1.1*
Al	3.67 ± 0.22	4.74 ± 1.5	*NA*	105 ± 3.6	112 ± 5.3	*105 ± 9*
As	< 5.7		*NA*	17.4 ± 1.9		*16.7 ± 1.4*
B	56.1 ± 1.5	48.7 ± 2.5	*54 ± 4*	48.6 ± 1.2	42.4 ± 2.2	*46.9 ± 5.6*
Ba	27.2 ± 0.72	29.4 ± 1.1	*NA*	73.3 ± 1.9	73.9 ± 2.3	*72.6 ± 4.1*
Be	< 0.049		*NA*	10.7 ± 0.47	10.6 ± 0.45	*9.99 ± 0.92*
Bi	< 3.8		*NA*	9.75 ± 1.9		*9.79 ± 2.13*
Ca	47,800 ± 1900	48,000 ± 960	*46,200 ± 1750*	22,300 ± 1000	21,500 ± 490	*NA*
Cd	< 0.47		*NA*	26.6 ± 0.62	26.5 ± 1.3	*25.7 ± 1.7*
Cl	70,200 ± 2000	74,300 ± 4300	*71,700 ± 1650*	17,600 ± 750	19,200 ± 990	*NA*
Co	< 0.51		*NA*	70.4 ± 1.9	70.1 ± 2.6	*68.7 ± 4.5*
Cr	< 0.47		*NA*	66.1 ± 1.9	66.8 ± 3.2	*65.1 ± 4.3*
Cu	< 2.5		*NA*	80.3 ± 2.2	73.8 ± 2.3	*77.4 ± 5.4*
Fe	< 5.4		*NA*	111 ± 3.4	107 ± 3.7	*108 ± 10*
K	4820 ± 310	4140 ± 210	*3980 ± 165*	1130 ± 38	1120 ± 150	*NA*
Li	6.62 ± 0.52		*NA*	20 ± 0.82	19.1 ± 4.4	*19.4 ± 1.9*
Mg	13,200 ± 320	12,900 ± 510	*12,700 ± 500*	5410 ± 200	5690 ± 200	*NA*
Mn	< 0.26		*NA*	76.6 ± 2.3	77.9 ± 3.4	*78.7 ± 4.4*
Mo	3.08 ± 0.25	3.14 ± 0.77	*NA*	58.3 ± 2	53.2 ± 2	*55 ± 4.5*
Na	40,700 ± 1400	44,400 ± 1400	*42,300 ± 1700*	10,500 ± 320	10,300 ± 370	*NA*
Ni	1.38 ± 0.55		*NA*	65.6 ± 2.3	65.3 ± 3.4	*65.3 ± 4.3*
P	18.9 ± 1.7	21.5 ± 8.6	*NA*	< 4.5		*0.95 ± 0.22*[*]
Pb	< 2.2		*NA*	63.6 ± 3	61.9 ± 5.6	*63.7 ± 5.6*
S	14,800 ± 480	15,200 ± 750	*14,454 ± 600*	5700 ± 160	5830 ± 280	*NA*
Sb	< 5.3		*NA*	16.7 ± 2		*15.2 ± 1.3*
Se	< 7.1		*NA*	15.1 ± 2.6		*14.3 ± 1.9*
Si	945 ± 34	895 ± 37	*883 ± 40*	286 ± 9.1	268 ± 12	*NA*
Sn	< 1.3		*NA*	17 ± 0.81		*16.4 ± 1.4*
Sr	418 ± 6.8	404 ± 13	*NA*	122 ± 2	122 ± 4.3	*118 ± 7*
Ti	< 0.22		*NA*	14.6 ± 0.38	14.4 ± 0.49	*14.1 ± 1*
V	< 0.67		*NA*	48.5 ± 1.2	48.1 ± 2.4	*46.5 ± 3.5*
Zn	6.62 ± 0.29	6.14 ± 0.7	*NA*	154 ± 6.3	141 ± 5.1	*140 ± 13*

[2] *Environment and Climate Change Canada (2019).*
[3] *Environment and Climate Change Canada (2021).*
[*] *Information values obtained by ICP–MS analysis during IMW-100 method validation.*
Compiled data given as mean ± 1 standard deviation of results. Reference values are average ± 1 standard deviation of laboratory means. NA = not available.

