ISSN 1916-6117 (online)
ISBN 978-1-4868-8545-9 (PDF)

ISSN 0826-9580 (print)
ISBN 978-1-4868-8544-2 (print)

It is recommended that reference to the Content be made in the following form:

Ontario Geological Survey 2024. Summary of Field Work and Other Activities, 2024; Ontario Geological Survey, Open File Report 6413, 270p.

or, for partial Content

Easton, R.M., Hastie, E.C.G., Kamo, S.L. and Duguet, M. 2024. Newly identified magmatic and metamorphic events in the Southern Province near Walford, Ontario; in Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.10-1 to 10-12.

Contact:

FOR FURTHER INFORMATION ON	PLEASE CONTACT:	BY TELEPHONE:	BY E-MAIL:
The Reproduction of the EIP or Content	MINES Publication Services	Local: (705) 670-5691 Toll-Free: 1-888-415-9845, ext. 5691 (inside Canada, United States)	Pubsales.ndm@ontario.ca
The Purchase of MINES Publications	MINES Publication Sales	Local: (705) 670-5691 Toll-Free: 1-888-415-9845, ext. 5691 (inside Canada, United States)	Pubsales.ndm@ontario.ca
Crown Copyright	King's Printer	Local: (416) 326-2678 Toll-Free: 1-800-668-9938 (inside Canada, United States)	Copyright@ontario.ca

Ontario

Ontario Geological Survey
Open File Report 6413

Summary of Field Work and Other Activities, 2024

2024

Ontario

ONTARIO GEOLOGICAL SURVEY

Open File Report 6413

Summary of Field Work and Other Activities, 2024

by

Ontario Geological Survey

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

2024

Easton, R.M., Hastie, E.C.G., Kamo, S.L. and Duguet, M. 2024. Newly identified magmatic and metamorphic events in the Southern Province near Walford, Ontario; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.10-1 to 10-12.

Users of OGS products should be aware that Indigenous communities may have Aboriginal or treaty rights or other interests that overlap with areas of mineral potential and exploration.

ISBN 978-1-4868-8544-2 (print)
ISBN 978-1-4868-8545-9 (PDF)

Open File Reports of the Ontario Geological Survey are available for viewing at the John B. Gammon Geoscience Library in Sudbury and at the regional Mines and Minerals office whose district includes the area covered by the report (see below).

Copies can be purchased at Publication Sales and the office whose district includes the area covered by the report. Although a particular report may not be in stock at locations other than the Publication Sales office in Sudbury, they can generally be obtained within 3 working days. All telephone, fax, mail and e-mail orders should be directed to the Publication Sales office in Sudbury. Purchases may be made using cash, debit card, VISA, MasterCard, cheque or money order. Cheques or money orders should be made payable to the *Minister of Finance*.

John B. Gammon Geoscience Library 933 Ramsey Lake Road, Level B2 Sudbury, Ontario P3E 6B5	Tel:	(705) 670-5614
Publication Sales 933 Ramsey Lake Rd., Level B2 Sudbury, Ontario P3E 6B5	Tel: Toll-free: Fax: E-mail:	(705) 670-5691 (local) 1-888-415-9845 ext. 5691 (705) 670-5770 pubsales.ndm@ontario.ca

Regional Mines and Minerals Offices:

Kenora – Suite 104, 810 Robertson St., Kenora P9N 4J2

Kirkland Lake – 1451 Hwy. 66, P.O. Box 40, Swastika P0K 1T0

Red Lake – 227 Howey Street, P.O. Box 324, Red Lake P0V 2M0

Sault Ste. Marie – 740 Great Northern Rd., Sault Ste. Marie P6A 5M1

Southern Ontario – 126 Old Troy Rd., Tweed K0K 3J0

Sudbury – 933 Ramsey Lake Rd., Level B2, Sudbury P3E 6B5

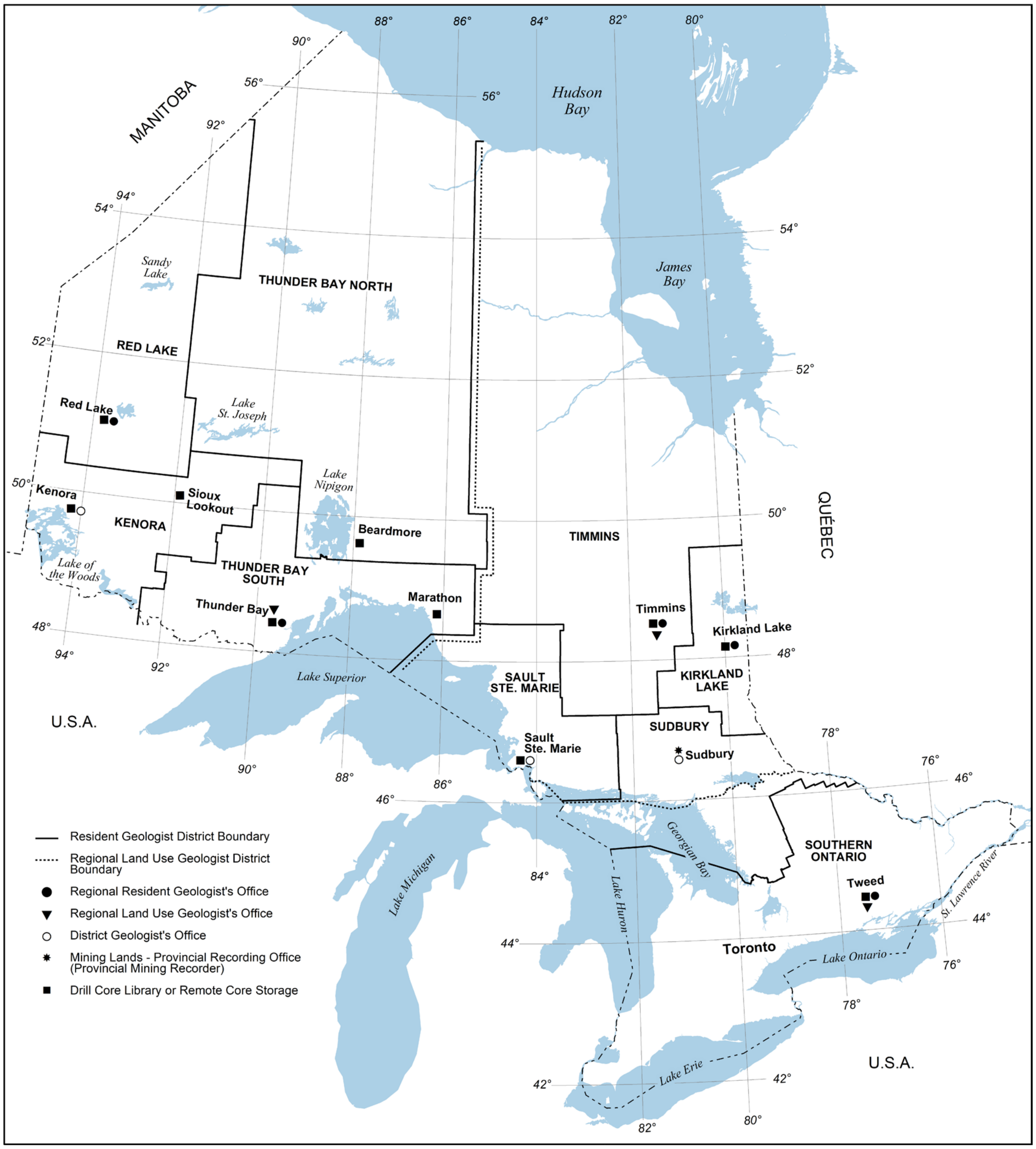
Thunder Bay – Suite B002, 435 James St. S., Thunder Bay P7E 6S7

Timmins – Ontario Government Complex, P.O. Bag 3060, 5520 Hwy. 101 East, South Porcupine P0N 1H0

Cette publication est disponible en anglais seulement.

Parts of this report may be quoted if credit is given. It is recommended that reference be made in the following form:

Easton, R.M., Hastie, E.C.G., Kamo, S.L. and Duguet, M. 2024. Newly identified magmatic and metamorphic events in the Southern Province near Walford, Ontario; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.10-1 to 10-12.



Mines and Minerals Division Regional and District Offices

CITY	ADDRESS	OFFICE(S)	TELEPHONE
Kenora	Suite 104, 810 Robertson St., Kenora P9N 4J2	○ ■	(807) 456-2496
Red Lake	227 Howey Street, P.O. Box 324, Red Lake P0V 2M0	● ■	(807) 464-3934
Thunder Bay – North Thunder Bay – South	Suite B002, 435 James St. S., Thunder Bay P7E 6S7	● ■ ▼	(807) 475-1332
Sault Ste. Marie	740 Great Northern Road, Sault Ste. Marie P6A 5M1	○ ■	(705) 943-2219
Timmins	Ontario Government Complex, P.O. Bag 3060, 5520 Hwy 101 East, South Porcupine P0N 1H0	● ■ ▼	(705) 465-2210
Kirkland Lake	1451 Hwy. 66, P.O. Box 40, Swastika P0K 1T0	● ■	(705) 668-0211
Sudbury	Willet Green Miller Centre, Level A2, 933 Ramsey Lake Rd., Sudbury P3E 6B5	○	(705) 670-5733
Provincial Recording Office (PRO)	Willet Green Miller Centre, Level A2, 933 Ramsey Lake Rd., Sudbury P3E 6B5	★	(705) 670-5742 FAX (705) 670-5681 *Toll-Free (Canada, USA):* (888) 415-9845 FAX (877) 670-1444
Tweed (Southern Ontario)	126 Old Troy Rd., Tweed K0K 3J0	● ■ ▼	(613) 243-0739

Ministry of Mines

Ontario Geological Survey Branch

Director's Office

(705) 618-3643

- Strategic Co-ordination
- Indigenous Engagement and Relationship Building
- Communication

Earth Resources and Geoscience Mapping

(705) 670-5758

- Geoscience Surveys and Mapping
  - Precambrian, Paleozoic, and Quaternary Geology
  - Surficial Geochemistry
  - Aggregate Resources
  - Industrial Minerals
  - Groundwater
  - Geophysics
- Warehouse

Resident Geologist Program

(807) 621-5846

- Direct Client Services
- Land-Use Planning
- Local Area Expertise
- Mineral Resource Potential
- Investment Attraction
- Recommendations For Exploration

GeoServices Section

(705) 670-5632

- Geoscience Laboratories
  - Inorganic Geochemical and Mineralogical Analytical and Research Services
  - Reference Material
- Publication Services Unit
  - Publications
  - Publication Sales
  - Geoscience Library
  - Archives

For all OGS general enquiries, contact us at OGS@ontario.ca.

Contents

Surficial Geochemistry Studies

Paleozoic Geology and Energy Studies

Groundwater Studies

Aggregate Studies

Geoscience Laboratories

Resident Geologist Program

This page left blank intentionally

Office of the Director, Ontario Geological Survey

1. Ontario Geological Survey: Update of Strategic Perspective for 2024–2025

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 2024–2025 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, 2024,
Ontario Geological Survey, Open File Report 6413, p.1-1 to 1-12.

The OGS continues to generate world-class geoscience information, products and services, including the 30 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 2024–2025* in late January 2025. In 2024, the Geoscience Laboratories continued to provide valuable, high-quality geoanalytical data to the Ontario Geological Survey.

VISION, MISSION AND MANDATE OF THE ONTARIO GEOLOGICAL SURVEY

The OGS vision, mission and mandate statements 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 the groundwater geoscience in southern Ontario 2024 Open House program and abstracts (Open File Report 6406);
- publication of Ontario airborne geophysical survey, magnetic gradiometer data, grid, profile and vector data, Winisk River area (Geophysical Data Set 1069, Maps 82 542 to 82 579);
- publication of 2021–2023 indexes to publications (MP177 Interim Supplement 2021–23 and MP178 Interim Supplement 2021–23);
- publication of remote predictive mapping of surficial deposits in the Spirit Lake region of Ontario's Far North providing extremely useful information for infrastructure development, land-use planning, habitat prediction and environmental baseline (Preliminary Maps P.3676 to P.3678, P.3689 to P.3691, P.3702 and P.3703);
- publication of the geology of Strathcona Township, Temagami greenstone belt, northeastern Ontario (this volume, Article 5);
- publication of an introduction to the Timmins and Kirkland Lake geological mapping project, northeastern Ontario (this volume, Article 6);
- publication of structural field observations of deformation zones in the northeastern Michipicoten greenstone belt, northeastern Ontario (this volume, Article 7);

- publication of the Precambrian geology and mineral potential of Totten Township, Superior Province, Sudbury District, northeastern Ontario (this volume, Article 8);
- publication of fractionation patterns and economic potential of the peraluminous magmatism of the southern Quetico Subprovince, northwestern Ontario (this volume, Article 9);
- publication on newly identified magmatic and metamorphic events in the Southern Province near Walford, Ontario (this volume, Article 10);
- publication of an update on geoscience studies in the Sudbury area, northeastern Ontario (this volume, Article 11);
- publication on Far North terrain mapping in the northern Opasquia Lake area, northern Ontario (this volume, Article 13);
- publication on riverbank mapping for Quaternary stratigraphy along the Attawapiskat River, James Bay Lowland (this volume, Article 14);
- publication of an update on the determination of indicator minerals in archived fine-fraction non-magnetic heavy mineral concentrate samples using scanning electron microscope energy dispersive spectrometry (this volume, Article 15);
- publication of preliminary results from till sampling and surficial mapping south of the Georgia Lake area, northwestern Ontario (this volume, Article 16);
- publication of preliminary results from surficial geochemical sampling of the Marathon deposit, northwestern Ontario (this volume, Article 17);
- publication of preliminary results from top-to-bottom surficial geochemical characterization of the Great Bear gold deposit, Red Lake, northwestern Ontario (this volume, Article 18);
- publication of a project description and status report related to restarting the lake sediment and water geochemistry program in the Batchawana greenstone belt, northeastern Ontario (this volume, Article 19);
- publication of the Paleozoic geology of eastern south-central Ontario: Tichborne–Sydenham and Bath–Yorkshire Island areas (this volume, Article 20);
- publication on an internal test of proposed nomenclature for new water well records (this volume, Article 21);
- publication of preliminary results from the groundwater geochemistry mapping across the Ottawa Valley, eastern Ontario (this volume, Article 22);
- publication of a project description and status report from the Ambient Groundwater Geochemistry Project sampling in the Thunder Bay area, northwestern Ontario (this volume, Article 23);
- publication of a project description and status report from the three-dimensional Quaternary mapping of the Guelph area, southwestern Ontario (this volume, Article 24);
- publication of an update on an aggregate resources inventory study of the District of North Bay (this volume, Article 25);
- publication of a project update on the characterization of the geochemistry and nickel-copper-platinum group elements potential of selected mafic to ultramafic intrusions in northwestern Ontario (this volume, Article 29);
- publication of a project update on the identification of fertile parent granitoid units in the Superior Province of Ontario (this volume, Article 30);

- 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 12)
- ongoing delivery of the services of a world-class inorganic geochemical laboratory, which supports the OGS geochemical program (*see also* this volume, Articles 26, 27 and 28);
- publication of Recommendations for Exploration 2023–2024;
- delivery of the 2023 OGS Virtual Showcase, held November 28 to 30, a free, public, three-day event held via Microsoft® Teams® Live that highlighted OGS activities and projects. Presentations from this event were available online until November 15, 2024;
- 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 10 395 maps, 3651 reports, 680 data releases and 2 video releases. In the period November 1, 2023 to October 31, 2024, the OGS published 8 new reports, 46 new maps, 1 new data release and 1 new video product.

From November 1, 2023, to October 31, 2024, numerous publications and data files were downloaded or accessed:

- ➢ downloaded from our GeologyOntario Hub Web sites:
  - ◇ in excess of 39 622 maps and reports in portable document format (*.pdf*) and image (*.jpg*) format
  - ◇ 17 745 compressed (*.zip*) files
- ➢ downloaded from our OGSEarth Web site:
  - ◇ 31 485 master *.kml* and/or *.kmz* files, and 883 compressed (*.zip*) files
  - ◇ Resident Geologist Program databases and recommendations
    - Ontario Mineral Inventory (OMI) 422 *.zip* files
    - Ontario Assessment File Database (OAFD) 364 *.zip* files
    - Ontario Drill Hole Database (ODHD) 422 *.zip* files
      - OGSFocus (quantifies data from OMI, OAFD and ODHD) 214 *.kml* files and 127 *.zip* files
    - *Recommendations for Exploration* 792 *.pdf* files, including the *Special Edition: Critical Minerals Compilation*.
      The current *2023–2024 Recommendations for Exploration* was 309 (39%), 2005–2022 was 396 (50.0%), the *Special Edition: Critical Minerals Compilation* was 15 (1.9%) and the *Introduction to Ontario's Critical Minerals* was 72 (9.1%).
- ➢ downloaded, viewed and accessed from our OGSEarth RGP Activity Reports—Mineral Exploration (AR—ME), compiled by the district offices:
  - ◇ AR—ME *.kml* file on OGSEarth Web page downloaded 902 times
  - ◇ AR—ME Web page list, including individual pages for the district offices accessed 3614 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 2023–2024 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 2023–2024, 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

Four strategic priorities continue to be the focus of the OGS for the fiscal year out to 2025.

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;
- a ground-based geophysical survey conducted in southern 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.

<table>
<tr><th colspan="5">Strategic Objectives – Public Geoscience Information</th></tr>
<tr><th>Outcomes</th><th>Strategic Objectives</th><th>Activities</th><th>How?</th><th>Who? *</th></tr>
<tr><td rowspan="13">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</td><td rowspan="2">Establish a geoscience baseline for Ontario to identify economic opportunity</td><td rowspan="2">Establish geoscience priorities based on public policy direction and input from stakeholders and clients</td><td>Gap analysis meetings with external clients, stakeholders, and with OGS staff who serve as proxy for external clients</td><td>Director's Office, ERGMS, RGP</td></tr>
<tr><td>Project planning</td><td>ERGMS, RGP, GeoServices</td></tr>
<tr><td rowspan="6">Establish a geoscience baseline for Ontario to safeguard public health and safety</td><td rowspan="6">Collect, analyze, advise and archive geoscience information</td><td>Mapping (OGS and collaborative projects with external collaborators or other governments)</td><td>ERGMS, GeoServices, RGP</td></tr>
<tr><td>Property or site visits: mineral and aggregates</td><td>RGP</td></tr>
<tr><td>Geochemistry</td><td>ERGMS, RGP, GeoServices</td></tr>
<tr><td>Geophysics</td><td>ERGMS</td></tr>
<tr><td>Receive third-party geoscience information</td><td>RGP, ERGMS</td></tr>
<tr><td>Geoscience Library</td><td>GeoServices</td></tr>
<tr><td rowspan="5">Establish a geoscience baseline for Ontario to inform environmental and land-use planning decisions</td><td rowspan="3">Provide access to OGS geoscience goods and services in a form that meets client needs</td><td>Geoscience Library</td><td>GeoServices</td></tr>
<tr><td>GeologyOntario, OGSEarth and OGS Geoscience Atlas</td><td>GeoServices, RGP, ERGMS</td></tr>
<tr><td>OGS expert technical staff participation in third-party technical meetings</td><td>ERGMS, RGP, GeoServices</td></tr>
<tr><td rowspan="2">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</td><td>Multi-ministry committees</td><td>Director's Office, ERGMS, GeoServices, RGP, other MINES business units</td></tr>
<tr><td>Provide geoscience information at technical meetings, symposia, workshops, and through direct client visits</td><td>ERGMS, RGP, GeoServices</td></tr>
</table>

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

Results

Focus during the 2023–2024 fiscal year was to continue collaborations and relationship building with Algonquins of Ontario, Anishinabek Nation, Atikmaneksheng Aninshinabek First Nation, Beausoleil First Nation, Big Island First Nation, Dokis First Nation, Fort William First Nation, Grand Council Treaty #3, Marten Falls First Nation, Matachewan First Nation, Métis Nation of Ontario, 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, Sheshegwaning First Nation, Six Nations of the Grand River First Nation, Taykwa Tagamou Nation, Temagami First Nation, Thessalon 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 Mines and Minerals Division (MMD), Strategic Services Branch:

- promoting the products and services of Mines and Minerals Division, 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

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 Mines and Minerals Division 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.*

attraction and promotional activities led by the Strategic Services Branch (Table 1.3). 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 2024; the Prospectors and Developers Association of Canada (PDAC) 2024 Annual Convention; and co-hosted the 2024 Ontario Geological Survey—Geological Survey of Canada—Conservation Ontario Geoscientists Open House. Staff also participated in-person at the 2024 Lithium Pegmatite Short Course and the 2024 International Nickel-Copper Symposium, both at Lakehead University; the Canadian Mining Expo 2023 Big Event; the Central Canada Resource Expo 2023; the 2024 Ontario Prospector's Exploration Showcase; the 2024 Geological Association of Canada–Mineralogical Association of Canada–10th International Symposium on Granitic Pegmatites, Joint Annual Meeting; the 2024 Canadian Quaternary Association Meeting; the 2024 Northeastern Ontario Mines and Minerals Symposium; and the Quebec Mineral Exploration Association Convention Xplor 2024.