Overall, the accuracies of most elements in the IAW-100 method meet the Geo Labs quality assurance target, with better than ±10% trueness and/or bias at concentrations greater than 3×LoQ. The exceptions to this are Bi (±12.8% average trueness) and K (+14.8% bias). The poorer accuracies for bismuth and potassium may be attributed to the limited concentration range of the validation test samples and the high viewing position of the potassium wavelength in the plasma affected by the axial view configuration, respectively.

For the IAW-101 method, all elements with exception of B (±13.3% average trueness and −12.3% bias) meet the Geo Labs ±10% quality assurance target for accuracy. The poorer accuracy for boron may be attributed to larger uncertainties at high concentrations from in-house solutions and is under investigation.

Precision

The method precisions for the elements in the IAW-100 and IAW-101 methods were estimated from the average 2σ standard deviation at concentrations greater than 3×LoQ.

Overall, the precision of most elements in the IAW-100 method meet the Geo Labs ±10% quality assurance target. The exceptions are Bi (±12.8%), Fe (±14.0%) and Li (±12.2%). The poorer precision for bismuth may be attributed to the limited concentration range of the validation test samples above 3×LoQ, whereas for lithium, the cause may be increased noise close to the plasma detection zone for the lithium wavelength in the axial view method.

For the IAW-101 method, most elements meet the precision quality assurance target with exception of Cd (±11.2%), Cl (±10.6%) and Li (±10.4%). Similarly to bismuth in the IAW-100 method, the poorer precision of cadmium may be attributed to the limited concentration range of the validation test samples above 3×LoQ. The cause of poorer precision of chlorine and lithium is unknown and under investigation.

Method Uncertainty

The measurement uncertainties of the IAW-100 and IAW-101 methods were estimated from duplicate analysis of validation samples. For each method, the results were obtained on different days with variable separation, different calibration preparations and fresh sample solutions, and should reasonably incorporate all sources of variation from sample processing and preparation, contamination and environmental conditions at the time of analysis for short-term analytical periods. However, the limited time frame of analysis for these data may exclude variations from chemical processes and longer periods between analyses. Currently, the measurement uncertainties do not account for the full concentration range because of insufficient certified or reference materials at very low or very high concentrations and may not include variations associated with field sampling.

The Thompson and Howarth (1976) method was used to organize the data into interval blocks of duplicate pairs to calculate the duplicate pair average and to determine the absolute differences of each pair. For each interval, the mean concentration, group median difference, relative difference (%) and expected difference (95% relative uncertainty) were calculated. The uncertainty associated with sample analysis for each analyte is estimated from a regression of the group median differences against the group mean and is defined at 10 times the LoQ of the method. Larger uncertainties are the result of insufficient data coverage across the full working range for each method. A re-evaluation of these measurement uncertainties using real-world data will be completed once a larger data set of analytical duplicates has been obtained.

SUMMARY

The IAW-100 and IAW-100 methods demonstrate overall trueness and precision better than ±10% at 3 times the lower limit of quantification for most elements, which is consistent with the Geo Labs' quality objectives. The exceptions to this quality objective are bismuth, iron, lithium and potassium by the IAW-100 method and boron, cadmium, chlorine and lithium by the IAW-101 method, with accuracies and/or precisions between 10 and 15%. Future improvements to the methods may improve these results.

Once sufficient data have been collected to incorporate variations associated with real-world samples and field sampling, the measurement uncertainties for both methods are to be re-evaluated.

ACKNOWLEDGMENTS

I'd like to thank Christopher Beckett-Brown for supplying data on lake and stream water anion concentrations, and to Marcus Burnham for his compilation of historical lake and groundwater data measured at the Geo Labs. The results were used to tailor the IAW-100 and IAW-101 methods for lower detection limits for the lake waters and to ensure maximum concentration coverage of the working ranges for the groundwaters.

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27. Determination of Anions in Water Samples by Ion Chromatography: Method Improvements and Capabilities on New Instrumentation



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INTRODUCTION

For many years, the Geoscience Laboratories ("Geo Labs") have employed ion chromatography to determine anion concentrations in lake and surface waters, using a variety of instruments and configurations. Under method code ICW-100, up to 7 anions (fluoride, chloride, nitrite, bromide, nitrate, phosphate and sulphate) at concentrations ranging from a few parts per billion (ppb or ng/mL) to many parts per million (ppm or µg/mL) have been reported historically and the technique provided the majority of the data for the OGS lake water mapping program conducted from 1997 until its interruption in 2014. Initial analyses were carried out on a Dionex DX-300 from which the analyses were transferred to a Thermo Dionex ICS-3000 in 2009 and to a Thermo Scientific ICS-6000 in 2024. With each transfer to newer technologies, the method improved, with lower detection limits, lower sample volume requirements, shorter total analytical times per sample, and increases in productivity resulting from larger sample capacities per run.

This article summarizes the most recent change in instrumental capabilities and method statistics ahead of the recent resumption of the lake water mapping program.

METHODOLOGY

A small volume of sample is aspirated from a sealed sample container and injected directly onto a guard column. The resin of the guard column captures organic compounds and particles that are otherwise not removed by field or laboratory filtration. Automatically generated eluent pushes the sample through the separation column at high pressure, through an eluent suppressor to reduce the background signal, and to a conductivity detector that measures the current generated as each anion is eluted. The anions are identified by their retention time in the separation column and their concentrations are derived against an 8- to 9-point linear calibration curve prepared from artificially prepared NIST-traceable certified stock solutions.

Field-filtered samples are normally analyzed as received, but additional laboratory filtration may be required for strongly coloured samples that may affect the quality of sample analysis.

Summary of Field Work and Other Activities, 2025,
Ontario Geological Survey, Open File Report 6421, p.27-1 to 27-7.

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During the transfer to the new instrumentation, several changes were made to the method:

- The transferred method uses smaller vials (1.5 mL polypropylene vials with septa or 2 mL deep well plates) compared to 5 mL vials used previously.
- An internal standard, composed of low concentrations of formate, bromate and chlorite, is added to each sample as a precaution against missed samples or partial injections.
- Where the previous method rinsed the sample line between samples and injected 50 µL of sample solution, the transferred method rinses the sample line between samples and pre-flushes the sample loop with 500 µL of sample solution before injecting 100 µL of sample solution for analysis. The additional wash and conditioning minimize contamination for low anion concentrations. The increase in sample size, in combination with background suppression technology, works toward further decreasing the lower detection limit of the method.
- The separation column is shorter than the standard length of the previous method (150 mm versus 250 mm) and, under the method conditions, can elute all 7 anions within 10 minutes. This halves the previous run time on previous equipment and allows for shorter turnaround times in combination with the increased maximum capacity and unattended operation.
- The instrument software uses more advanced detection algorithms to find, identify and evaluate the peak areas and calculates the concentration against a calibration curve. Each resulting chromatograph is manually examined on a peak-by-peak basis to ensure the accuracy of detection, whereas the peaks associated with internal standards are evaluated to confirm the integrity of sample injection.
- The automated sampler has a maximum capacity of 288 positions assigned to samples, duplicates and blank check solutions. There are an additional 15 positions dedicated to calibration solutions and 6 to in-house reference materials, certified reference materials and system blank solutions. The temperature-controlled sample chamber is set to 11°C to minimize the effect of redox reactions on the anions. Previously, the sampler did not have temperature control, and its maximum sample capacity was limited to 100 positions for calibration, samples and quality-control material. In combination with the increased speed of analysis, the method is better equipped to handle large sample submissions.

One significant impact of the separation column's shorter length is an equivalent decrease in column capacity, which can lead to an unusual peak splitting for bromide and nitrate ions. An algorithm has been added to the method to evaluate both peaks within the retention window for these anions and to avoid low biases. Additionally, anions present in concentrations exceeding the method upper limits are poorly resolved and must be diluted and reanalyzed. For this reason, sample conductivity data are critical to identify those that require additional handling before analysis to minimize reporting delays.

HOLDING TIME

Depending on the storage conditions and preservation methods, some anions may decompose or transform into different species. The United States Environmental Protection Agency published recommended holding times for solutions collected in polyethylene bottles (Table 27.1), which are used as a reference at the Geo Labs. These holding times extend from the date of collection and may vary depending on field storage and preservation conditions.

Another factor affecting holding times are large submissions or many simultaneous submissions. To minimize laboratory delays, the Geo Labs endeavour to analyze samples in the order of receipt as soon as feasible within 30 days from the date of delivery.

Table 27.1. Recommended holding times reported by the United Environmental Protection Agency (1997) for anions in water for ion chromatography analysis.