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.

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 2024 OGS Virtual Showcase in November 2024, 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". To date, 9 OGS activities have been initiated or completed in support of Ontario's Critical Minerals Strategy (Table 1.4).

THE FUTURE

Building on the work initiated by 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;

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

Goal	Geoscience Activity	Status
Releasing innovative, new geospatial data products that provide quicker, easier access to OGS geoscience data	Release of new Critical Mineral Ontario Mineral Inventory geospatial products	Completed
	Release of OGSFocus and OGS GeoData Listing through OGSEarth	Completed
Introduce a modernized digital platform for mineral exploration companies to access Ontario's critical minerals geoscience information from anywhere in the world	The Ontario Geological Survey (OGS) and the Information and Lands Branch (ILB) are collaborating to develop a new GeologyOntario application	Completed
Introduce new products that improve compilation and interpretation of existing OGS data, combined with digitizing archival information	Introduction to Ontario's Critical Minerals publication	Completed
	Release of OGSFocus and OGS GeoData Listing through OGSEarth	Completed
Reassessing historical geoscience information to better identify critical minerals deposits	Publish *Recommendations for Exploration Special Edition: Critical Minerals Compilation 2000–2022*	Completed
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 6, 8, 12, 13, 14, 17, 18, 19)
	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

- 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 February 2024, Lesley McAdam accepted a temporary assignment as a Financial Officer in the Northern Development Division. In July 2024, Darla Bennett left her position as Indigenous Geoscience Liaison. In August 2024, Beata Mazan-LaRocque was the successful candidate for the temporary Administrative Assistant position within the Ontario Geological Survey, Director's Office.

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 e-mail 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, 2024,
Ontario Geological Survey, Open File Report 6413, p.2-1 to 2-8.

VALUE-ADDED PRODUCTS AND SERVICES

The GeoServices Section (GSS) of the OGS conducts an annual client survey specific to its program areas using SurveyMonkey® software, 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 annual Ontario Groundwater Geoscience Open House hosted in-person in southern Ontario with a virtual attendance option. Participants are surveyed, using SurveyMonkey®, on their overall satisfaction with the event and results are 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 2024 and will continue to monitor and document success metrics from such initiatives.

Table 2.1. Client survey results from the Resident Geologist Program, GeoServices Section and events hosted and/or co-hosted by the OGS.

Survey Question	Program Area	2015–2016	2016–2017	2017–2018	2018–2019	2019–2020	2020–2021	2021–2022	2022–2023	2023–2024
How satisfied are you with the analyses and services provided by the Geoscience Laboratories?	GSS	84%	n/a	83%	97%	99%	100%*	87%*	82%*	85%
Please rate your overall satisfaction with the Groundwater Open House.	Groundwater Open House	n/a	94%	93%	99%	100%	93%	92%	95%	95%
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%
How satisfied are you with the RGP products and services?	RGP	n/a	79%	94%	96%	100%*	n/a **	n/a **	n/a **	n/a **

n/a = no data available
** Less than 40 respondents.*
*** Results from 2016 to 2020 were collected from hard-copy surveys distributed by the RGP. Due to pandemic restrictions, surveys were not conducted throughout 2020 to 2022. In 2023, the Annual OGS Client Survey was deemed to be an acceptable metric for measuring client satisfaction with RGP products and services (see results in Tables 2.3 and 2.4).*

ANNUAL CLIENT SURVEY

Method

The 2023–2024 OGS Client Survey was conducted from April 17 to May 24, 2024. A database of 752 clients was compiled by OGS staff, with 676 of these clients having valid contact information. The survey was conducted by sending electronic invitations to clients, who had an e-mail address with their contact information, to complete the survey online via SurveyMonkey®. A total of 5 follow-up reminders were then sent to those who did not complete the survey.

A total of 278 responses were captured, resulting in a 41% response rate. This response was consistent with the 2023 rate and remains within the range of those obtained in previous years (40–53%). Another factor to consider is that this year's sample size was the largest in the 11-year history of the survey.

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 sixth 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, for those clients who identified as service users.

Table 2.2. Ontario Geological Survey 2023–2024 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
What category best describes the majority of work that you conduct?	66%	65%	72%	77%	80%	72%	84%	83%	84%	85%
How would you rate your overall satisfaction with the OGS?	85%	80%	85%	73%	81%	86%	83%	84%	89%	89%

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
What category best describes the majority of work that you conduct?	34%	35%	28%	23%	20%	28%	16%	17%	16%	15%
How would you rate your overall satisfaction with the OGS?	95%	94%	93%	96%	90%	96%	86%	95%	91%	91%

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. The OGS recorded 48 total mineral sector activities between September 2023 and August 2024 where OGS data had an impact and/or was referenced. Recent significant successes are described as follows.

1. December 2023—Big Gold completed an infill sampling program for their Tabor property, located in northwestern Ontario. Resampling and cutting of historical drill core were carried out at the Thunder Bay Drill Core Library. In the press release, Scott Walters, CEO, commented: "We express our gratitude to the Thunder Bay Core Library for granting us access to the invaluable historic core, enabling us to explore additional opportunities at the Tabor Project in a cost-effective manner". Assay results released by the company in February 2024, indicated elevated gold, silver and zinc values in 3 of the 4 resampled drill holes.
   (Big Gold, news releases, www.biggold.ca/news, December 20, 2023, and February 13, 2024)

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**
Percentage of clients who used OGS products within the past 12 months?	90%	94%	90%	89%	94%	92%	84%	93%	92%	90%
Overall satisfaction with the quality of OGS products	n/a	n/a	88%	79%	80%	85%	86%	90%	92%	88%
Percentage of clients who used OGS products to make a decision	69%	80%	68%	54%	57%	50%	62%	63%	57%	69% [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% [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% [2]
Did the use of OGS products improve clients' exploration models or strategies?	80%	76%	55%	46%	40%	46%	51%	54%	47%	57% [3]
Did the use of OGS products reduce clients' decision risks?	74%	65%	60%	39%	28%	34%	36%	33%	38%	40% [3]
Did the use of OGS products/services 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% [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***
Percentage of clients who used OGS products within the past 12 months?	85%	94%	91%	89%	90%	89%	86%	93%	90%	89%
Overall satisfaction with the quality of OGS products	n/a	n/a	91%	97%	89%	95%	94%	88%	97%	97%
Percentage of clients who used OGS products to make a decision	90%	91%	78%	77%	77%	71%	74%	83%	76%	73% [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% [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% [2]
Did the use of OGS products improve clients' exploration models or strategies?	80%	58%	50%	69%	64%	86%	77%	71%	59%	70% [3]
Did the use of OGS products reduce clients' decision risks?	78%	36%	50%	60%	34%	36%	42%	37%	59%	52% [3]
Did the use of OGS products/services 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% [3]

** Less than 40 respondents.*

[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: 22% had no specific reason why; 22% said the information was used for other purposes than decision-making (i.e., academic, educational, etc.). Land-use/groundwater/environmental clients: 57% said the information was used for other purposes than decision-making; 29% 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: 16% of mineral/resource/exploration clients and 10% 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: 15% of mineral/resource/exploration clients and 11% 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**
Percentage of clients who used OGS services within the past 12 months?	n/a	n/a	96%	85%	53%	54%	42%	44%	52%	53%
Overall satisfaction with the quality of OGS services	n/a	n/a	91%	82%	84%	81%	80%	85%	91%	89%
Percentage of clients who used OGS services to make a decision	69%	80%	68%	54%	48%	32%	35%	46%	47%	54% [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% [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% [5]
Did the use of OGS services improve clients' exploration models or strategies?	80%	76%	55%	46%	46%	56%	53%	53%	50%	55% [6]
Did the use of OGS services reduce clients' decision risks?	74%	65%	60%	39%	25%	32%	32%	40%	32%	30% [6]
Did the use of OGS products/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% [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***
Percentage of clients who used OGS services within the past 12 months?	n/a	n/a	100%	97%	75%	68%	48%	39%	52%	59%
Overall satisfaction with the quality of OGS services	n/a	n/a	91%	97%	87%	100%	89%	100%	89%	95%
Percentage of clients who used OGS services to make a decision	90%	91%	78%	77%	77%	74%	47%	86%	69%	48% [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% [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% [5]
Did the use of OGS services improve clients' exploration models or strategies?	80%	58%	50%	69%	59%	83%	75%	71%	58%	58% [6]
Did the use of OGS services reduce clients' decision risks?	78%	36%	50%	60%	23%	40%	44%	29%	53%	32% [6]
Did the use of OGS products/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% [6]

** Less than 40 respondents.*

[4] An open-ended question was asked to respondents if there was a specific reason why they did not use OGS services to make a decision. Mineral/resource/exploration clients: 34% said that the information was used for other purposes than decision-making (i.e., academic, educational, etc.); 31% had no specific reason why. Land-use/groundwater/environmental clients:100% 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: 20% of mineral/resource/exploration clients and 10% 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: 16% of mineral/resource/exploration clients and 11% of land-use clients responded.

n/a = no data available.

2. February 2024—International Lithium Corp. announced that it has entered into an agreement to acquire a 90% ownership of the Firesteel Copper project in northwestern Ontario, consisting of 316 mining claim units covering 6600 hectares. The acquisition was informed by insights gained from a property site visit in October 2021 by the Thunder Bay South Resident Geologist, which highlighted significant copper and cobalt mineralization, as well as OGS publications, including the 2021 Report of Activities (Campbell et al. 2022) and Open File Report 5422 (Stone 2010).
   (International Lithium Corp., news releases, www.internationallithium.ca/news, February 20 and May 21, 2024)

3. March 2024—First Class Metals PLC acquired the Quinlan lithium property in northwestern Ontario, which includes a significant lithium anomaly (966.3 ppm) identified in an OGS lake sediment survey (Jackson and Dyer 2000). The Quinlan site was further recommended for exploration by the Thunder Bay South Resident Geologist as a potential pegmatite corridor in the OGS–Resident Geologist Program (RGP) *Recommendations for Exploration 2023–2024* (Campbell 2024).
   (First Class Metals, news release, https://firstclassmetalsplc.com/announcements, March 21, 2024)

4. March 2024—First Lithium Minerals Corp. staked 547 additional mining claims at its existing Lidstone exploration project in northwestern Ontario, with plans for follow-up activities including reconnaissance exploration and geologic mapping during the 2024 field season. The company credits the Thunder Bay North Regional Resident Geologist's recommendation for exploration released in the OGS–RGP *Recommendations for Exploration 2023–2024* (Churchley 2024) for influencing the decision to expand. In the news release, Rob Saltsman, CEO and Director, commented: "While we have long recognized the Lidstone project area as an attractive exploration target for lithium and potentially copper, the recent Ontario Geological Survey report on recommendations for exploration in the Lidstone project area solidified our belief and made our project even more exciting."
   (First Lithium Minerals Corp., news release, https://firstlithium.ca/news, March 27, 2024)

5. June 2024—Ashley Gold Corp. identified drilling targets for its Burnthut property (northwestern Ontario) summer drilling program. The news release acknowledged the Kenora District Geologist and OGS Geoscience Laboratories for their role in assisting with the identification of mineralization and geological timing of the Oro Grande West Discovery site on this property.
   (Ashley Gold Corp., news release, https://ashleygoldcorp.com/news-releases, June 12, 2024)

6. June 2024—Solstice Gold Corp. commenced a till sampling program at the Atikokan gold project in northwestern Ontario, noting the decision to proceed was based on the results of OGS lake sediment data (Ontario Geological Survey 2020) and the 2017–2018 OGS–RGP *Recommendations for Exploration* (Campbell and Puumala 2018), which identified significant gold anomalies in the Lost Moose Lake area.
   (Solstice Gold Corp., https://solsticegold.com/news-releases/2024, news release, June 12, 2024)

7. August 2024—Equinox Gold celebrated the grand opening of its Greenstone gold mine, an open-pit mine in northwestern Ontario. During the opening ceremony, General Manager, Eric Lamontagne, recognized the OGS' critical role in the early stages of the project. Lamontagne credited John Mason, Gerry White and Mark Smyk—former RGP staff—for introducing the property to Premier Gold Mines in 2007. Their support included providing geological tours, access to historical mine plans, and data from Mineral Deposit Inventory files, which proved pivotal in identifying past exploration and mining activities on the land package they had acquired. This early work facilitated the re-evaluation of the historical deposits and the discovery of new mineralization, contributing to the project's development. The Greenstone

gold mine story exemplifies how OGS' public historical geoscience data continues to support the advancement of exploration projects across Ontario.

(Greenstone Mine, YouTube video, www.youtube.com/live/uJDOdchylVI?t=6778s, August 29, 2024 [timestamp: 1:53:00])

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 2023 and September 2024, the OGS collaborated with multiple Indigenous communities, delivering 19 presentations to communities, conducting a total of 5 days of field mapping with local community members, and was invited to host a booth and participate in 9 major community events. The following successes were documented (for a full summary about the OGS' community engagement activities in 2023–2024, *see also* Levesque, this volume).

1. In May 2024, OGS staff assisted Pays Plat First Nation with sourcing local flint stone for ceremonial use, marking the OGS' first interaction with this community in several years. As a result, the OGS was invited to the Pays Plat Annual Gathering (July 2024), where RGP staff held a booth with educational activities for youth and met with local prospectors. Following this event, RGP staff conducted a property site visit with a community prospector and collected samples for analysis at the OGS Geoscience Laboratories, fostering an ongoing relationship.
2. In June 2024, Gail Bannon, Mountain Keeper for Fort William First Nation (FWFN), accompanied OGS Earth Resources and Geoscience Mapping section (ERGMS) field staff for a collaborative day of reconnaissance field mapping on federal reserve land to scout locations for future field work (*see also* Launay and Metsaranta, this volume). This knowledge exchange led to further collaboration with FWFN's Junior Mountain Keeper Program, where OGS staff engaged with 20 high school students, discussing Mount McKay's geology and career pathways in geoscience. Plans for continued geological mapping on reserve land and participation in the program have been initiated, reinforcing the OGS' commitment to long-term, sustainable engagement.
3. On July 12, 2024, the OGS collaborated with Mining, Lands and Resources staff of Matachewan First Nation to host a one-day event for community youth to learn about local geology and careers in geoscience. Approximately 15 youth from the community joined the OGS Indigenous Geoscience Liaison, staff and students from ERGMS field crews mapping in this area and the RGP District Geologist on a geological field tour and experienced hands-on geological field mapping. The enthusiastic response from the youth has initiated planning for OGS to return next summer for more detailed field mapping.
4. The OGS was invited to participate as part of the programming at Camp Chikepak in Timmins, Ontario, a summer camp organized by Mushkegowuk Tribal Council, which represents 7 Far North communities. Over a two-week period, RGP staff conducted 2 daily educational outreach sessions, teaching youth aged 9 to14 about the practical applications of minerals in their lives and techniques for identifying them in the field. The OGS also provided support for mineral identification kits that were distributed to all participants, enhancing their hands-on learning experience and encouraging interest in the geosciences.

5. The OGS partnered with Mineral Development Advisors (MDA) and Community Consultation Liaison Officers (CCLO) to deliver a virtual information session for 20 to 25 MDAs from across the province in December 2023. June 2024, a second information session was held in-person in Thunder Bay, Ontario, where OGS presented on local geology, led field tours to highlight regional geology, conducted an exploration site visit and demonstrated the drill-core storage facility with participants.

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.

REFERENCES

Campbell, D.A. 2024. Rare element potential in the Garden Lake–Obonga Lake area; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.50-53.

Campbell, D.A., Jonsson, J.R.B., Kurcinka, C.E., Dorland, G., Pettigrew, T.K., Daniels, C.M. and Bousquet, P. 2022. Report of Activities 2021, Resident Geologist Program, Thunder Bay South Regional Resident Geologist Report: Thunder Bay South District; Ontario Geological Survey, Open File Report 6383, 102p.

Campbell, D.A. and Puumala, M.A. 2018. Lost Moose Lake area lake sediment gold anomalies near Atikokan; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2017–2018, p.80-83.

Churchley, S.V. 2024. LCT-type pegmatite potential in the Witchwood and Morden Lake areas, Eastern English River Subprovince; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.41-44.

Jackson, J.E. and Dyer, R.D. 2000. Lake sediment and water geochemical data from the Garden–Obonga Lake area, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 51.

Ontario Geological Survey 2020. Lake geochemistry of Ontario—2019; Ontario Geological Survey, Lake Geochemistry of Ontario—2019, online database, https://www.geologyontario.mines.gov.on.ca/publication/LakeGeochemON. [accessed October 25, 2024]

Stone, D. 2010. Precambrian geology of the central Wabigoon Subprovince area, northwestern Ontario; Ontario Geological Survey, Open File Report 5422, 130p.

3. Activities of the Indigenous Geoscience Liaisons in 2023–2024

M.D. Levesque[1]

[1]Director's Office, Ontario Geological Survey

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 the scope of 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 2024 field season resulted in the notification of 20 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.

MONTHLY INDIGENOUS LEARNING ACTIVITIES

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

- introductions to Indigenous groups across Ontario
- Grassy Narrows case study
- social licence updates
- OGS activity updates
- cultural events

These short presentations and/or activities help introduce staff to various Indigenous topics and aim to promote awareness of different cultures and increase inclusivity. These fifteen-minute monthly presentations are enjoyed by staff, and IGLs 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 IGLs for more information and resources and participate in the learning activities if they have

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.3-1 to 3-5.

something to contribute. These activities are set to continue in the fall and winter of 2024–2025, incorporating staff input 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 an annual event. The presentation is focussed on introducing woodland art and demonstrating the multiple ways of interpreting the art using paintings from the IGL's personal collection. 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 2024 field season, the IGLs 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 OGS projects before field work starts. This initiative continued to be highly successful in that the IGLs received more than 10 separate requests for presentations, opportunities to participate in field trips, extensions of mapping areas and collaborations. Many of this year's meetings led to invitations to community events, as highlighted in Table 3.1.

The IGLs worked very closely with Earth Resources and Geoscience Mapping Section (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. ERGMS staff brought their knowledge and passion about geology across Ontario, and the IGLs 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 Federal reserve mapping. OGS staff worked very hard under tight timelines to ensure the success of the entire process and they are gratefully recognized for adeptly incorporating and growing this process while managing other competing tasks.

INDIGENOUS ENGAGEMENT BY THE INDIGENOUS GEOSCIENCE LIAISONS

Indigenous community engagement by the OGS Indigenous Geoscience Liaisons in 2023–2024 are presented in Table 3.1 below.

Table 3.1. Indigenous community engagements by the OGS Indigenous Geoscience Liaisons. Listed by date of visits.