	Preservation	Holding Time
Bromide	None	28 days
Chloride	None	28 days
Fluoride	None	28 days
Nitrate	Refrigerate (4°C)	48 hours
Nitrite	Refrigerate (4°C)	48 hours
Phosphate	Refrigerate (4°C)	48 hours
Sulphate	Refrigerate (4°C)	28 days

Table 27.2. ICW-100 method limits and statistics. The overall accuracy is the trueness between the measured and certified values, whereas the bias is the average difference between the measurement and the certified value. While the precision is the reproducibility of the measured value and a component of measurement uncertainty, the measurement uncertainty is an estimated range of measured values with inclusion of all components contributing to the uncertainty.

Analyte	LLoD (ppm)	LoQ (ppm)	UWL (ppm)	Accuracy (%)	Precision (%)	Bias (%)
Short holding time						
Bromide	0.013	0.017	20	±4.1	±12.2	1.8
Nitrate	0.019	0.025	56	±11.8	±12.8	9.5
Nitrite	0.019	0.024	20	±3.2	±9.6	2.9
Phosphate	0.018	0.024	20	±1.9	±11.4	−1.5
TN (total nitrogen)	0.01	0.013	13	±17.3	±10.6	−14.1
Long holding time						
Chloride	0.015	0.020	130	±2	±2.6	−1.5
Fluoride	0.005	0.007	20	±1.5	±2.8	−0.1
Sulphate	0.013	0.017	245	±2.2	±3.2	−0.3

***Abbreviations**: LLoD: limit of detection; LoQ: limit of quantitation; MU: measurement uncertainty; UWL: upper working limit.*

ANALYTICAL RESULTS

The transferred ICW-100 method was evaluated for accuracy and precision using certified reference materials, recent proficiency test samples from Environment Canada and Climate Change (ECCC), commercially available artificial reference materials and dilutions of selections of these materials to fully evaluate the working range of the method. These samples were analyzed in duplicate across 9 separate analyses over a one-month period.

While fluoride, chloride, sulphate and total nitrogen were evaluated using between 51 to 58 reference values, the shorter holding times attributed to nitrite, bromide, nitrate and phosphate limited available materials for validation to 8 to 10 artificial solutions. While most validation materials were analyzed within the solution's expiration time frame, these solutions were not necessarily within 30 days of receipt. The analysis of anions outside of their holding time had an impact on their accuracy and precision, particularly for the determination of nitrite and nitrate.

A summary of the method statistics and working range is presented in Table 27.2. Table 27.3 contains method validation data for certified reference materials, which may be used during routine analysis.

Table 27.3. Commercially available certified reference materials used during the ICW-100 method validation. These materials may also be used routinely during sample analysis.

Material Description	HAMIL-20.3 Lake Water		ION-96.4 River Water		LETH-13 Drinking Water	
Analyte	ICW-100	Reference[1]	ICW-100	Reference[2]	ICW-100	Reference[3]
Bromide (ppm)	0.16 ± 0.016	*NA*	0.062 ± 0.0055	*NA*	0.012 ± 0.0036	*NA*
Chloride (ppm)	110 ± 2.9	*120 ± 6*	74 ± 0.28	*74 ± 3.8*	20 ± 0.36	*20 ± 1*
Fluoride (ppm)	0.28 ± 0.0035	*0.27 ± 0.054*	0.12 ± 0.00065	*0.12 ± 0.035*	0.77 ± 0.0016	*0.77 ± 0.074*
Nitrate (ppm)	11 ± 0.41	*NA*	11 ± 0.99	*NA*	0.25 ± 0.019	*NA*
Nitrite (ppm)	< 0.019	*NA*	0.099 ± 0.015	*NA*	0.052 ± 0.0026	*NA*
Phosphate (ppm)	0.013 ± 0.0059	*NA*	< 0.018	*NA*	< 0.018	*NA*
Sulphate (ppm)	51 ± 0.4	*51 ± 2.7*	76 ± 0.23	*76 ± 4.2*	41 ± 0.42	*41 ± 2.1*
TN (ppm)	2.6 ± 0.094	*NA*	2.5 ± 0.22	*2.9 ± 0.3*	0.071 ± 0.0043	*NA*