Community	Visits(s)	Description
Mississaugi First Nation	September 13, 2023	In-person staff meeting for all MMD employees in Sudbury. IGL organized local Traditional Knowledge Keeper for opening and closing ceremonies.
Anishinabek Nation Northern Superior Regional Table	September 20, 2023 July 23, 2024	Quarterly regional roundtable meeting to provide OGS updates and maintain positive relationships. IGL focussed on listening to and gaining a greater understanding of the participating Indigenous communities' priorities and directions.

Table 3.1, *continued.*

Community	Visits(s)	Description
Anishinabek Nation Joint Advisory Committee	September 27, 2023 December 12, 2023 May 28, 2024	Quarterly regional roundtable meeting to provide OGS updates and maintain positive relationships. IGL focussed on listening to and gaining a greater understanding of the participating Indigenous communities' priorities and directions.
Big Island First Nation	November 2, 2023	In-community meeting to provide information about local geology. RGP will continue to work with community prospectors and potentially submit samples for analysis. First interaction with Big Island First Nation in many years and was a successful and well received presentation.
Mississaugi First Nation	November 15, 2023	Mapping presentation: Met with lands and resources staff to update and interpret findings of ERGMS mapping project in the area.
Anishinabek Nation Southeast and Southwest Regional Table	November 16, 2023	Quarterly regional roundtable meeting to provide OGS updates and maintain positive relationships. IGL focussed on listening to and gaining a greater understanding of the participating Indigenous communities' priorities and directions.
Rainbow District School Board	November 21, 2023	Yearly IGL presentation introducing Ontario Indigenous Woodland Art to a grades 5 and 6 art class. See section on "Indigenous Woodland Art".
Missanabie Cree First Nation	November 29, 2023	Mapping presentation: ERMGS presented virtual mapping update for project in the area to staff and community members.
Mineral Development Advisor and Community Consultation Liaison Officer Information Session	December 14, 2023	IGL provided "Minerals in our Lives" virtual presentation and OGS products and services presentations to approximately 20 staff from Indigenous communities across Ontario.
Great Lakes Geologic Mapping Coalition	January 24, 2024	IGL presented how OGS obtains social license for ERGMS mapping projects in Ontario. Land tenure discussion between Ontario and United States.
Informal and formal notification letters for proposed mapping projects	February 2024	Informal and formal notifications were sent for 20 ERGMS mapping projects. OGS notified over 50 Indigenous communities 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" section.
Grand Council Treaty #3	February 21, 2024	Introductory OGS presentation to staff and community members about OGS products and services as well as introducing local geology. OGS booth set up with local samples and geology resources.
Mississaugi First Nation	March 13, 2024	Mapping presentation: Continued conversation with ERGMS on mapping updates and interesting findings on Mississaugi Federal reserve land.
Fort William First Nation	March 14, 2024	Logistics planning for ERGMS Federal reserve mapping and for future event with Fort Willian First Nation Junior Mountain Keepers program.
Sand Point First Nation	April 3, 2024	Mapping presentation: Virtual meeting with Chief and land and resources staff to present and discuss local mapping project and ways they can participate.
Temagami First Nation	April 18, 2024	Mapping presentation: Meeting with Temagami First Nation land and resources staff and community members to discuss upcoming mapping in their traditional land-use area. Many attendees were present at this virtual presentation and asked many questions about mapping and mining activity in the area. This meeting resulted in summer plans to provide a field trip to interested members.
PDACs student-Industry Mineral Exploration workshop (S-IMEW) presentation	May 3, 2024	IGL presented OGS consultation approach and collaborations throughout the years to students in the S-IMEW program. Benefits include providing insight into Indigenous relations in the mining sector in government and industry when the students enter their chosen field.

Table 3.1, *continued.*

Community	Visits(s)	Description
Marten Falls First Nation	May 13, 2024	Mapping presentation: Virtual meeting with lands and resources staff to discuss ERGMS mapping project in the area. Initial meeting to gain and maintain social license for the project. Flight over project area was offered to point out areas not to be sampled.
Anishinabek Nation Virtual mining session	May 14, 2024	Virtual meeting for all Anishinabek Nation regions. IGL focussed on listening and gaining a greater understanding of the participating Indigenous communities' priorities and directions.
Pays Plat First Nation	May 24, 2024	Pays Plat staff members requested local flint for ceremonial use. Staff visited office to collect the flint and learnt about the OGS. Initial meeting led to in-community event planned for summer.
Fort William First Nation	June 11, 2024	Mappers conducting field work near FWFN submitted a request to map outcrops on reserve. Spent day with FWFN Mountain Keeper to find suitable area for ERGMS mapping on Federal reserve land. Knowledge sharing between mappers and the Mountain Keeper made the experience beneficial for all in attendance. FWFN were happy to host mappers for a day on reserve. Will return next summer to map with community members.
Mineral Development Advisor and Community Consultation Liaison Officer Information Session	June 11–13, 2024	In-person training session in Thunder Bay. OGS provided many presentations and led field tours to explain local geology and visit a local exploration site and drill-core storage.
Anishinabek Nation Lake Huron Regional Table	June 20, 2024	Quarterly 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.
Thessalon First Nation	July 2, 2024	Mapping presentation: IGL and ERGMS staff presented virtually on a proposed geophysical survey to Thessalon First Nation staff.
Beausoleil First Nation	July 3, 2024	OGS staff were invited to collaborate 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 local information. The day included both in-class and outdoor activities.
Sandy Lake First Nation	July 8–9, 2024	IGL visited Sandy Lake with ERGMS crew for mapping project. IGL secured accommodations, meals and vehicle for project. IGL attended to help with initial crew logistics.
Matachewan First Nation	July 12, 2024	In-community youth event with ERGMS and RGP. Explained the role of geologists and brought youth to local outcrops to discuss introductory geology. Youth were very engaged. Plan is to bring out youth next summer for actual mapping on their community lands.
Pays Plat First Nation	July 23, 2024	Annual gathering: As a result of earlier meetings, OGS was invited to set up OGS booth with "Minerals in our Lives" display, panning for gold activity and other geology resources. RGP formed relationship with local prospector returning for site visits and sample submission.
Fort William First Nation	July 24, 2024	IGL, ERGMS and RGP spent a half day with approximately 20 FWFN Junior Mountain Keeper high school students. Discussed careers in geology and geology of Mt. McKay and surrounding area. Moving forward, this is likely to be an annual event.
Mushkegowuk tribal council	August 5-16, 2024	Youth Camp: Camp Chikepak flew-in hundreds of youth from 7 surrounding Mushkegowuk communities. RGP put on 2 one-hour geology sessions per day which included introductory geology presentation, "Minerals in our Lives" display and mineral identification and hardness kit for youth to take home.

Table 3.1, *continued.*

Community	Visits(s)	Description
Missanabie Cree First Nation	August 14, 2024	Annual gathering: OGS staff were invited for a third consecutive year to set up a booth at the Missanabie Cree annual gathering. IGLs and ERGMS mappers working in the area attended the event and interacted with community members throughout the day. OGS booth and panning for gold activity for youth.
Taykwa Tagamou Nation	August 21, 2024	Career Fair: RGP set up OGS booth with "Minerals in our Lives" display and other geology resources.
Temagami First Nation	August 29, 2024	In-person geology and mining day with staff and community. OGS presentation on the reason Temagami is an area of high mineral potential, and booth set up.
Sagamok First Nation	October 1, 2024	Annual Gathering: First invitation to Sagamok Fall Harvest Celebration. OGS booth set up with "Minerals in our Lives" display, panning for gold activity and other geology resources. Very successful interactions and likely to lead to more events with Sagamok First Nation.

***Abbreviations**: ERGMS, OGS Earth Resources and Geoscience Mapping Section; FWFN, Fort William First Nation; IGL, OGS Indigenous Geoscience Liaison; MMD, Mines and Minerals Division, Ontario Ministry of Mines; OGS, Ontario Geological Survey; PDAC, Prospectors and Developers Association of Canada; RGP, OGS Resident Geologist Program.*

Earth Resources and Geoscience Mapping Section

4. Earth Resources and Geoscience Mapping Section: 2024–2025 Program and Projects Overview

L. Robichaud[1], R.M. Easton[1], S. Préfontaine[1], M. Duguet[1], C.A. Gordon[1], R. Cormier[1] and K.J.J. Kalmo[2]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey
[2]Director's Office, Ontario Geological Survey

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. 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 Mines and Minerals Division of the Ministry of 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

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 64135, p.4-1 to 4-22.

an annual, project planning exercise, including project proposals 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 77 active projects during the 2024–2025 fiscal year, which includes 62 active core projects and 15 active collaborative projects (Table 4.1). The collaborative projects include 2 projects with other provincial ministries; 1 project with the City of Ottawa; 1 project in collaboration with the Mineral Exploration Research Centre (MERC) at Laurentian University, Metal Earth and the Royal Ontario Museum (ROM); 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 2023 to December 2024, inclusive, ERGMS produced 3 Open File Reports, 8 Preliminary Maps, 1 Miscellaneous Release—Data, 1 Geophysical Data Set (GDS), 38 airborne geophysical survey maps, and 17 presentations as part of OGS Virtual Showcase 2023 (12 of which were available online in video format through GeologyOntario for a limited time in 2024) (*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 Mines and Minerals 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.

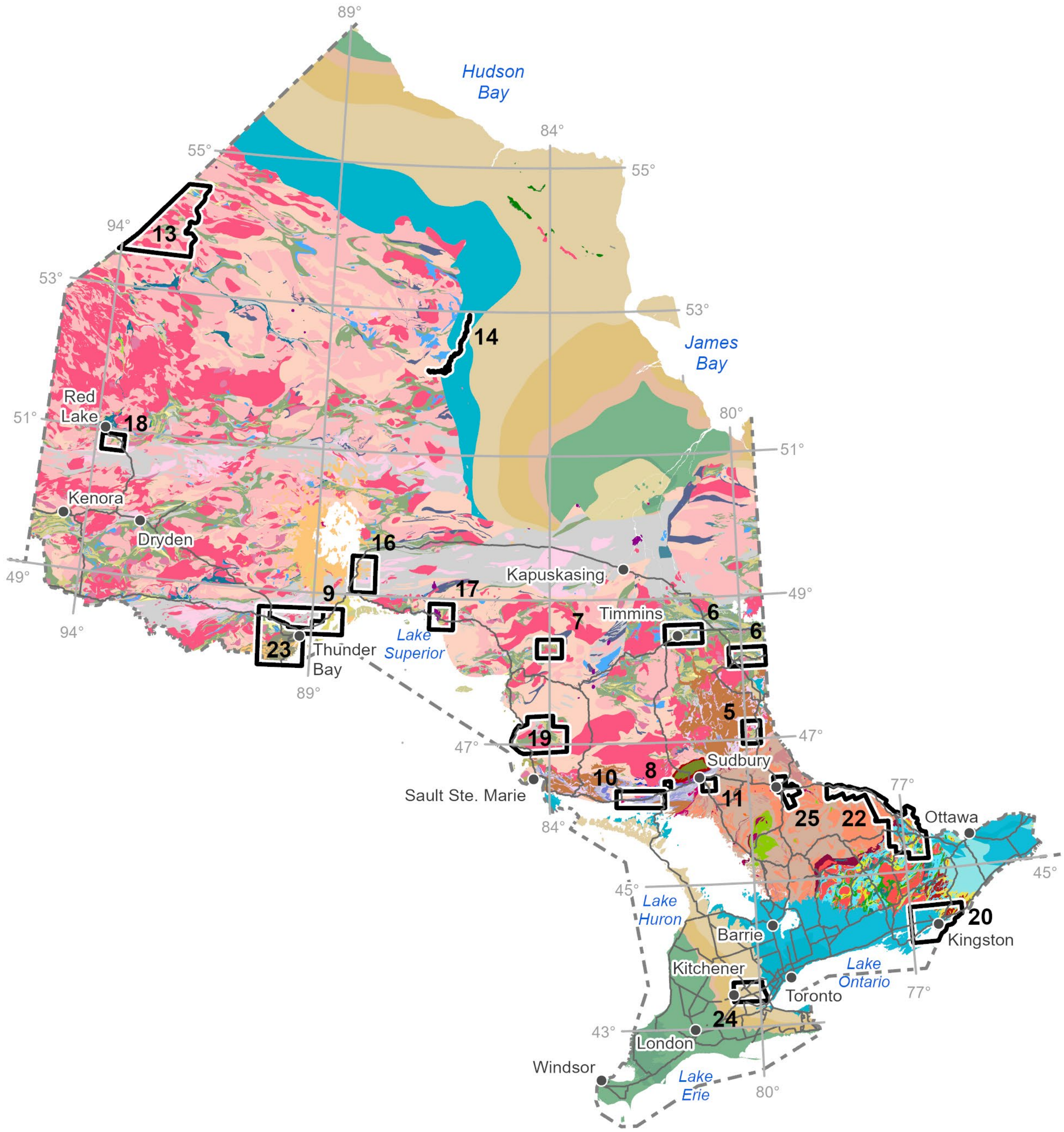


Figure 4.1. Locations of the Earth Resources and Geoscience Mapping Section projects in Ontario as described in *Summary of Field Work and Other Activities, 2024.* Numbers correspond to article numbers; note articles 12, 15 and 21 are provincial in scope and are not indicated on the figure. Bedrock geology *from* Ontario Geological Survey (2011).

Table 4.1. Earth Resources and Geoscience Mapping Section collaborative initiatives and projects, 2024–2025.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Geophysical Techniques in Support of Bedrock Geology Mapping Initiative	Ground geophysical survey ▸ Collect gravity data in support of the three-dimensional (3-D) sediment mapping project in the Guelph area	ERGMS Core Program	Ongoing – data acquired in August to September 2023, data analysis complete, Geophysical Data Set and map in preparation for publication in 2025 ▸ *Summary of Field Work* article published in 2023
	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 2023 and 2024, data analysis in progress, publication in preparation ▸ *Summary of Field Work* article published in 2023 ▸ *Summary of Field Work* (this volume, Article 11)
	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)	Ongoing – 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	ERGMS Core Program	Ongoing – compilation in progress
	Bedrock geological compilation of the Opapimiskan Lake area, North Caribou greenstone belt ▸ 1:50 000 scale	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	New project – field work in 2024 ▸ *Summary of Field Work* (this volume, Article 14)

	Far North terrain mapping project
	▸ remote predictive mapping, field checking; Quaternary mapping
	  ▸ Sandy Lake area
	  ▸ Pickle Lake–Cat Lake area
	  ▸ Opasquia Lake area
		ERGMS Core Program	Ongoing – predictive Quaternary geology mapping in the Sandy Lake area in 2018
			▸ *Summary of Field Work* articles published in 2017, 2018
			▸ MRD and Preliminary maps published in 2023, 2024
			▸ journal publication: Gao (2024)
			Ongoing – predictive Quaternary geology mapping in the Pickle Lake–Cat Lake area, preliminary maps in progress
			▸ *Summary of Field Work* articles published in 2019, 2020
			▸ MRD published in 2023
			Ongoing – predictive Quaternary geology mapping in the northern Opasquia Lake area in 2024
			▸ *Summary of Field Work* (this volume, Article 13)
			▸ Preliminary maps for the southern Opasquia Lake area published in 2024

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

Table 4.1, *continued.*

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Surficial Geochemistry of Northern Ontario Initiative	Top-to-bottom surficial geochemical characterization of the Great Bear gold deposit, Red Lake	ERGMS Core Program	New project – field work in 2024 ▸ *Summary of Field Work* (this volume, Article 18)
	Lake sediment and water geochemistry program: Batchawana greenstone belt, northeastern Ontario	ERGMS Core Program	New project – field work in 2024 ▸ *Summary of Field Work* (this volume, Article 19)
	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	New project – field work in 2024 ▸ *Summary of Field Work* (this volume, Article 17)
	Till sampling and surficial mapping in the Georgia Lake area, northwestern Ontario	ERGMS Core Program	Ongoing – field work in 2023 and 2024 ▸ *Summary of Field Work* article published in 2023 ▸ *Summary of Field Work* (this volume, Article 16)
	Marathon region sediment and water sampling project high-density lake sediment and water geochemistry survey	ERGMS Core Program	Ongoing – MRD in progress
	Surficial geochemistry sampling over the Borden Lake area and Kapuskasing Structural Zone	ERGMS Core Program	Ongoing – OFR and MRD in preparation for publication in 2025 ▸ *Summary of Field Work* article published in 2016
	Highway 17 mapping and sampling project	ERGMS Core Program	Ongoing – field work in 2024, 2023 and 2022 ▸ *Summary of Field Work* articles published in 2022, 2023
Proterozoic Initiative	Totten Township bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	New project – field work in 2024 ▸ *Summary of Field Work* (this volume, Article 8)
	Hyman Township bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2023 and 2022, data analysis 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	ERGMS Core Program	Ongoing – Preliminary Map, OFR and MRD for Denison Township in progress ▸ *Summary of Field Work* articles published in 2016, 2017, 2018
	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; data analyses in progress, MRD in preparation ▸ *Summary of Field Work* (this volume, Article 11) ▸ Field trip guidebook: Easton (2022)
	Proterozoic mafic intrusions of the Sudbury area ▸ Compilation and characterization project	ERGMS Core Program	Ongoing – compilation and database construction

Abbreviations: *GSC, Geological Survey of Canada, 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*	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
	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 2023 and 2022 ▸ *Summary of Field Work* article published in 2022
	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 in progress ▸ *Summary of Field Work* articles published in 2012, 2013 (2), 2016
	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 in progress ▸ *Summary of Field Work* articles published in 2012, 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	New project – field work in 2024 ▸ *Summary of Field Work* (this volume, Article 6)
	Southern Swayze area (Abitibi greenstone belt) bedrock geology mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work near Chapleau in 2024 ▸ *Summary of Field Work* articles published in 2015, 2016, 2017, 2018, 2019, 2022, 2023 ▸ Preliminary Maps and MRDs published in 2017, 2018, 2019, 2020
	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
	Structural and tectonic study of the Swayze area of the Abitibi greenstone belt	PhD thesis (Q. Wu) University of Waterloo	Completed – thesis defended in August 2024 ▸ *Summary of Field Work* articles published in 2015, 2016 ▸ Thesis: Wu (2024)
	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 and compilation map in progress ▸ *Summary of Field Work* articles published in 2018, 2019 ▸ Preliminary Maps and MRDs published in 2020, 2021

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

Table 4.1, *continued.*

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Geology of Northeastern Ontario Initiative, *continued*	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 ▸ *Summary of Field Work* articles published in 2016, 2017, 2018, 2019, 2021, 2022, 2023 ▸ *Summary of Field Work* (this volume, Article 7)
	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 2022, 2023, 2024 ▸ *Summary of Field Work* article published in 2022
	Temagami greenstone belt bedrock mapping project ▸ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work in 2024 and 2023 ▸ *Summary of Field Work* articles published in 2019, 2021, 2023 ▸ *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 2024 and 2023 ▸ *Summary of Field Work* published in 2023
	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 project ▸ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – field work completed ▸ Preliminary Maps and MRD in progress ▸ *Summary of Field Work* articles published in 2016, 2017
	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

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

Table 4.1, *continued*.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Geology of Northwestern Ontario Initiative, *continued*	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 2024, 2023 and 2022 ▸ *Summary of Field Work* articles published in 2019, 2020, 2022, 2023 ▸ *Summary of Field Work* (this volume, Article 9)
	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
	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
2-D and 3-D Surficial Sediment Groundwater Mapping Initiative	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 – field work in 2024, 2022 ▸ *Summary of Field Work* article published in 2022 ▸ *Summary of Field Work* (this volume, Article 24) ▸ OGS Geophysical survey conducted in 2023
	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 2015, 2016, 2017 and 2018 ▸ Preliminary Maps published in 2017; other Preliminary Maps in progress; MRD and GRS in progress; 4 external papers published; 2 external papers in progress; PhD completed in 2019 ▸ *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)
	Regional groundwater systems mapping in the County of Simcoe, southern Ontario	ERGMS Core Program	Ongoing – groundwater sampling in 2018 and 2019 ▸ *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 ▸ *Summary of Field Work* articles published in 2019, 2022