Material Description	LETHBRIDG-03 Drinking Water		LON-07 Lake Water		MAURI-17 River Water	
Analyte	ICW-100	Reference[4]	ICW-100	Reference[5]	ICW-100	Reference[6]
Bromide (ppm)	0.015 ± 0.0032	*NA*	0.03 ± 0.003	*NA*	0.013 ± 0.003	*NA*
Chloride (ppm)	13 ± 0.12	*13 ± 0.53*	23 ± 0.23	*22 ± 1.5*	0.94 ± 0.033	*1 ± 0.08*
Fluoride (ppm)	0.77 ± 0.0011	*0.68 ± 0.044*	0.11 ± 0.00089	*0.12 ± 0.033*	0.03 ± 0.00079	*NA*
Nitrate (ppm)	0.64 ± 0.024	*NA*	1.5 ± 0.077	*NA*	0.11 ± 0.0049	*NA*
Nitrite (ppm)	< 0.019	*NA*	0.029 ± 0.004	*NA*	0.014 ± 0.0019	*NA*
Phosphate (ppm)	< 0.018	*NA*	< 0.018	*NA*	< 0.018	*NA*
Sulphate (ppm)	34 ± 0.29	*35 ± 1.5*	26 ± 0.24	*26 ± 1.9*	2.1 ± 0.027	*2 ± 0.13*
TN (ppm)	0.14 ± 0.0055	*0.18 ± 0.013*	0.34 ± 0.018	*0.44 ± 0.062*	0.028 ± 0.0023	*NA*

Material Description	MISSIPPI-14 River Water		ONTARIO-12 Lake Water		PERADE-17 River Water	
Analyte	ICW-100	Reference[7]	ICW-100	Reference[8]	ICW-100	Reference[9]
Bromide (ppm)	0.017 ± 0.0035	*NA*	0.035 ± 0.0027	*NA*	0.01 ± 0.0025	*NA*
Chloride (ppm)	16 ± 0.11	*16 ± 0.8*	23 ± 0.19	*23 ± 1.2*	1.4 ± 0.032	*1.4 ± 0.09*
Fluoride (ppm)	0.12 ± 0.00069	*0.12 ± 0.024*	0.11 ± 0.0009	*0.11 ± 0.023*	0.041 ± 0.00045	*NA*
Nitrate (ppm)	11 ± 0.43	*NA*	1.3 ± 0.073	*NA*	0.58 ± 0.03	*NA*
Nitrite (ppm)	< 0.019	*NA*	< 0.019	*NA*	0.017 ± 0.002	*NA*
Phosphate (ppm)	0.13 ± 0.0082	*NA*	< 0.018	*NA*	< 0.018	*NA*
Sulphate (ppm)	20 ± 0.38	*19 ± 1.1*	25 ± 0.17	*25 ± 1.3*	2.5 ± 0.021	*2.4 ± 0.17*
TN (ppm)	2.6 ± 0.098	*2.9 ± 0.23*	0.3 ± 0.016	*0.37 ± 0.051*	0.14 ± 0.007	*0.17 ± 0.014*

[1] *Environment and Climate Change Canada (2024b).*

[2] *Environment and Climate Change Canada (2016).*

[3] *Environment and Climate Change Canada (2009).*

[4] *Environment and Climate Change Canada (2021).*

[5] *Environment and Climate Change Canada (2014).*

[6] *Environment and Climate Change Canada (2020a).*

[7] *Environment and Climate Change Canada (2024a).*

[8] *Environment and Climate Change Canada (2024c).*

[9] *Environment and Climate Change Canada (2020b).*

Compiled data given as mean ±1 standard deviation of results. Reference values are average ±1 standard deviation of laboratory means. NA = not available.

Working Limits

Lower reporting limits of a method are typically determined through the analysis of matrix-matched blanks. For the ICW-100 method, the closest approximation to a matrix-matched blank is deionized water. However, as deionized water prepared with the Millipore Advantage system equipped with a low halogen end filter are free of cations and anions, with the use of a suppressor, carefully handled blank samples are indistinguishable from an eluent background.

Instead of matrix-matched blanks for the estimation of the lower limits of detection, the average background area amplitude caused by the high-pressure pump was determined across the width of the anion retention window from 7 water blank injections measured in each of the analyses for the validation samples. These values were converted by the average response factor resulting from the calibration of each anion to equivalent concentrations. The lower limit of detection was derived from this value plus 3 times the standard deviation of the compiled results.

Because this method yielded unusually low estimates of the lower reporting limit compared to the previous ICW-100 method on older instrumentation, further work was done to verify the results. The Hubaux–Vos method of predicted limits (Hubaux and Vos 1970) with a 95% confidence interval was applied to the compiled calibration data. The results, while comparable to those resulting from the blank estimate, were slightly higher, and these calculations were used to set the method lower limits of detection.