Abbreviations: *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* article published in 2023 ▸ *Summary of Field Work* (this volume, Article 25)
	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 ▸ *Summary of Field Work* article published in 2018 ▸ OFR in progress
2-D and 3-D Paleozoic Bedrock Geology Groundwater Mapping Initiative	Porosity and permeability analysis of deep subsurface Lockport Group ▸ project included compilation of 11 759 core analysis data sets from 150 wells and an update of more than 15 000 formational rank contacts	ERGMS Core Program and collaboration with GSC and OGSRL, NWMO and Mitacs (University of Western Ontario)	Ongoing – subsurface mapping completed 2021 ▸ GSC Open File published (Sun et al. 2023)
	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	Ongoing – in wrap-up stage ▸ *Summary of Field Work* articles published in 2021, 2022, 2023
	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
	Various groundwater geoscience projects (3-D geological model of Paleozoic bedrock) in southern Ontario as part of the Federal groundwater program	ERGMS Core Program and Geological Survey of Canada	Ongoing – 3-D model version 2 and report published in 2021 (Carter et al. 2021) ▸ *Summary of Field Work* articles published in 2017, 2018

Abbreviations: *ARIP, Aggregates Resources Inventory Paper; ARO, Aggregate Resources of Ontario; GSC, Geological Survey of Canada; MNR, Ministry of Natural Resources; NWMO, Nuclear Waste Management Organization; 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	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 ▸ 1 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 ▸ *Summary of Field Work* (this volume, Article 20)
	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 projects, southern Ontario ▸ data interpretation	ERGMS Core Program	Ongoing ▸ update of MRD 283 (MRD 283—Revision 2) published December 2021
	Ambient Groundwater Geochemistry project, southwestern Ontario ▸ Six Nations First Nation	ERGMS Core Program	New project – 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	New project – field work completed in 2024 ▸ *Summary of Field Work* (this volume, Article 23)
	Ambient Groundwater Geochemistry project, eastern Ontario ▸ Ottawa Valley	ERGMS Core Program	New project – field work completed in 2024 ▸ *Summary of Field Work* (this volume, Article 22)
	Ambient Groundwater Geochemistry project, northeastern Ontario ▸ North Bay ▸ Manitoulin and North Shore ▸ Sudbury	ERGMS Core Program	Ongoing – field work completed in 2018, 2017 and 2016, respectively ▸ Data to be incorporated into new northern Ontario ambient groundwater geochemistry MRD
	Characterizing the controls on groundwater chemistry in north-central Ontario	ERGMS Core Program MSc thesis (K.M. Dell) Queen's University	Ongoing – field work completed; thesis defended in 2024 ▸ OFR and northern Ontario ambient groundwater geochemistry MRD in progress ▸ *Summary of Field Work* article published in 2020 ▸ Thesis: Dell (2024)

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

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 2024–2025
	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 ▸ *Summary of Field Work* (this volume, Article 21)
	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 – second year of multi-year study ▸ *Summary of Field Work* article published in 2023 ▸ *Summary of Field Work* (this volume, Article 15)
	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; MSc thesis by J.D. Melo-Gómez, defended in 2023 ▸ *Summary of Field Work* articles published in 2020, 2021, 2022
	Critical Minerals in Gold Deposits	ERGMS Core Program; collaboration with industry	Ongoing – sampling began in 2023; data acquisition and analysis in progress ▸ *Summary of Field Wo*rk article published in 2023
	Field structure measurement database	ERGMS Core Program	Ongoing – compilation of field structure measurements collected since 2000 ▸ compilation completed; database is currently in review

Abbreviations: *MERC, Mineral Exploration Research Centre.*

The ERGMS program is organized into 5 objectives based on the collection, interpretation, synthesis and distribution/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.

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 October 13, 2024].

Collaborative Initiatives 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 GSC, in collaboration with the United States Geological Survey and Geoscience Australia formed the Critical Minerals Mapping Initiative (CMMI) in 2019 to combine expertise and collaboratively conduct research on critical mineral resources. As part of this program, ERGMS staff assisted W. Bleeker of the GSC in co-leading a field trip for CMMI researchers between September 6 and 14, 2024, focussing on Critical Mineral exploration projects in the Grenville, Southern and Superior provinces, as well as the Sudbury Structure.

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 2024 (*see* Table 4.1). For example, since 2013, the OGS has partnered with local municipalities in eastern Ontario to support the development of an Aquifer Capability Screening Tool (ACST). This support continued in 2024–2025 with the City of Ottawa.

The OGS has been involved in discussions with the geological surveys of Saskatchewan and Manitoba regarding a proposed lithodemic nomenclature proposal, especially as it applies to Precambrian rocks. This work was published in 2024 (Maxeiner et al. 2024).

INTERJURISDICTIONAL AND COMMITTEE REPRESENTATION

Staff of the ERGMS represented the Ministry of Mines, the OGS and other geoscience organizations on several interjurisdictional committees, internal committees and associations during the 2024–2025 fiscal year, which are summarized as follows:

- North American Commission on Stratigraphic Nomenclature (representing the Geological Association of Canada, and as a commissioner-at-large)
- International Subcommission on Stratigraphic Classification (ISSC)
- Great Lakes Geologic Mapping Coalition
- Conservation Authorities Geosciences Committee
- Far North Information and Knowledge Management Working Group
- Growing the Green Belt to Protect Water Interministerial Team
- OPS Land Information Ontario (LIO) Imagery Group
- OPS Elevation Coordination & Consultation Committee (EC3)
- Geoscience Laboratories (Geo Labs)–ERGMS Working Group
- Willet Green Miller Centre (WGMC) Joint Health and Safety Committee
- GIS in the Ontario Public Service (OPS) License Management Task Force
- Southern Ontario Stream Sediment Geochemistry Project Steering Committee
- Canadian Working Group on Regional Groundwater Flow Systems of the International Association of Hydrogeologists
- International Joint Commission (IJC) Great Lakes Science Advisory Board
- thesis committees and adjunct professorships at universities (Laurentian University, Carleton University, University of Western Ontario, University of Toronto, University of New Brunswick)
- Mineralogical Association of Canada, Council Member
- Prospectors and Developers Association of Canada (PDAC) Health and Safety Committee (representing the Committee of Provincial and Territorial Geological Surveys)
- Prospectors and Developers Association of Canada (PDAC) Student–Industry Mineral Exploration Workshop (S-IMEW)

STAFFING CHANGES IN THE SECTION

Caroline Gordon accepted the Manager, Geoscience Mapping position within the Bedrock Mapping and Geophysics Section of ERGMS in April 2024. Two new staff have accepted positions in ERGMS: Nathan Carter, Precambrian Geoscience Intern; and James Thayer, Aggregate Resources Geoscientist.

LIST OF PUBLICATIONS[3]

Atasiei, D., Tsujita, C.J., Brunton, F.R., Jin, J. and Yeung, K.H. 2023. Stratigraphy and sedimentology of Upper Ordovician strata, southern Ontario and Manitoulin Island; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.25-1 to 25-11.

Béland Otis, C. 2023. Paleozoic geology of eastern Ontario: Hawkesbury and Alexandria area; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.24-1 to 24-9.

Béland Otis, C., Hahn, K.E. and Brunton, F.R. 2023. Cambro-Ordovician in Ontario: From the outcrop belt to the subsurface; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-209.

Biswas, S., Evangelatos, J. and Burt, A.K. 2023. New ground gravity data from Guelph, Ontario; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-211.

Bleeker, W., Kamo, S.L., Easton, R.M. and Davis, D.W. 2023. New mafic sill complex identified in the lower Huronian Supergroup succession: the May Township sills; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.14-1 to 14-13.

Burnham, O.M. and Hastie, E.C.G. 2023. Characterization of new in-house quality control materials for tellurium analysis: Results of a round robin study; in Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.33-1 to 33-18.

Burt, A.K., Colgrove, L.M., Kalmo, K.J.J., Ford, D., Holysh, S. and Russell, H.A.J. compilers. 2024. Ontario Groundwater Geoscience 2024 Open House; Ontario Geological Survey, Open File Report 6406, 47p.

Burt, A.K., Yeung, K.H., Grant, D. and Mulligan, R.P.M. 2023a. Keeping it simple: Recording geological information on water well records; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-309.

——— 2023b. Keeping it simple: Geologic information on water well records; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.28-1 to 28-7.

Colgrove, L.M. and Dell, K.M. 2023a. Ambient groundwater geochemistry project: Summary and updates; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-308.

——— 2023b. Ambient groundwater geochemistry project: Six Nations of the Grand River; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.30-1 to 30-7.

Dell, K.M. and Hamilton, S.M. 2024. Ambient groundwater geochemical and isotopic data for northeastern Ontario, 2016–2018; Ontario Geological Survey, Miscellaneous Release—Data 401.

Duguet, M. 2023. Archean geology of the Georgia Lake area, Quetico Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.12-1 to 12-11.

Duguet, M. and Launay, G. 2023a. Update on the Precambrian geology of the Georgia Lake area, structural control on the rare-element pegmatites, Quetico Subprovince, northwestern Ontario; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-108.

[3] *This list provides references for publications produced by ERGMS, during the period from December 2023 to December 2024, inclusive, comprising 3 Open File Reports, 8 Preliminary Maps, 1 Miscellaneous Release—Data, 1 Geophysical Data Set (GDS), 38 airborne geophysical survey maps (the geophysical maps are grouped by theme for the survey area), and 17 presentations as part of OGS Virtual Showcase 2023 (12 of which were available in video format through GeologyOntario for a limited time in 2024).*

——— 2023b. Structural control of the Georgia Lake lithium-cesium-tantalum-type pegmatite field, northwestern Ontario: Preliminary results of lineament analyses; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.13-1 to 13-10.

Easton, R.M. 2023a. A study of why some fine-grained sedimentary rocks of the Gowganda Formation in northeastern Ontario are magnetic; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.15-1 to 15-12.

——— 2023b. Geology of the Grenville Front tectonic zone near Sudbury, northeastern Ontario: An update; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.18-1 to 18-7.

Easton, R.M., Marich, A.S. and Wall, C.J. 2023. Geochronological study of a saprolite atop the Grenvillian Mulock pluton near Redbridge, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.17-1 to 17-7.

Evangelatos, J. and Biswas, S. 2023a. The role of geophysics at the Ontario Geological Survey; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-304.

——— 2023b. Summary of geophysical projects and activities; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, 2023, Open File Report 6405, p.20-1 to 20-4.

Gao, C. 2024. Late history of glacial Lake Agassiz in northwestern Ontario, Canada: a case study in the Sandy Lake basin; Canadian Journal of Earth Sciences, v.61, p.377-400.

Gao, C., Hagedorn, G.W., Crabtree, D.C., Clarke, S.A., Hastie, E.C.G., Launay, G. and Beckett-Brown, C.E. 2023a. Determination of indicator minerals in archived fine-fraction non-magnetic heavy mineral concentrate samples using scanning electron microscope energy dispersive spectrometry; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-306.

——— 2023b. Determination of indicator minerals in archived fine-fraction non-magnetic heavy mineral concentrate samples using scanning electron microscope energy dispersive spectrometry; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.21-1 to 21-8.

Gao, C. and Yeung, K.H. 2024a. Surficial geology of the Island Lake area southeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3676, scale 1:100 000.

——— 2024b. Surficial geology of the Opasquia Lake area southwest, northern Ontario; Ontario Geological Survey, Preliminary Map P.3677, scale 1:100 000.

——— 2024c. Surficial geology of the Opasquia Lake area southeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3678, scale 1:100 000.

——— 2024d. Surficial geology of the Deer Lake area, northern Ontario; Ontario Geological Survey, Preliminary Map P.3689, scale 1:100 000.

——— 2024e. Surficial geology of the North Spirit Lake area northwest, northern Ontario; Ontario Geological Survey, Preliminary Map P.3690, scale 1:100 000.

——— 2024f. Surficial geology of the North Spirit Lake area northeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3691, scale 1:100 000.

——— 2024g. Surficial geology of the Deer Lake area, south, northern Ontario; Ontario Geological Survey, Preliminary Map P.3702, scale 1:100 000.

——— 2024h. Surficial geology of the North Spirit Lake area southwest, northern Ontario; Ontario Geological Survey, Preliminary Map P.3703, scale 1:100 000.

Gemmell, T.P. and Creppin, J.R.H. 2023. Preliminary geology and mineral potential of Cunningham Township and part of Garnet Township, Swayze area, Abitibi greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.7-1 to 7-10.

Gemmell, T.P. and Hagedorn, G.W. 2023. Student information session: OGS employment opportunities; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-212.

Gordon, C.A. 2023a. Peperites in the McKim Formation of the Huronian Supergroup, northeastern Ontario; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-204.

——— 2023b. Occurrences of critical minerals in Hyman Township, Southern Province, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.16-1 to 16-13.

Hagedorn, G.W. 2023. Till sampling, ice-flow history and surficial mapping of the Georgia Lake area, northwestern Ontario: Implications for mineral exploration; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-109.

Hagedorn, G.W. and Beckett-Brown, C.E. 2023. Till sampling and surficial mapping in the Georgia Lake area, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.23-1 to 23-9.

Hahn, K.E. 2023. Paleozoic geology of eastern south-central Ontario: Tweed–Kaladar and Belleville–Wellington areas; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.27-1 to 27-11.

Handley, L.A. 2023a. Aggregate Resources of Ontario: Past, present and future updates; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-303.

——— 2023b. Aggregate resources inventory of the North Bay area, central Nipissing District, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.31-1 to 31-9.

Hastie, E.C.G. 2023. Critical Minerals in Gold Deposits: Exploration insights and by-product potential; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-305.

Hastie, E.C.G., Malegus, P.M., Campbell, D.A., Burnham, O.M. and MacDonald, P.J. 2023. An overview of the Critical Minerals in gold deposits project; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.19-1 to 19-5.

Hechler, J.H. 2023. Ontario Geological Survey: Update of Strategic Perspective for 2023–2024; in Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.1-1 to 1-13.

Hechler, J.H., Easton, R.M., Préfontaine, S, Duguet, M., Robichaud, L. and Cormier, R. 2023. Earth Resources and Geoscience Mapping Section: 2023–2024 Program and Projects Overview; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.4-1 to 4-21.

Kalmo, K.J.J. 2023. Ontario Geological Survey: Measuring Success; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.2-1 to 2-9.

Launay, G. and Metsaranta, R.T. 2023a. Geology and rare-element potential of the southern Quetico Subprovince in the Sunshine, Onion Lake, and Loon areas, northwestern Ontario; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-107.

——— 2023b. Precambrian bedrock geology mapping in the Onion Lake and Sunshine areas, Quetico and Wawa subprovinces, northwestern Ontario, *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.11-1 to 11-12.

Levesque, M.D. and Bennett, D.J. 2023. Activities of the Indigenous Geoscience Liaisons in 2022–2023; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.3-1 to 3-8.

MacDonald, P.J. 2023. Geology of Strathy Township, Temagami greenstone belt, northeastern Ontario *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.9-1 to 9-8.

MacDonald, P.J., Kamo, S.L. and Malegus, P.M. 2023. Geochronology of the LP zone volcanic rocks, Red Lake area, Uchi Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.10-1 to 10-8.

Marich, A.S. 2023. Quaternary geological mapping of the eastern part of the Lake Nipissing Basin, northeastern Ontario: An update half a century in the making; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.22-1 to 22-10.

Mulligan, R.P.M. 2023. More than just cold hard science: Applications of new Quaternary investigations in central and eastern Ontario; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-210.

Mulligan, R.P.M., Burt, A.K., Yeung, K.H. and Brunton, F.R. 2023. A unified stratigraphic framework for the Provincial Groundwater Monitoring Network; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.29-1 to 29-6.

Ontario Geological Survey 2023a. Ontario Geological Survey Showcase 2023; Ontario Geological Survey, OGS Showcase 2023.

——— 2023b. Summary of Field Work and Other Activities, 2023; Ontario Geological Survey, Open File Report 6405, 390p.

——— 2024a. Ontario airborne geophysical surveys, magnetic gradiometer data, grid and profile data (ASCII and Geosoft® formats) and vector data, Winisk River area; Ontario Geological Survey, Geophysical Data Set 1069.

——— 2024b. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 542, scale 1:50 000.

——— 2024c. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 543, scale 1:50 000.

——— 2024d. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 544, scale 1:50 000.

——— 2024e. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 545, scale 1:50 000.

——— 2024f. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 546, scale 1:50 000.

——— 2024g. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 547, scale 1:50 000.

——— 2024h. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 548, scale 1:50 000.

——— 2024i. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 549, scale 1:50 000.

——— 2024j. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 550, scale 1:50 000.

——— 2024k. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 551, scale 1:50 000.

——— 2024l. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 552, scale 1:50 000.

——— 2024m. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 553, scale 1:50 000.

——— 2024n. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 554, scale 1:50 000.

——— 2024o. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 555, scale 1:50 000.

——— 2024p. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 556, scale 1:50 000.

——— 2024q. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 557, scale 1:50 000.

——— 2024r. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 558, scale 1:50 000.

——— 2024s. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 559, scale 1:50 000.

——— 2024t. Airborne magnetic gradiometer survey, colour-filled contours of the residual magnetic field, Winisk River area; Ontario Geological Survey, Map 82 560, scale 1:50 000.

——— 2024u. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 561, scale 1:50 000.

——— 2024v. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 562, scale 1:50 000.

——— 2024w. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 563, scale 1:50 000.

——— 2024x. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 564, scale 1:50 000.

——— 2024y. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 565, scale 1:50 000.

——— 2024z. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 566, scale 1:50 000.

——— 2024aa. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 567, scale 1:50 000.

——— 2024ab. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 568, scale 1:50 000.

——— 2024ac. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 569, scale 1:50 000.

——— 2024ad. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 570, scale 1:50 000.

——— 2024ae. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 571, scale 1:50 000.

——— 2024af. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 572, scale 1:50 000.

——— 2024ag. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 573, scale 1:50 000.

——— 2024ah. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 574, scale 1:50 000.

——— 2024ai. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 575, scale 1:50 000.

——— 2024aj. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 576, scale 1:50 000.

——— 2024ak. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 577, scale 1:50 000.

——— 2024al. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 578, scale 1:50 000.

——— 2024am. Airborne magnetic gradiometer survey, shaded colour image of the first vertical derivative of the residual magnetic field and Keating correlation coefficients, Winisk River area; Ontario Geological Survey, Map 82 579, scale 1:50 000.

Phillips, A.R., Brunton, F.R. and Yeung, K.H. 2023. Revisiting the Cambrian stratigraphy in southwestern Ontario: Next steps; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.26-1 to 26-7.

Préfontaine, S. 2023. Ramsey–Algoma granitoid complex, northeastern Ontario: An update on geochronology and lithogeochemistry; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-206.

Préfontaine, S. and Kamo, S.L. 2023. Preliminary uranium-lead ages from the Ramsey-Algoma granitoid complex and surrounding area, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.5-1 to 5-11.

Ratcliffe, L.M. 2023. Geology of Conmee Township - Shebandowan greenstone belt, northwestern Ontario; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-106.

Slagstad, T., Easton, R.M., Huyskens, M. and Culshaw, N. 2024. Complementarity of Lu–Hf isotopes from detrital and igneous zircon: An example from the Central Gneiss Belt, Grenville Province, Ontario; Canadian Journal of Earth Sciences, v.61, 19p., available online June 10, 2024. doi.org/10.1139/cjes-2024-0017

Vice, L.E.D., Perrouty, S. and Pelletier, S.G. 2023. Preliminary geology of Riggs and Glasgow townships, Michipicoten greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.6-1 to 6-10.

Walker, J. 2023a. Reconnaissance mapping in Van Hise, Haultain and Nicol townships, Abitibi greenstone belt, northeastern Ontario; Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023, presentation SHOWCASE-23-205.

——— 2023b. Reconnaissance bedrock geological mapping in Haultain, Van Hise and Nicol townships, Abitibi greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.8-1 to 8-10.

REFERENCES

Carter, T.R., Logan, C.E., Clark, J.K., Russell, H.A.J., Brunton, F.R., Cachunjua, A., D'Arienzo, M., Freckelton, C., Rzyszczak, H., Sun, S. and Yeung, K.H. 2021. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario (version 2); Geological Survey of Canada, Open File 8795, 103p.

Dell, K.M. 2024. Water–rock interactions in geologically diverse regional aquifers of northeastern Ontario; unpublished MSc, Queen's University, Kingston, Ontario, 106p.

Easton, R.M. 2022. Field Trip 2 – Geology of the Grenville Front and the Grenville Front tectonic zone in the Sudbury area; *in* 68th Institute on Lake Superior Geology, Sudbury, Ontario, Proceedings, v.68, part 2, p.102-146.

Gao, C. 2024. Late history of glacial Lake Agassiz in northwestern Ontario, Canada: A case study in the Sandy Lake basin; Canadian Journal of Earth Sciences, v.61, p.377-400.

Maxeiner, R.O., Bosman, S.A., Card, C.D., Marsh, A., Morell, R.M., Coueslan, C., Martins, T., Reid, K., Easton, R.M., Knox, B., Mihalynuk, M.G., Ootes, L., Cui, Y., Grobe, M., Guemache, M.A., Lawley, C.J.M., Böhm, C. and Ashton, K.E. 2024. Classifying intrusive and strongly metamorphosed rock units: CLASS – A Cooperative Lithodemic and Stratigraphic System; Canadian Journal of Earth Sciences, v.61, p.1014-1042.

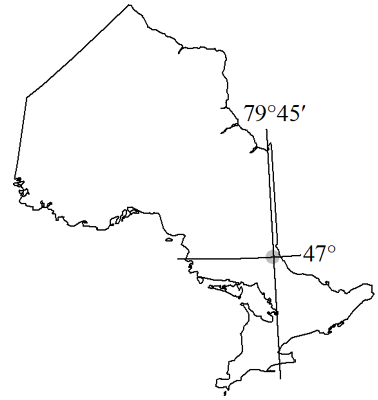
Ontario 2022. Ontario's Critical Mineral Strategy: Unlocking the potential to drive economic recovery and prosperity; Ministry of Northern Development, Mines, Natural Resources and Forestry, 53p., www.ontario.ca/page/ontarios-critical-minerals-strategy-2022-2027-unlocking-potential-drive-economic-recovery-prosperity, also available to download: select "Download English PDF". [accessed October 16, 2023]

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Sun, S., Brunton, F.R., Carter, T.R., Clarke, J.R., Russell, H.A.J., Yeung, K.[H.], Cachunjua, A. and Jin, J. 2023. Porosity and permeability variations in the Silurian Lockport Group and A-1 carbonate unit, southwestern Ontario; Geological Survey of Canada, Open File 8977, 46p.

Wu, Q. 2024. Numerical modelling of structural patterns in tectonic flow with applications to the Neoarchean crustal dynamics; unpublished PhD thesis, University of Waterloo, Waterloo, Ontario, 179p.

5. Project NE-24-002. Geology of Strathcona Township, Temagami Greenstone Belt, Northeastern Ontario



P.J. MacDonald[1]

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

INTRODUCTION

The Temagami greenstone belt mapping project is a multiyear bedrock mapping project initiated in 2019 by the Earth Resources and Geoscience Mapping Section of the Ontario Geological Survey (*see* MacDonald 2019; MacDonald and Kamo 2021; MacDonald 2023). The objectives are to 1) update township-scale bedrock geology maps, 2) investigate the geological architecture, 3) seek correlation with Abitibi greenstone belt chronostratigraphic episodes, if possible, and 4) document geological controls on mineralization.

Field work during the summer of 2024 focussed on 1:20 000 scale bedrock geology mapping in Strathcona Township and the western part of Riddell Township (Figure 5.1). This article presents a brief summary of the main rock types present in the study area, as well as a brief discussion about the Northeast Arm deformation zone.

ROCK TYPES IN STRATHCONA TOWNSHIP AND WESTERN RIDDELL TOWNSHIP

The Temagami greenstone belt is a Neoarchean granite–greenstone inlier surrounded by Paleoproterozoic Huronian Supergroup metasedimentary rocks (Bennett, Dressler and Robertson 1991; Ayer et al. 2006). This section summarizes the Archean and Proterozoic supracrustal and intrusive rocks observed in Strathcona Township and the western part of Riddell Township.

Archean Supracrustal Rocks

Archean supracrustal rocks in Strathcona Township and western Riddell Township include 3 metavolcanic rock packages and 1 metasedimentary package. Supracrustal rocks exposed in the southern two-thirds of the map area are basaltic metavolcanic rocks (*see* Figure 5.1). These metabasalts are typically observed as massive, fine-grained flows, with lesser pillowed flows and flow breccia. Flow thicknesses and facing direction were not observed. Pillowed flows are thin selvedged, with small to medium-sized pillows, but primary pillow shapes are distorted by strong deformational flattening. Gossanous outcrops are related to thin (<1 m thick) interflow sulphide-facies ironstone dominantly composed of pyrite and or pyrrhotite. Metamorphism of the metabasalts ranges from lower amphibolite in the south to greenschist in the north. Thin aplitic granite dikes are commonly observed intruded into fractures crosscutting the metabasalts. No age for the southern metabasalts exists, although as the granite dikes are interpreted to be associated with the Iceland Lake pluton, then this metabasalt package can be interpreted to be older than 2736 Ma (*see* section on “Archean Intrusive Rocks” below).

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.5-1 to 5-6.

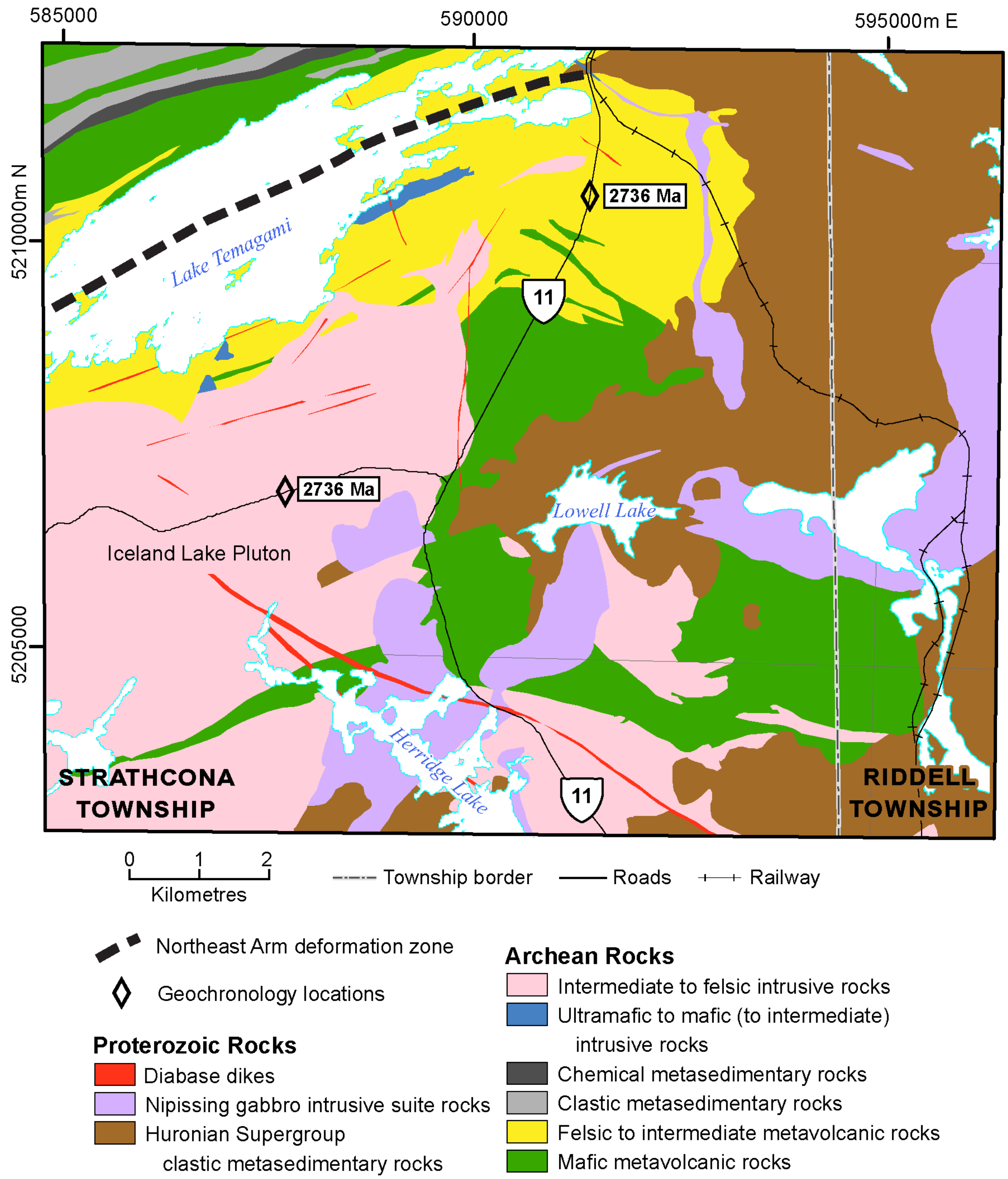


Figure 5.1. Simplified geological map of Strathcona Township and western Riddell Township. The 2 ages shown on the map (geochronology locations) are discussed in the text. Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1989 (NAD83) in Zone 17 (geology *modified from* Bennett 1976; Born, Stephenson and Hitch 1989; Ayer et al. 2006).

Occurring immediately north, the metabasalts in northern Strathcona Township are felsic to intermediate metavolcanic rocks (*see* Figure 5.1). These rhyodacitic metavolcanic rocks are predominantly thickly bedded, polymictic breccia–tuffs (Photo 5.1A), with lesser thin-bedded ash-tuff, massive high-silica rhyolite flows and/or domes and minor siliciclastic metasedimentary rocks. The metavolcanic rocks transition from more intermediate composition in the south, to more felsic in the north. The siliciclastic metasedimentary rocks interbedded within this metavolcanic package occur in the northern half of the package and include thin units of polymictic pebble conglomerates and thinly bedded siltstones. The felsic to intermediate metavolcanic rocks young to the north, and have a previous age determination of 2736 $^{+3}/_{-1}$ Ma (Bowins and Heaman 1991; *see* Figure 5.1). The felsic to intermediate metavolcanic rock package is strongly deformed and altered (i.e., sericite and iron-carbonate) where it is intersected by the Northeast Arm deformation zone at the northern end of the map area. Both the metavolcanic rock package and the deformation zone are exposed along, and proximal to, the shorelines of Lake Temagami.

The third package of metavolcanic rocks occurs in the northwest corner of Strathcona Township (*see* Figure 5.1) and is composed of mafic metavolcanic rocks. Although only limited exposure occurs in Strathcona Township, where observed, this unit is composed of weakly deformed and unaltered pillowed and massive metabasalt flows of unknown thicknesses. Along strike to the northeast, an age determination of *circa* 2717 Ma has been reported for this metavolcanic package (Ayer et al. 2006).

The metasedimentary package of rocks is also located in the northwest corner of Strathcona Township (*see* Figure 5.1). It is composed of thin-bedded sandy siltstone, interbedded and overlain by oxide-facies ironstone. Along strike to the northeast, an age determination of 2721.5±1.1 Ma has been reported for this metasedimentary package (Ayer et al. 2006).

Archean Intrusive Rocks

The largest Archean intrusion in Strathcona Township is the Iceland Lake pluton. The Iceland Lake pluton varies from medium-grained quartz-rich tonalite in the central part of the intrusion (west of Herridge Lake; *see* Figure 5.1) to medium-grained hornblende-rich phases at the eastern edge of the pluton along Highway 11 (*see* Figure 5.1). Late phases of the pluton include aplitic, and lesser pegmatitic, dikes up to 15 cm thick, that form a stockwork crosscutting the main phases of the intrusion (Photo 5.1B) and surrounding metavolcanic rocks. An age determination of 2736±2 Ma for the intrusion (Bowins and Heaman 1991) suggests it is coeval with the felsic to intermediate metavolcanic rocks immediately to the north, and discussed above.

Younger and smaller Archean bodies of intrusive rocks within the map area include both gabbro and porphyritic tonalites. Small gabbro intrusions occur along the southern shore of Lake Temagami (*see* Figure 5.1) and include medium-grained, interlocking plagioclase and amphiboles, with locally significant amounts of semi-massive pyrrhotite, chalcopyrite, pentlandite and magnetite. Porphyritic tonalite intrusions occur throughout the area, with varying amounts of medium-grained plagioclase, quartz and hornblende phenocrysts in a fine-grained quartz-feldspathic matrix (Photo 5.1C).

Proterozoic Rocks

Huronian Supergroup metasedimentary rocks of the Gowganda Formation (Cobalt Group; Bennett, Dressler and Robertson 1991) are exposed in eastern Strathcona Township and western Riddell Township (*see* Figure 5.1). The rocks are typically polymictic pebble conglomerates, with clasts supported in a green to grey mudstone matrix. Near the Archean–Proterozoic unconformity along the Northeast Arm deformation zone, the Gowganda Formation consists of an approximately 10 m thick clast-supported polymictic conglomerate with cobble-, pebble- and boulder-sized granitoid and metavolcanic clasts in a sandy gravel matrix (Photo 5.1D). Bedding within the Gowganda Formation is generally subhorizontal

Photo 5.1. Selected photographs of geological features from Strathcona and western Riddell townships. **A**) Felsic to intermediate breccia-tuff metavolcanic rock (substation 24PMT0698SS, 592676E 5211593N). **B**) Hornblende tonalite intrusion crosscut by pink aplite dikes, Iceland Lake pluton (substation 24PMT0014SS, 591110E 5203747N). **C**) Plagioclase-hornblende-phyric porphyritic tonalite intrusion (station 24PMT093: 591533E 5211528N). **D**) Clast-supported Gowganda Formation conglomerate (station 24PMT104: 591378E 5212066N, photo facing west, visible portion of pen magnet is 10 cm long). **E**) Strongly deformed and altered felsic metavolcanic rocks exposed along Northeast Arm deformation zone (station 24PMT101: 591471E 5211841N, photo facing southeast, visible portion of field assistant is approximately 1 m tall). **F**) Ankerite–quartz ladder vein within strongly deformed felsic metavolcanic rocks along the Northeast Arm deformation zone (station 24PMT093: 591533E 5211528N). Compass for scale is 22 cm long and points north. Location information provided as UTM co-ordinates using NAD83 in Zone 17.

with minor open folds. A well-developed vertical cleavage is present in the exposure along the Northeast Arm deformation zone, suggesting that at least 1 phase of penetrative deformation postdates deposition.

Proterozoic mafic intrusions include Nipissing intrusive suite gabbro sills, Sudbury swarm diabase dikes and diabase dikes of unknown affinity (*see* Figure 5.1). The Nipissing intrusive suite rocks have intruded the Gowganda Formation metasedimentary rocks and the Archean metavolcanic rocks in the map area. The Nipissing intrusive suite rocks are medium-grained plagioclase- and pyroxene-bearing gabbros. The Nipissing intrusive suite has an emplacement age of 2217±2 Ma (Davey et al. 2019). One large northwest-trending Sudbury diabase dike is located north of Herridge Lake (*see* Figure 5.1). It is 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 nonmagnetic, fine-grained chloritized diabase dikes also occur throughout the area, but to which swarm these diabase dikes are associated with is unknown.

NORTHEAST ARM DEFORMATION ZONE

The Northeast Arm deformation zone occurs in northwest Strathcona Township, approximately following the shorelines of Lake Temagami (*see* Figure 5.1). This deformation zone is upward of 2 km thick (north to south) and is composed of multiple east-northeast-trending high-strain zones (Photo 5.1E), that can individually exceed 100 m thickness. Shear sense indicators, including C-S fabric, shear bands and drag folds observed within the Archean rocks indicate predominantly sinistral movement along the deformation zone. Localized exposures that display dextral movement may indicate structural compensation, reactivation, and/or back rotation. Indicators of vertical movement were not documented, although south-side up may be inferred from stratigraphy (i.e., exposed rocks to the south are older). Horizontal and vertical displacement distances have not been determined.

The Northeast Arm deformation zone was both a conduit for magmatism and hydrothermal fluids. Archean gabbros and porphyritic tonalites occur as elongate intrusive bodies within and parallel to the deformation zone. This suggests that the intrusions utilized the deformation zone as a conduit for emplacement. Neither the gabbros nor the porphyritic tonalite intrusions appear deformed, suggesting they were emplaced late in the main phase of deformation that formed the Northeast Arm deformation zone. The deformation zone was also a conduit for hydrothermal fluids. The felsic to intermediate metavolcanic rocks within the zone are sericite and ankerite altered, and have been intruded by narrow (<15 cm thick) ankerite–quartz veins (Photo 5.1F).

The Northeast Arm deformation zone was reactivated during the Proterozoic. Clast-supported conglomerates of the Gowganda Formation were deposited into an assumed paleo-topographical low over the deformation zone. Exposures of the conglomerates show a preferred vertical reorientation of the cobble clasts, suggesting postdepositional realignment. The Proterozoic rocks along the Northeast Arm deformation zone also display a well-developed vertical spaced cleavage that is not observed elsewhere in Strathcona or western Riddell townships. Timing of the reactivation is unknown, but postdates Gowganda Formation deposition in the Paleoproterozoic.

ACKNOWLEDGMENTS

The author acknowledges the project is located on the traditional land-use area of Temagami First Nation/Teme-Augama Anishnabai, Matachewan First Nation, Nipissing First Nation, Abitibi Inland Historic Métis Community (MNO Region 3), Timiskaming First Nation and Atikameksheng Anishnawbek, and is thankful for continued support. The author is grateful to Devon Patterson for field assistance; and to OGS staff: Michael Easton for scientific review; Mathieu Levesque for project support; Patrick Gervais for assisting with figures; and OGS Publication Services for editorial assistance. Special thanks to Candice Rogerson and David Schade for their hospitality at Andorra Accessible Cottages.

REFERENCES

Ayer, J.A., Chartrand, J.E., Grabowski, G.P.D., Josey, S., Rainsford, D. and Trowell, N.F. 2006. Geological compilation of the Cobalt–Temagami area, Abitibi greenstone belt; Ontario Geological Survey, Preliminary Map P.3581, scale 1:100 000.

Bennett, G. 1976. Briggs and Strathcona townships, Nipissing District; Ontario Geological Survey, Map 2324, scale 1:31 680.

Bennett, G.B., Dressler, B.O. and Robertson, J.A. 1991. The Huronian Supergroup and associated intrusive rocks; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.549-591.

Born, P., Stephenson, C.D. and Hitch, M.S. 1989. Precambrian geology, Cassels, and Riddell townships; Ontario Geological Survey, Map 2526, scale 1:20 000.

Bowins, R.J. and Heaman, L.M. 1991. Age and timing of igneous activity in the Temagami greenstone belt, Ontario: A preliminary report; Canadian Journal of Earth Sciences, v.28, p.1873-1876.

Davey, S., Bleeker, W., Kamo, S[.L.], Davis, D.[W], Easton, [R.]M. and Sutcliffe, R.H. 2019. Ni-Cu-PGE potential of the Nipissing sills as part of the ca. 2.2 Ga Ungava large igneous province; *in* Targeted Geoscience Initiative: 2018 Report of Activities; Geological Survey of Canada, Open File 8549, p.403-419.