The ICW-100 upper working limits are constrained by the column capacity and the accurate and precise determination of the highest concentration of available validation samples.

Accuracy

Reference values were used to determine the overall accuracy of the analytes measured by the ICW-100 method. The accuracy was estimated in 2 ways:

- from a weighted linear regression of measured values against reference values, weighted according to the uncertainties in the reference values (York 1966) to give an overall bias in the measurement.
- from the average absolute deviation of the mean measured concentration relative to the reference values, giving a measure of the average accuracy (trueness) at concentrations greater than 3 times the limit of quantification.

Because of the long-term stability of certain anions, few reference materials are characterized for all analytes in the ICW-100 method. The determined accuracies show the impact of holding times (United States Environmental Protection Agency 1997) on anion analyses:

- anions with longer holding times (fluoride, chloride, bromide and sulphate) have accuracies better than ±5.0%. Despite having a shorter holding time, nitrite and phosphate also fall in this category. These analytes meet the Geo Labs' ±10% quality assurance target for accuracy.
- nitrate and total nitrogen (derived from nitrite + nitrate), which were analyzed within the expiration date of the solutions but may not have been analyzed within their shorter holding times, have poorer accuracies and a persistent low bias.

Precision

The method precision for the anions in the ICW-100 method were estimated from the average 2σ standard deviation at concentrations greater than 3 times the LoQ.

The holding time of an anion impacts the precision of an analyte, such that

- anions with longer holding times (fluoride, chloride and sulphate) have precisions better than ±2.5%. Despite having a similar holding time, bromide has poorer precision (±9.6%), indicating slower degradation of the anion during an equivalent holding time. These analytes meet the Geo Labs' ±10% quality assurance target for precision.
- anions with shorter holding times (nitrite, nitrate, phosphate and total nitrogen) have precisions up to ±13%.

Method Uncertainty

The measurement uncertainty of the ICW-100 method was estimated from duplicate analysis of validation samples. The results were obtained on different days with variable separation, different calibration preparations and fresh sample solutions and should reasonably incorporate all sources of variation from sample processing and preparation, contamination, and environmental conditions at the time of analysis for short-term analytical periods. However, the limited time frame of analysis for these data may exclude variations from sample heterogeneity, chemical processes and analytical issues for long-term analytical periods. The estimation currently does not include variations associated with field collection or from biological and chemical processes in natural samples.

The Thompson and Howarth (1976) method was used to organize the data into up to 30 intervals of 13 duplicate pairs to calculate the duplicate pair average and to determine the absolute differences of each pair. For each interval, the mean concentration, group median difference, relative difference (%) and expected difference (95% relative uncertainty) were calculated. The precision for sample analysis, excluding holding time limitations, which is achievable for each analyte is estimated from a regression of the group median differences against the group mean and is defined at 3 times the LoQ of the method.

SUMMARY

The transferred ICW-100 method on the new ICS-6000 ion chromatograph demonstrates truenesses of better than ±5% and average precisions better than ±2.5% at 3 times the lower limit of quantification for anions with longer holding times, which are consistent with the Geo Labs' quality objectives. Anions with shorter holding time have truenesses and precisions within ±20% and ±15%, respectively.

Restrictions associated with the holding time can be managed by scheduling instrument analysis around field sampling. Samples containing anion concentrations exceeding method upper limits are pre-screened for elevated conductivities, which flag for additional solution preparation steps to minimize delays on analysis.

Additional work is needed to determine whether the low bias observed on nitrite, nitrate and total nitrogen can be addressed. Collection of data for the inclusion of long-term uncertainty into precision calculations is also underway.

ACKNOWLEDGMENTS

I'd like to thank Christopher Beckett-Brown for supplying data on lake and stream water anion concentrations, and to Marcus Burnham for his compilation of historical lake water data obtained at the Geo Labs. The results were used to tailor the ICW-100 method for lower detection limits and to ensure maximum concentration coverage of the anion working ranges.

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
		LENGTH			
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
		AREA			
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
		VOLUME			
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
		CAPACITY			
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
		MASS			
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton(short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 9**	t
		CONCENTRATION			
1 g/t	0.029 166 6	ounce (troy) / ton (short)	1 ounce (troy) / ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights / ton (short)	1 pennyweight / ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

*Note: Conversion factors in **bold** type are exact. The conversion factors have been taken from or have been derived from factors given in the* Metric Practice Guide for the Canadian Mining and Metallurgical Industries*, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.*

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