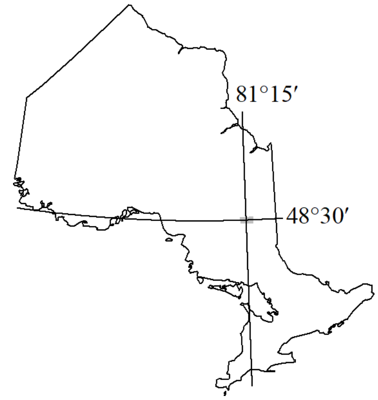
Krogh, T.E., Corfu, F., Davis, D.W., Dunning, G.R., Heaman, L.M., Kamo, S.L., Machado, N., Greenough, J.D. and Nakamura, E. 1987. Precise U-Pb isotopic ages of diabase dykes and mafic to ultramafic rocks using trace amounts of baddeleyite and zircon; *in* Mafic Dyke Swarms, Geological Association of Canada, Special Paper 34, p.147-152.

MacDonald, P.J. 2019. Geological introduction to the Temagami greenstone belt mapping project; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.7-1 to 7-10.

MacDonald, P.J. 2023. Geology of Strathy Township, Temagami greenstone belt, Northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.9-1 to 9-8.

MacDonald, P.J. and Kamo, S.L. 2021. New uranium–lead geochronology from the Temagami greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2021, Ontario Geological Survey, Open File Report 6380, p.8-1 to 8-9.

6. Project NE-24-003. An Introduction to the Timmins–Kirkland Lake Compilation Mapping Project



E.C.G. Hastie[1] and P.J. MacDonald[1]

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

INTRODUCTION

The Abitibi greenstone belt (AGB) is globally recognized as one of the richest metallogenic belts, with total gold endowment (production, reserves, and measured and indicated resources) of over 300 Moz (Hastie et al. 2023). The Timmins and Kirkland Lake camps represent the most important gold camps within the AGB of Ontario, having produced approximately 72 Moz and 40 Moz gold, respectively (Chadwick et al. 2024; D’Angelo et al. 2024). This historical production makes these camps a centre of mining and mineral exploration within Ontario.

Camp-scale bedrock maps (1:50 000 scale) covering the Timmins and Kirkland Lake areas that include all the significant gold-producing mines and developed prospects have never been published publicly. This lack of modern camp-scale maps for the Timmins and Kirkland Lake areas has forced companies and individuals to rely on maps from over 55 years ago, with compilations of data from their own properties added to attempt interpretation of camp-scale features. In addition, new data (e.g., MacDonald and Kamo 2022) indicate that intrusive activity related to ore-forming processes requires additional refined geochronological constraints as well as a reinterpretation of the structural history of these camps. Thus, there is a need for updated compilation bedrock maps and associated data to assist clients with detail that is not limited to their property boundaries.

The Timmins–Kirkland Lake compilation mapping project described herein will publish separate camp-scale (1:50 000 scale) bedrock geology maps of both camps (Figure 6.1). The new maps will improve on previous work by including recently available company data (e.g., assessment files, NI 43-101 technical reports, company releases and presentations), new academic data, reprocessed geophysical data, proprietary company data, and newly collected field, geochemical and geochronological data as part of field work related to this project. Also, it will combine significant areas of the camps that were previously under-mapped along with townships that are newly recognized as being prospective. To achieve these aims the project has 3 main components: 1) compile historical maps, up-to-date company maps and data, and confirm these compilations with bedrock mapping and field work; 2) collect and analyze samples for major and trace element geochemistry and petrography from surface, underground workings and drill core; and 3) collect and analyze key samples for geochronology from surface, underground workings and drill core.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.6-1 to 6-7.

Within the Ontario portion of the AGB, the Timmins compilation area will cover approximately 18 townships (Bristol, Carman, Cody, Deloro, German, Godfrey, Hoyle, Jamieson, Jessop, Macklem, Matheson, Mountjoy, Murphy, Ogden, Shaw, Thomas, Tisdale, Whitney; *see* Figures 6.1 and 6.2) and the Kirkland Lake compilation area will cover approximately 18 townships (Arnold, Bernhardt, Boston, Eby, Gauthier, Grenfell, Hearst, Katrine, Lebel, Maisonville, McElroy, McFadden, McGarry, McVittie, Morrisette, Ossian, Otto, Teck; *see* Figure 6.1). During the 2024 field season, preliminary field work was conducted in the Timmins compilation area, with mapping and sampling focussing on the central portion of the Timmins camp (*see* Figure. 6.2), while preliminary reconnaissance was performed on the townships bordering the Timmins compilation area and throughout the Kirkland Lake compilation area. The planned five-year project will focus on the Timmins compilation area initially in the first few years and then gradually shift focus to the Kirkland Lake compilation area toward the second half of the project. As a result, this article restricts itself to observations made in the Timmins compilation area during the 2024 field season (*see* Figure 6.2).

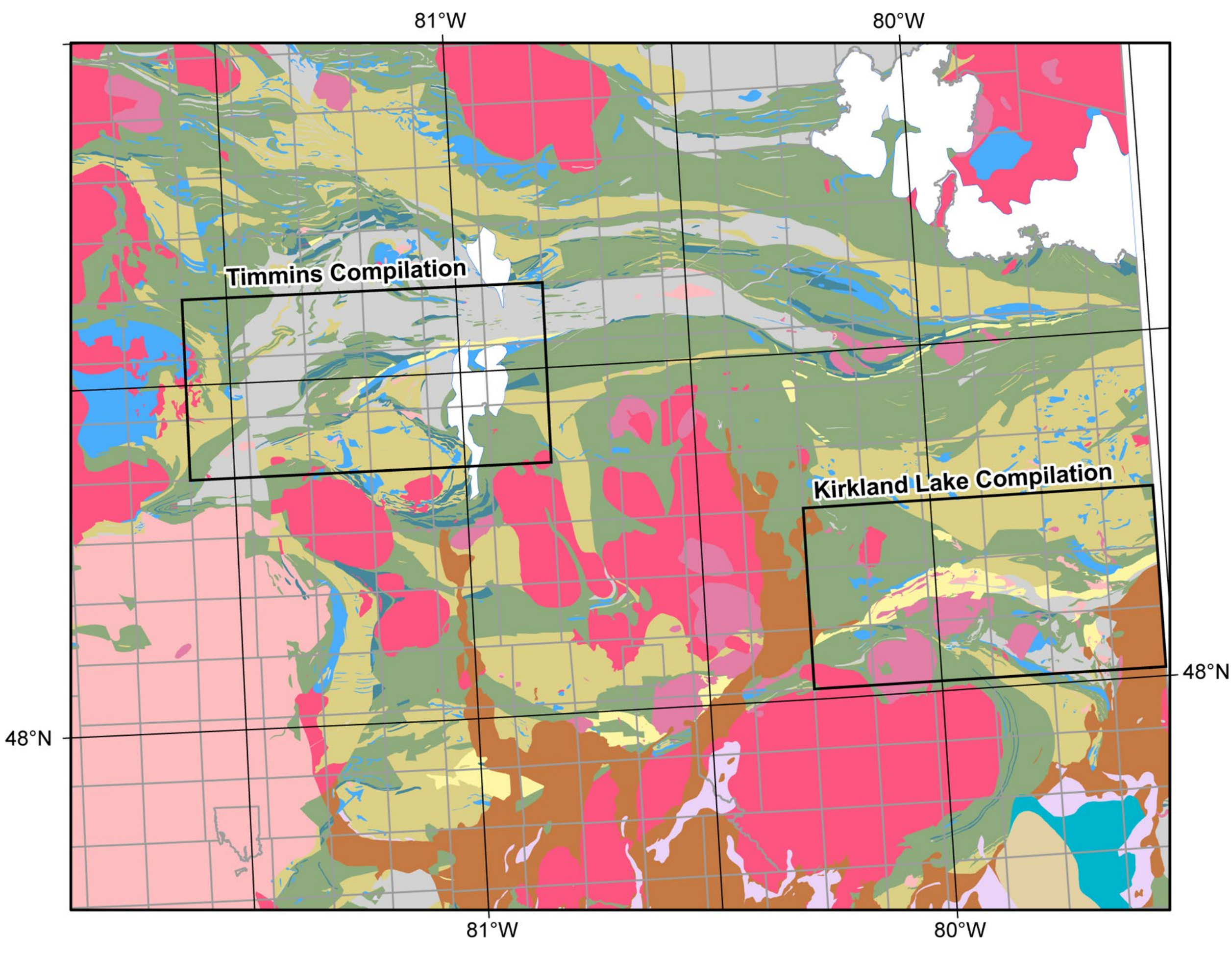


Figure 6.1. Simplified bedrock geology map (*modified from* Ontario Geological Survey 2011) highlighting areas included in the Timmins–Kirkland Lake compilation mapping project (NE-24-003). Detailed legend for the geology can be found in Ontario Geological Survey (2011).

REGIONAL GEOLOGY

The AGB comprises 6 major volcanic assemblages—Pacaud (2750-2735 Ma), Deloro (2734–2724 Ma), Stoughton–Roquemaure (2723–2720 Ma), Kidd–Munro (2720–2710 Ma), Tisdale (2710–2704 Ma) and Blake River (2704–2695 Ma)—followed by the 2 major sedimentary successions, the Porcupine (2690–2685 Ma) and Timiskaming (2679–2669 Ma) (Ayer, Ketchum and Trowell 2002; Monecke et al. 2017; Dubé and Mercier-Langevin 2020). Prior to Timiskaming sedimentation, at least 1 deformation event occurred that was followed by further shortening, strike-slip movement, and shear zone development (Robert 2001; Dubé and Gosselin 2007; Bateman, Ayer and Dubé 2008; Thurston et al. 2008; Monecke et al. 2017, Dubé and Mercier-Langevin 2020). The Porcupine–Destor and Larder Lake–Cadillac fault zones, along with secondary splays, host many of the gold deposits in the AGB (Dubé and Gosselin 2007; Monecke et al. 2017; Dubé and Mercier-Langevin 2020). After the deposition of Timiskaming sedimentary rocks, the western AGB was metamorphosed to temperatures of 350° to 450°C and maximum metamorphic pressures of approximately 3 kbars (Thompson 2005).

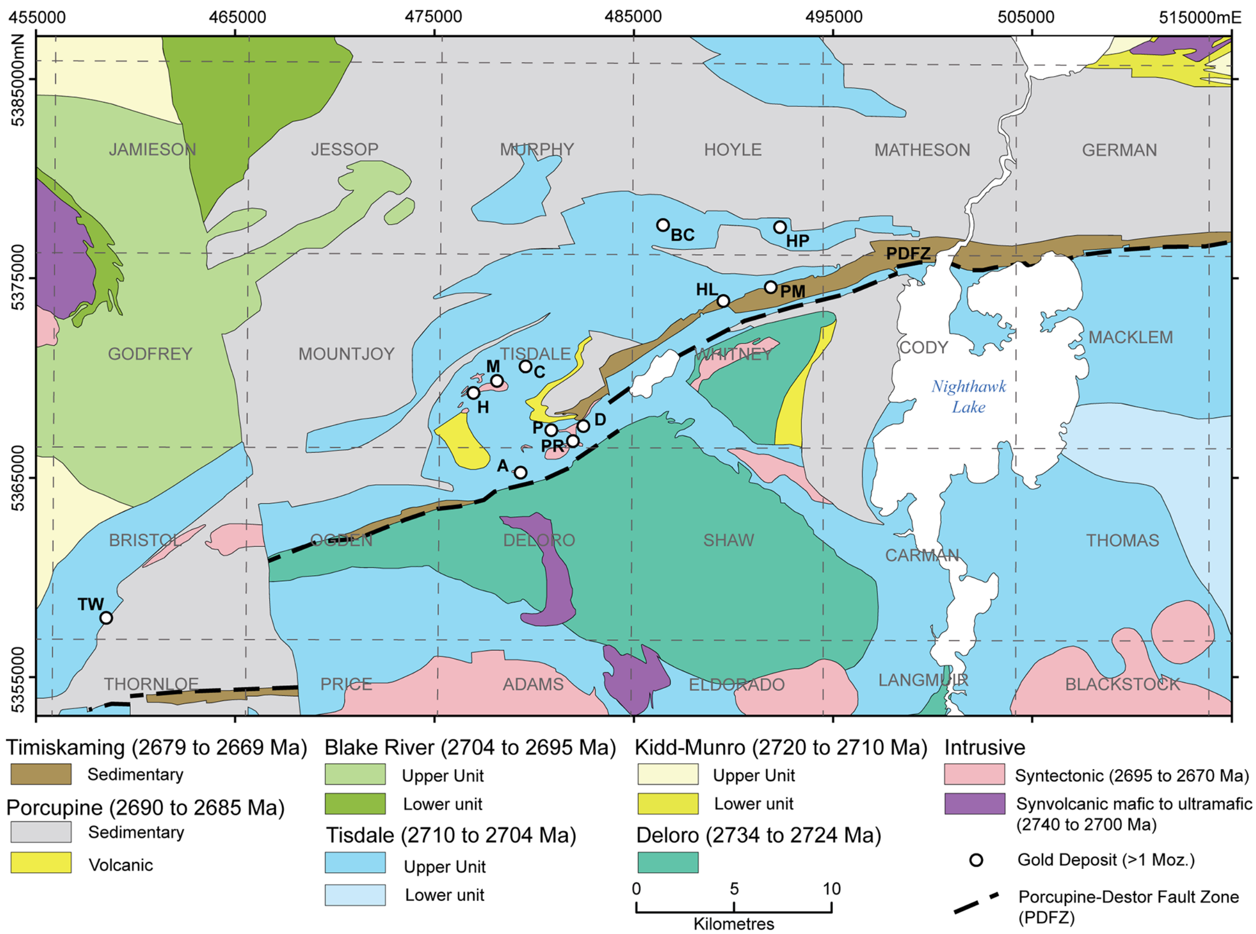


Figure 6.2. Current assemblage map of the Timmins compilation area and the location of active and historical gold mines (>1 Moz). Map *modified from* Bateman (2004); Ayer et al. (2005); and Dubé et al. (2020). Abbreviations: A = Aunor, BC = Bell Creek, C = Coniaurum, D = Dome, H = Hollinger, HL = Hallnor, HP = Hoyle Pond, M = McIntyre, P = Paymaster, PM = Pamour, PDFZ = Porcupine–Destor Fault Zone, PR = Preston, TW = Timmins West.

The Timmins compilation area is dominated by rocks of the Deloro, Tisdale, Porcupine and Timiskaming assemblages (briefly discussed here), with some rocks of the Blake River and Kidd Munro assemblages to the west and north (*see* Figure 6.2). The Deloro assemblage is composed of mafic and intermediate to felsic volcanic and volcaniclastic rocks, with banded iron formation at the stratigraphic top of the assemblage (Dubé et al. 2020). These rocks occur south of the Porcupine–Destor fault zone (*see* Figure 6.2). The Tisdale assemblage stratigraphically overlies the rocks of the Deloro assemblage and is composed of ultramafic and mafic volcanic rocks (Photo 6.1A) as well as minor carbonaceous interflow sedimentary rocks (Dubé et al. 2020 and references therein). From oldest to youngest, the Tisdale assemblage has been subdivided into the Hersey Lake Formation, Central Formation, Vipond Formation and the Gold Centre Formation (Graton et al. 1933; Ferguson et al. 1968; Bateman, Ayer and Dubé 2008; Dubé et al. 2020). From oldest to youngest, the Porcupine assemblage comprises carbonaceous mudstone, volcaniclastic rocks (Krist Formation), greywacke, siltstone, mudstone ± iron formation and conglomerate (Beatty and Hoyle formations). The Timiskaming angular unconformity separates the Porcupine from the Timiskaming assemblages (Photo 6.1B). From oldest to youngest, the Timiskaming assemblage is composed of a basal conglomerate, mudstone and sandstone (Dome Formation) as well as younger sandstone, pebbly sandstone and conglomerate of the Three Nations Formation (Dubé et al. 2020 and references therein). Syntectonic intrusions that range in age from 2695 to 2670 Ma cut rocks in the Timmins compilation area and in many cases are spatially associated with gold mineralization (MacDonald and Piercey 2019; *see* Figure 6.2).

Figure 6.2 shows the location of both currently producing gold mines in the Timmins compilation area (Bell Creek, Hollinger, Hoyle Pond and Timmins West mines), as well as historic gold mines with gold production greater than 1 Moz. Gold mineralization and most deposits in the Timmins camp are currently interpreted to be orogenic deposits, with timing broadly contemporaneous with peak metamorphism and the main phase of shortening (*circa* 2665 to 2640 Ma). There is evidence, however, to support an earlier gold mineralization event associated with pyrite nodules and auriferous clasts that occur in the Porcupine and Timiskaming assemblages, respectively (Gray and Hutchinson 2001; Pilote et al. 2019, 2020), as well as early copper–gold—molybdenum mineralization associated with the Pearl Lake porphyry (*circa* 2689 Ma)(Photos 6.1C and 6.1D) at the McIntyre Mine (Mason and Melnick 1986; Brisbin 1997; Dubé et al. 2020). This allows for the possibility that early gold was remobilized and concentrated into economic deposits during orogenic processes, rather that being introduced in the system during that time, i.e., 2665 to 2640 Ma (Hastie, Kontak and Lafrance 2020).

DISCUSSION

Most field data collection during the summer of 2024 focussed on examining and sampling outcrop and drill core from the main portion of the Timmins camp (i.e., Tisdale, Whitney and Hoyle townships; *see* Figure 6.2) to understand geological sites that show representative mineralization styles (e.g., Hunter Mine; Photo 6.1E) and compare these sites to more recently developed parts of the camp (e.g., Timmins West; Photos 6.1F and 6.1G) to establish a list of priority geoscience questions to be answered. An example of new data that provides a reason to re-examine geological relationships in the main camp is the Crown porphyry age of 2682.8±1.1 Ma, obtained from the Hollinger pit (MacDonald and Kamo 2022). This is significantly younger than the previous age on the Crown porphyry (2688±2 Ma, Corfu et al. 1989) as well as on porphyry bodies that are interpreted to connect at depth (i.e., the Pearl Lake porphyry and Millerton porphyry, both *circa* 2689 Ma). In addition, the previous interpretation that the porphyries in the camp were coeval with the Kirst Formation of the Porcupine assemblage (2690–2685 Ma) necessitates reinterpretation of other ages based on crosscutting relationships as well as reinterpreting the structural framework of the camp based on the new timing of Crown porphyry emplacement.

Photo 6.1. Representative photos of geological features in the map area. **A)** Pillows in Tisdale assemblage mafic volcanic rocks**.** (Universal Transverse Mercator (UTM) 478171E 5368945N). **B)** Angular unconformity between the Porcupine (top right) and Timiskaming (bottom left) sedimentary rocks (UTM 484596E 5371456N). **C)** Contact between the Tisdale volcanic rocks (left, dark) and the Pearl Lake porphyry (right, lighter). Area within box outline shown in close-up view in **D** (UTM 477377E 5369277N). **D)** Inset from C showing a closer look at the contact between the Tisdale volcanic rocks (left) and the Pearl Lake porphyry (right). **E)** Quartz–carbonate veining and mineralization associated with rocks at the Hunter Mine (UTM 487220E 5370719N). **F)** Gold-bearing intrusive rocks underground at the Timmins West 144 Gap deposit (685 level, crosscut 17). **G)** Molybdenite (middle, bluish-grey) and (top, yellow) chalcopyrite associated with gold ore at the Timmins West 144 GAP deposit.

ACKNOWLEDGMENTS

This project is supported through industry collaborators and special thanks are offered to companies and their staff for assisting with the project: Agnico Eagle Mines Ltd., Canadian Gold Miner Corp., International Explorers and Prosp2ectors Inc., Kirkland Lake Discoveries Corp., Newmont Corp. and Pan American Silver Corp. We would also like to thank OGS staff including mapping assistants Mia Pereira and Weeda Tiraei for their hard work during the mapping season; Vittoria D'Angelo and James Suma-Momoh for project support; Michael Easton for revisions to this article; Pat Gervais for work on the figures; and Jennifer Hargreaves and Marg Rutka for editorial assistance.

REFERENCES

Ayer, J.A., Ketchum, J.W.F. and Trowell, N.F. 2002. New geochronological and neodymium isotopic results from the Abitibi greenstone belt, with emphasis on the timing and the tectonic implications of Neoarchean sedimentation and volcanism; *in* Summary of Field Work and Other Activities, 2002, Ontario Geological Survey, Open File Report 6100, p.5-1 to 5-16.

Ayer, J.A., Thurston, P.C., Bateman, R., Dubé, B., Gibson, H.L., Hamilton, M.A., Hathway, B., Hocker, S.M., Houlé, M.G., Hudak, G., Ispolatov, V.O., Lafrance, B., Lesher, C.M., MacDonald, P.J., Péloquin, A.S., Piercey, S.J., Reed, L.E. and Thompson, P.H. 2005. Overview of results from the Greenstone Architecture Project: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6154, 146p.

Bateman, R. 2004. Precambrian geology, parts of Whitney and Hoyle townships; Ontario Geological Survey, Preliminary Map P.3547—Revised, scale 1:10 000.

Brisbin, D.I. 1997. Geological setting of gold deposits in the Porcupine gold camp, Timmins, Ontario; unpublished PhD thesis, Queen's University, Kingston, Ontario, 523p.

Chadwick, P.J., Péloquin, A.S., Suma-Momoh, J., McKinnon, B.B., Bousquet, P., LeBaron, P.S., Daniels, C.M., Hinz, S.L.K., Meyer, G. and Sabiri, N. 2024. Report of Activities 2023, Resident Geologist Program, Kirkland Lake Regional Resident Geologist Report: Kirkland Lake and Sudbury Districts; Ontario Geological Survey, Open File Report 6411, 191p.

Corfu, F., Krogh, T.E., Kwok, Y.Y. and Jensen, L.S. 1989. U-Pb zircon geochronology in the southwestern Abitibi greenstone belt, Superior Province; Canadian Journal of Earth Sciences, v.26, p.1747-1763.

D'Angelo, V., Krukowski, M., Maity, B.K., Bousquet, P., Daniels, C.M., Hinz, S.L.K., Meyer, G., Sabiri, N., Swiercz, J. and Adrianwalla, C.J. 2024. Report of Activities 2023, Resident Geologist Program, Timmins Regional Resident Geologist Report: Timmins and Sault Ste. Marie Districts; Ontario Geological Survey, Open File Report 6410, 130p.

Dubé, B. and Gosselin, P. 2007. Greenstone-hosted quartz-carbonate vein deposits; Geological Association of Canada, Mineral Deposits Division, Special Publication 5, p.49-73.

Dubé, B. and Mercier-Langevin, P. 2020. Gold deposits of the Archean Abitibi greenstone belt, Canada; Society of Economic Geologists, Special Publication 23, p.669-708.

Dubé, B., Mercier-Langevin, P., Ayer, J., Pilote, J-L. and Monecke, T. 2020. Gold deposits of the world-class Timmins–Porcupine camp, Abitibi greenstone belt, Canada; Society of Economic Geologists, Special Publication 23, p.53-80.

Ferguson, S.A., Buffam, B.S.W., Carter, O.F., Griffis, A.T., Holmes, T.C., Hurst, M.E., Jones, W.A., Lane, H.C. and Longley, C.S. 1968. Geology and ore deposits of Tisdale Township, District of Cochrane; Ontario Department of Mines, Geological Report 58, 177p.

Graton, L.C., McKinstry, H.E. and others [not named]. 1933. Outstanding features of Hollinger geology; Transactions of the Canadian Institute of Mining and Metallurgy, v.36, p.1-20.

Gray, M.D. and Hutchinson, R.W. 2001. New evidence for multiple periods of gold emplacement in the Porcupine mining district, Timmins area, Ontario, Canada; Economic Geology, v.96, p.453-475.

Hastie, E.C.G., Kontak, D.J. and Lafrance, B. 2020. Gold remobilization: Insights from gold deposits in the Archean Swayze greenstone belt, Abitibi Subprovince, Canada; Economic Geology, v.115, no.2, p.241-277.

Hastie, E.C.G., Kontak, D.J., Lafrance, B., Petrus, J.A., Sharpe, R. and Fayek, M. 2023. Evaluating geochemical discriminants in Archean gold deposits: A Superior Province perspective with an emphasis on the Abitibi greenstone belt; Economic Geology, v.118, no.1, p.123-155.

MacDonald, P.J. and Kamo, S.L. 2022. New geochronological data from the Hollinger Mine, Timmins area, Abitibi greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.5-1 to 5-11.

MacDonald, P.J. and Piercey, S.J. 2019. Geology, lithogeochemistry, and significance of porphyry intrusions associated with gold mineralization within the Timmins–Porcupine gold camp, Canada; Canadian Journal of Earth Sciences, v.56, p.399-418.

Mason, R. and Melnik, N. 1986. The anatomy of an Archean gold system-the McIntyre-Hollinger complex at Timmins, Ontario, Canada; extended abstract *in* Gold '86: An International Symposium on the Geology of Gold Deposits, Toronto, Canada, 1986, Proceedings, p.40-55.

Monecke, T., Mercier-Langevin, P., Dubé, B. and Frieman, B.M. 2017. Geology of the Abitibi greenstone belt; Reviews in Economic Geology, v.19, p.7-49.

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Pilote, J.L., Jackson, S.E., Mercier-Langevin, P., Dubé, B. and Rhys, D. 2019. Characteristics of diagenetic and epigenetic sulphides in deformed and metamorphosed Archean carbonaceous metasedimentary rocks of the Timmins-Matheson corridor: Establishing a framework for fingerprinting ore-forming processes in shear zone-hosted orogenic gold systems; Geological Survey of Canada, Open File 8549, p.33-41.

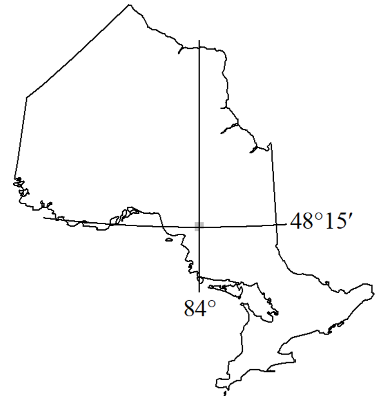
Pilote, J.-L., Jackson, S.E., Mercier-Langevin, P., Dubé, B., Lawley, C.J.M., Petts, D.C., Yang, Z., van Hees, E. and Rhys, D. 2020. Fingerprinting ore processes in orogenic auriferous systems: Insights into metallogenic and exploration implications from argillite-hosted iron sulphide nodules from the Timmins-Matheson gold corridor; *in* Targeted Geoscience Initiative 5: Contributions to the Understanding of Canadian Gold Systems; Geological Survey of Canada, Open File 8712, p.165-178.

Robert, F. 2001. Syenite-associated disseminated gold deposits in the Abitibi greenstone belt, Canada; Mineralium Deposita, v.36, p.503-516.

Thompson, P.H. 2005. A new metamorphic framework for gold exploration in the Timmins–Kirkland Lake area, western Abitibi greenstone belt: Discover Abitibi Initiative; Ontario Geological Survey, Open File Report 6162, 104p.

Thurston, P.C., Ayer, J.A., Goutier, J. and Hamilton, M.A. 2008. Depositional gaps in Abitibi greenstone belt stratigraphy: A key to exploration for syngenetic mineralization; Economic Geology, v.103, p.1097-1134.

7. Projects NE-23-004, NE-22-002. Preliminary Structural Mapping of Deformation Zones in the Northeastern Michipicoten Greenstone Belt, Northeastern Ontario



L.E.D. Vice[1,2] and S. Perrouty[2]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey
[2]Mineral Exploration Research Center (Metal Earth), Harquail School of Earth Sciences, Laurentian University, Sudbury, Ontario P3E 2C6

INTRODUCTION

The summer of 2024 marked the final field season of a multi-year bedrock mapping project that aims to re-examine the bedrock geology, characterize major rock units and stratigraphy, and evaluate the mineral potential of the northeastern Michipicoten greenstone belt. Field mapping was primarily undertaken in Glasgow, Riggs, Meath and Rennie townships, which included documenting structurally significant locations in the framework of an associated PhD project (Vice, Perrouty and Robichaud 2022). The preliminary geology of previously mapped townships is outlined in Robichaud (2013), Robichaud and McDivitt (2014), Robichaud, McDivitt and Trevisan (2015), Robichaud et al. (2016), Walker and Robichaud (2016), Walker (2017), Walker and Robichaud (2018), Vice (2022) and Vice, Perrouty and Pelletier (2023).

In addition to regional bedrock mapping, detailed structural observations were made in key areas to 1) document contact relationships between supracrustal assemblages; 2) investigate the nature, kinematic, and tectonic significance of major deformation zones; and 3) provide a regional structural framework for known mineral resources. Preliminary results and interpretation of detailed 1:10 000 scale bedrock mapping undertaken during the 2024 field season is outlined herein.

REGIONAL GEOLOGY

The Michipicoten greenstone belt consists of Archean mafic to felsic metavolcanic and metasedimentary rock successions intruded by Archean metagabbroic to metagranitic dikes, sills and plutons (Turek, Smith and Van Schmus 1982) and younger Paleoproterozoic mafic dikes. The supracrustal rocks of the belt have previously been subdivided into 3 distinct volcanic cycles occurring at 2900 Ma, 2750 Ma and 2700 Ma (Sage and Heather 1991; Heather and Arias 1992; Turek, Smith and Van Schmus 1982, 1984; Turek, Van Schmus and Sage 1988) that are all overlain by the Doré metasedimentary rocks (<2680 Ma: Corfu and Sage 1992). Geochronological data from the current mapping project suggest that volcanism is more continuous than previously interpreted, with ages ranging from 2731 to 2704 Ma (Vice, Perrouty and Robichaud 2022 and references therein).

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.7-1 to 7-11.

Multiphase regional deformation has been documented within the belt, with a dominant easterly trend parallel to assemblage boundaries (Goodwin 1962; Percival and Card 1983; McGill and Shrady 1986; Arias and Heather 1987; Heather and Arias 1987, 1992; Heather and Buck 1988; Arias and Helmstaedt 1990; Sage 1994; McDivitt et al. 2017; Jellicoe et al. 2022; Campos 2023). Recent studies of known gold deposits in the belt relates mobilization and concentration of gold to activation along high-strain zones (McDivitt et al. 2017; Jellicoe et al. 2022; Campos 2023). Additionally, significant gold occurrences in the central and western part of the belt are spatially associated with deformation zones, such as the Goudreau Lake deformation zone and the Cradle Lake deformation zone, which are mostly subparallel to the dominant penetrative foliation (Arias and Helmstaedt 1987; Heather and Arias 1992; Sage 1994). The continuation of these structural features into the eastern part of the belt is poorly constrained.

EASTERN MICHIPICOTEN GREENSTONE BELT GEOLOGY

The Archean bedrock geology of the eastern Michipicoten greenstone belt (Figure 7.1) includes mafic, intermediate and felsic metavolcanic rocks, as well as clastic and chemical metasedimentary rocks intruded by multiple suites of Archean ultramafic to felsic intrusions that are bounded to the north by the Wabatongushi Lake granitoid complex and to the east by the Missinaibi Lake batholith. Supracrustal rocks have been metamorphosed at greenschist to amphibolite facies conditions and locally metasomatized with primarily carbonate and potassic alteration (Robichaud 2013; Robichaud and McDivitt 2014; Robichaud, McDivitt and Trevisan 2015; Robichaud et al. 2016; Walker and Robichaud 2016; Walker 2017; Walker and Robichaud 2018; Vice 2022; Vice, Perrouty and Pelletier 2023). Mafic dikes, interpreted to belong to the Paleoproterozoic Matachewan dike swarm (*circa* 2460 Ma: Bleeker et al. 2015), crosscut all Archean rocks.

CONTACT RELATIONSHIPS

The nature of contacts between supracrustal units within the belt are either unconformity controlled and separated by ironstone units or they are structurally juxtaposed by zones of intense deformation. Along structural boundaries with the most intense deformation, a spatial association with clastic metasedimentary units that are primarily fine grained (clay-sand) and locally conglomeratic (gravel) is commonly observed (*see* Figure 7.1). The most prominent of these structures located along the northern margin of the greenstone belt separates clastic metasedimentary rocks to the north from metavolcanic rocks to the south by a zone of intense deformation known as the Easey Lake deformation zone (ELDZ; Vice, Perrouty and Pelletier 2023). The ELDZ appears to be continuous throughout Leeson, Rennie and Meath townships and has been offset along the Meath Lake fault to be exposed in northern Riggs Township (*see* Figure 7.1). A second significant location where clastic metasedimentary rocks are structurally juxtaposed with metavolcanic rocks is in central Stover Township along Baltimore Lake, a zone considered to be part of the Baltimore deformation zone (BDZ; Ontario Geological Survey 2024). Both structural features are discernible by low magnetic responses on airborne geophysical surveys (Ontario Geological Survey 1999, 2003, 2011).

Easey Lake Deformation Zone

The ELDZ is an east-trending first-order structure best exposed on the southern shore of Lochalsh Bay on Dog Lake in Riggs Township, the northern shore of Easey Lake in Meath Township, and along roads, trails and outcrops near Conboy Lake in Rennie Township. Kinematic indicators (described in the next sections) show a dominant dextral-transpressive displacement (Photo 7.1A and 7.1B); however, sinistral shear sense indicators are also sparsely observed along the structure. The bulk of the deformation can be estimated between 2692 to 2670 Ma, based on the following constraints: 1) a foliated granodiorite (2691.6±1.7 Ma, zircon) cut by a massive granite to syenite (2685.5±3.1 Ma, zircon) on

Wabatongushi Lake, with both returning *circa* 2677 Ma titanite ages (zircon and titanite ages were done by thermal ionization mass spectrometry (TIMS); Kamo 2024); 2) the strongly foliated, Conboy Lake porphyry (2675±6 Ma, TIMS zircon; Turek et al. 1996); and 3) the undeformed Lochalsh Bay stock, which crosscuts the main foliation, with zircon growth from 2678±0.65 Ma to 2670±1.1 Ma (laser ablation inductively coupled plasma mass spectrometry (LA-ICP–MS) zircon; J.H. Marsh, Mineral Exploration Research Centre Isotope Geochemistry Laboratory, Laurentian University, written communication, 2024).

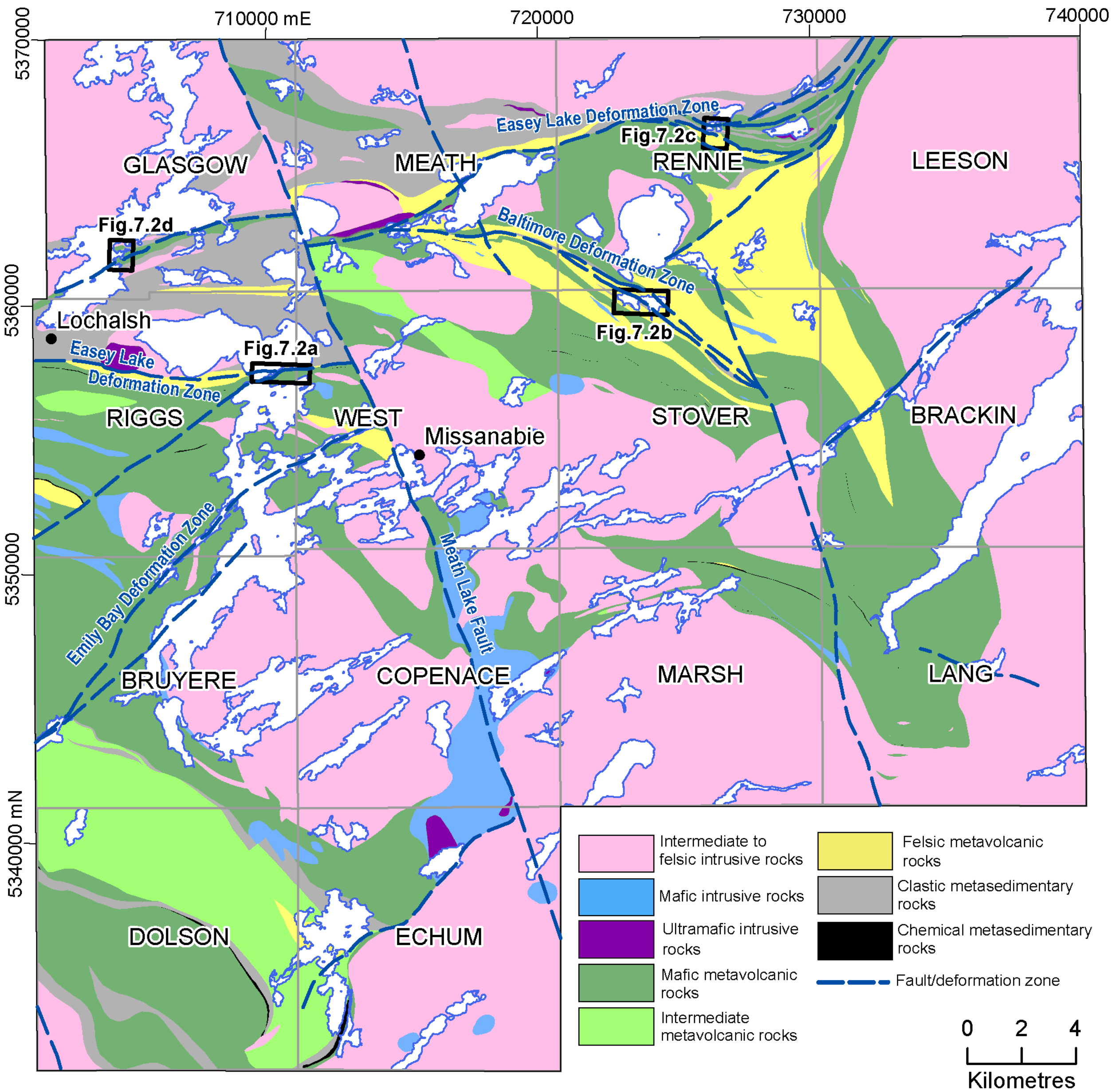


Figure 7.1. Simplified geological map of the eastern Michipicoten greenstone belt. Detailed map locations shown in Figure 7.2 are outlined in black. Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 16.

Ultramafic intrusions into supracrustal rocks are observed in spatial proximity to the ELDZ and the related high-strain zones. Ultramafic intrusive rocks are massive in nature but are locally strongly deformed parallel to the deformation fabrics seen in the adjacent supracrustal rocks, suggesting their emplacement was predeformation to syndeformation. These ultramafic rocks have high magnetic signatures and have returned anomalous values of nickel, cobalt and platinum group elements (Maity and Adrianwalla 2023, p.22); however, the nature and tectonic significance of this spatial association remains uncertain, as well as potential petrogenetic relationships with ultramafic lamprophyre intrusions in the Michipicoten greenstone belt.

DOG LAKE EXPOSURE

The best accessible exposure of the ELDZ is on the south shore of Lochalsh Bay, on Dog Lake, where a series of narrow 1 to 50 m high-strain zones juxtapose mafic and felsic metavolcanic rocks to the south with clastic metasedimentary rocks, apparently interlayered with felsic metavolcanic rocks to the north (Figure 7.2A). Deformation zones are defined by increasing intensity of the main foliation in supracrustal rocks into zones of highest strain (*see* Figure 7.2A; i.e., from distal spaced cleavage to a proximal

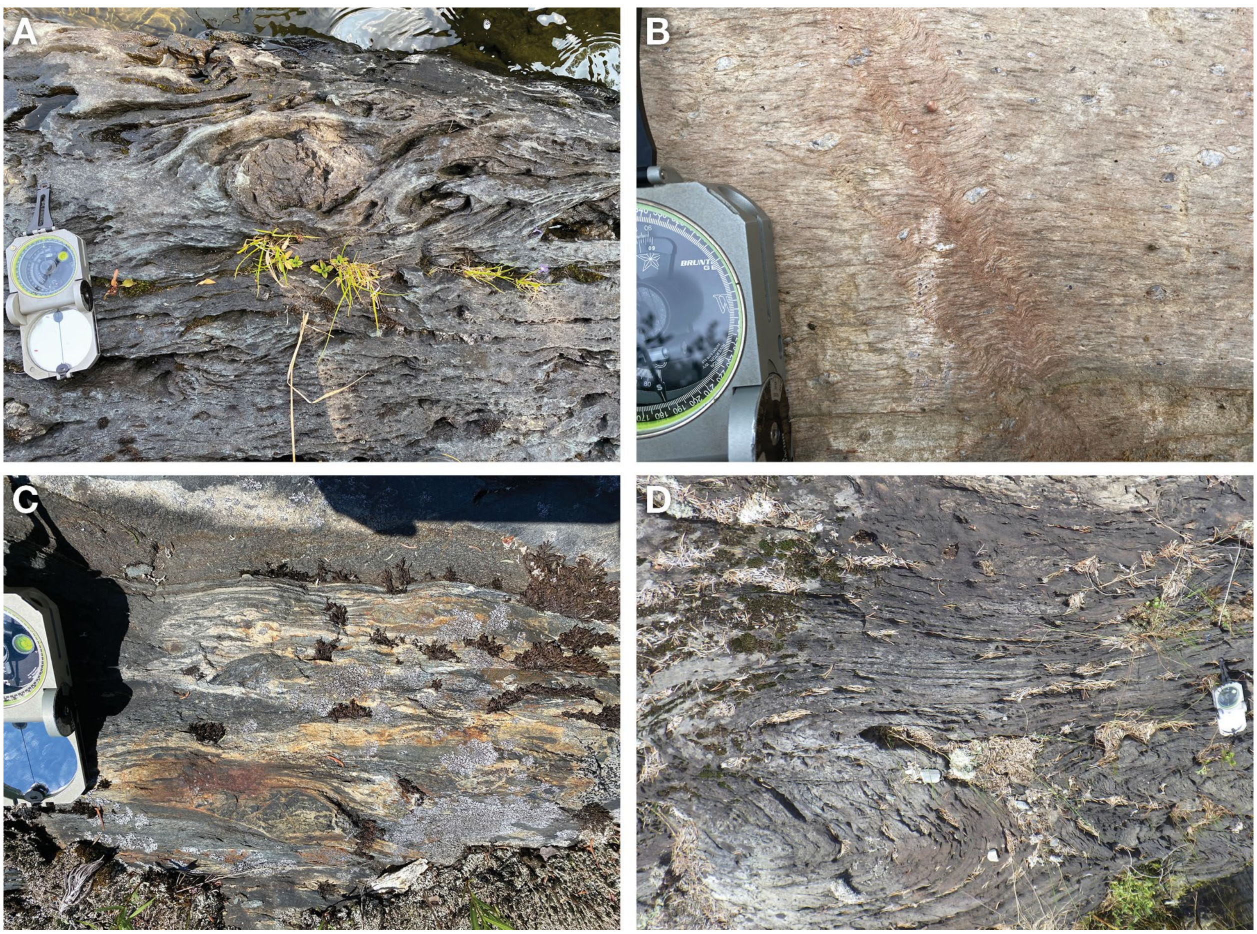


Photo 7.1. Selected photographs of structural features near zones of deformation. **A)** Dominantly dextral-transpressive shear sense indicators on shore of Lochalsh Bay, Dog Lake (substation 23LEV284SS; UTM 710632E 5357776N). **B)** Quartz crystals with the main foliation wrapping around them. The main foliation is kinked along a later northwest-trending fracture surface (substation 24LEV290SS; UTM 726042E 5367419N). **C)** Rotated clasts of foliated supracrustal rocks within brecciated zone on Wabatongushi Lake (substation 24LEV037SS; UTM 704707E 5361733N). **D)** S-asymmetric fold along Baltimore deformation zone on shore of Baltimore Lake (substation 22LEV200SS; UTM 724688E 5360662N). Compass for scale is 7.1 cm wide, with sighting arm pointing north. All UTM co-ordinates provided using NAD83 Zone 16.

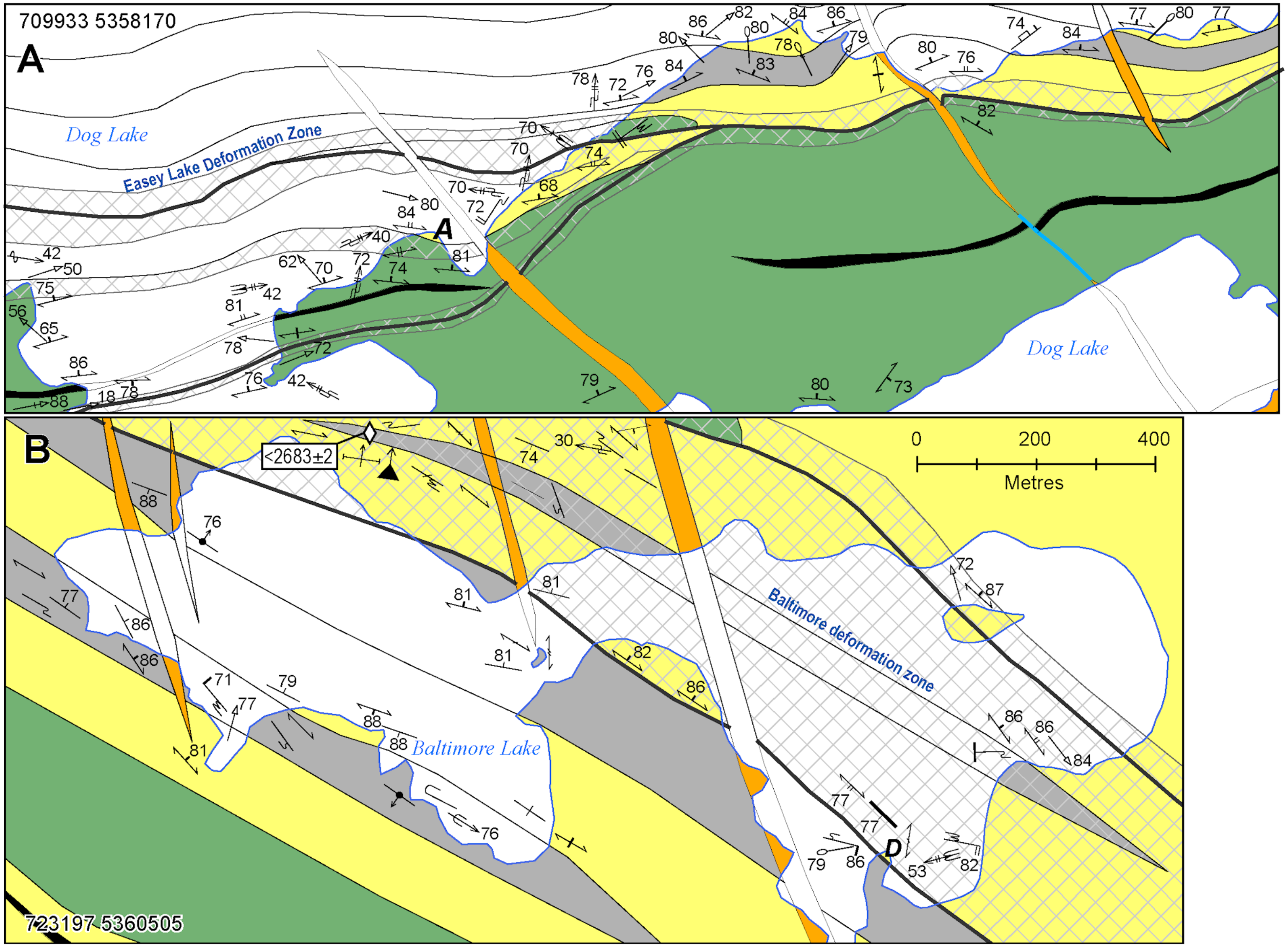


Figure 7.2. Detailed 1:10 000 scale bedrock geology maps of zones of intense deformation within the study area. Figures 7.2A and 7.2 B shown above, additional information with caption below.

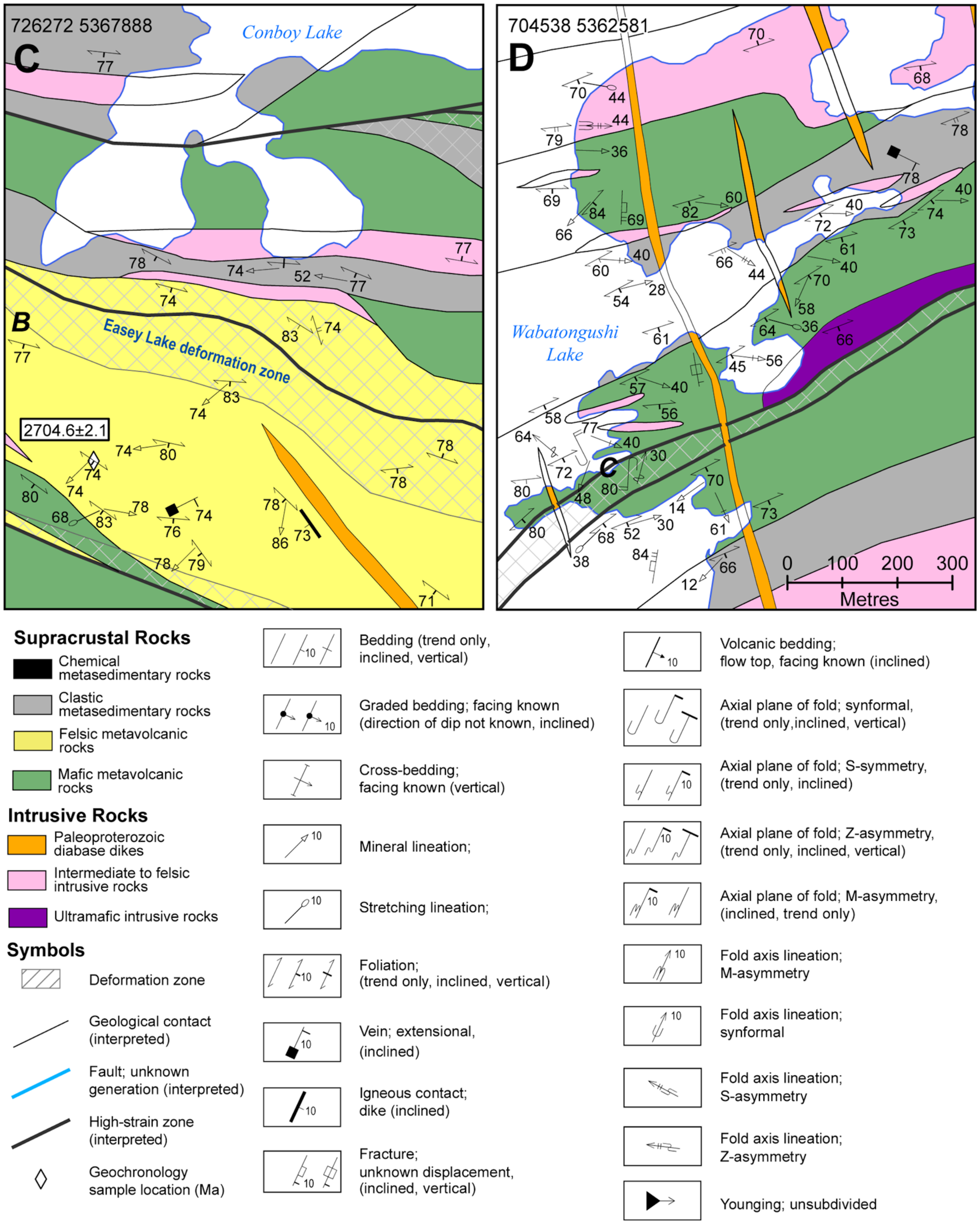


Figure 7.2 *continued.* Detailed 1:10 000 scale bedrock geology maps of zones of intense deformation within the study area. **A)** ***above*** Easey Lake deformation zone observed on Lochalsh Bay, Dog Lake, Riggs Township. Scale bar included in Figure 7.2B. **B)** ***above*** Baltimore deformation zone exposure on Baltimore Lake, Stover Township. **C)** Easey Lake deformation zone near Conboy Lake, Rennie Township. Scale bar included in Figure 7.2D. **D)** Zone of deformation north of Easey Lake deformation zone on Wabatongushi Lake, Glasgow Township. Legend is provided for map figures A to D; structural symbols in legend are represented as "unknown" generation of deformation, where generation of deformation is apparent in outcrop, additional tick marks are added to the symbol according to known generation (e.g., 2 tick marks added for dip of a foliation when it is observed as the 2nd generation, these tick marks do not correspond to interpreted structural events because these are preliminary maps). Age in Figure 7.2B reinterpreted from Davis (2016), age in Figure 7.2C from Kamo (2016). UTM co-ordinates of a selected corner point in each figure are in NAD83 Zone 16.

penetrative foliation), transposition and folding of an earlier bedding-subparallel foliation, boudinage and dismembered quartz veins. The main foliation is axial planar to tight to isoclinal, z- and m-asymmetry folds with steeply dipping hinges. Locally within the zones of highest intensity deformation, rock exposures are strongly silicified to a point that a protolith cannot be identified. Shear-sense indicators include wrapping of foliation in brecciated rock (*see* Photo 7.1A), z-asymmetrical folding, and a steeply dipping lineation, indicating primarily dextral-transpressive displacement with north over south movement.

Intensity of deformation and alteration increases near the inferred intersection between a northeast-trending high-strain zone and the ELDZ, resulting in irregular repetition of stratigraphy and somewhat chaotic interference patterns. It is unclear whether the northeast-trending high-strain zone represents a secondary splay of the ELDZ or if it belongs to a subsequent deformation event. Additional petrographic and microstructural work may help to distinguish these phases of deformation.

A later phase of deformation can be identified by the anastomosing nature and rotation of the main foliation and associated lineations, which is defined by open folds with northwest-trending axial planes parallel to observed fracture surfaces. This northwest-trending orientation is also consistent with local shears and sinistral movement along the nearby Meath Lake fault (*see* Figure 7.1), likely relating to this structural event. Additionally, this orientation parallels intrusive contacts of the Paleoproterozoic diabase dikes (*see* Figure 7.2A).

CONBOY LAKE EXPOSURE

Rocks in the Conboy Lake region depict relatively higher metamorphic grades indicative of amphibolite facies metamorphic conditions, including garnet, biotite and muscovite compared to greenschist facies metamorphic conditions observed at Dog Lake. The ELDZ in northern Rennie Township near Conboy Lake is not isolated along a single primary zone of deformation but occurs as a braided network of smaller deformation zones with local zones of high strain (*see* Figures 7.1 and 7.2C). One of these zones hosts the Conboy Lake base metal and gold occurrence (MDI42B05NW00021; Ontario Geological Survey 2024; Craig 2023). Within the Conboy Lake region, deformation zones, defined by increased intensity of the main foliation, separate mafic metavolcanic rocks, apparently interlayered with clastic metasedimentary rocks, from intermediate to felsic metavolcanic rocks. Stretching lineations from elongation of quartz grains and mineral alignment lineations of micaceous minerals are steeply dipping. Shear sense indicators such as the sigmoidal shape of the main foliation wrapping quartz grains within intermediate to felsic metatuff unit (*see* Photo 7.1B) indicate dextral-transpressive displacement.

A second deformation event postdating the main deformation is shown by rotation of the main foliation into open folds, as well as in kinks that both bend the main foliation and fracture it along a northwest-trending orientation (*see* Photo 7.1B).

WABATONGUSHI LAKE EXPOSURE

A possible splay of the ELDZ can be documented 3 to 5 km north of the main ELDZ on Wabatongushi Lake. Along this part of the lake, mafic metavolcanic rocks and clastic metasedimentary rocks are apparently interlayered with strain increasing toward a zone of brecciation (Figure 7.2D). The rotation of foliated supracrustal fragments (Photo 7.1C) within this deformation zone suggest primarily dextral-transpressive displacement corresponding to north over south movement. Outside of the zone of brecciation, rotated porphyroblasts suggest an opposite south over north movement; however, further petrographic investigation into these features is necessary.

The main foliation in this region approximately parallels the northeast-trending contact with the Wabatongushi Lake granitoid complex with steeply dipping lineations. Similar to other exposures described above, the main foliation, as well as associated lineations, is rotated in an anastomosing pattern, which indicates a later folding event with axial planes to open folds trending northwest. This northwest trend also parallels the trend of the Paleoproterozoic diabase dikes; however, further investigation into these northwest-trending structures is required to determine their timing.

Baltimore Deformation Zone

The Baltimore deformation zone is best observed around Baltimore Lake where intense deformation marks the contact between clastic metasedimentary rocks and felsic metavolcanic rocks (*see* Figure 7.2B). On Baltimore Lake, the main foliation is parallel to the axial plane of s- and m-asymmetry folding of interlayered clastic metasedimentary and felsic metavolcanic rocks. Fold-asymmetry along the Baltimore deformation zone (Photo 7.1D) indicates a primarily sinistral transpressive displacement with north over south movement. Timing of the Baltimore deformation zone can be constrained to be syndeposition to postdeposition of metaconglomeratic rocks with a maximum depositional age of 2683±2 Ma (reinterpreted from Davis 2016). This timing is consistent with estimates for deformation along the ELDZ, suggesting that these 2 regional-scale structural features could be coeval and possibly conjugate.

STRUCTURAL SUMMARY AND IMPLICATIONS

At least 3 deformation events are recorded in the rocks affected by the deformation zones described above. Consistent with previous interpretations, D_1 includes an S_1 bedding-parallel foliation and occasionally observed isoclinal folding (F_1; Arias and Helmstaedt 1990; Sage 1994; McDivitt et al. 2017).

D_2 is characterized by a dominant east-trending S_2 fabric observed throughout the belt and is transposed along the possibly conjugate ELDZ and BDZ, which, respectively, display dextral and sinistral transpressional shear indicators with a north over south movement. Further investigation of field observations with detailed petrography is necessary to determine whether northeast-trending high-strain zones at the Dog Lake exposure (*see* Figure 7.2A) represent an additional phase of deformation or are coeval with D_2; note that previous interpretations for a northeast-striking cleavage suggest a later phase of deformation in the region (McGill and Shrady 1986; Arias and Helmstaedt 1990; McDivitt et al. 2017).

A final deformation, D_3, is consistently observed and displays northwest-trending brittle-ductile structures expressed as ductile kinks (*see* Photo 7.1B), small shears and fractures that are parallel to the axial plane of open folds that overprint D_2 structures. The most prominent example of a northwest brittle-ductile feature in the study area is the Meath Lake fault (Vice, Perrouty and Pelletier 2023; *see* Figure 7.1). Similar faults subdivide the belt into fault-bounded blocks and are commonly occupied or surrounded by subparallel Paleoproterozoic diabase dikes (Sage 1994; McDivitt et al. 2017; Ma et al. 2023).

Observations along the ELDZ and BDZ confirm that a significant approximately north over south shortening event juxtaposed clastic metasedimentary assemblages with volcanic assemblages, as seen throughout the belt and elsewhere in the southern Superior Province. Further geochronological and petrographic analyses of samples from the regions discussed herein will better aid in the characterization of these structural features in terms of timing and kinematics, as well as their relationship to gold-bearing structures in the region.

ACKNOWLEDGMENTS

This mapping project benefitted from the assistance of Georgia Thompson and Lucas Edwards. The complementary doctoral thesis study by the senior author (L.E.D. Vice) is supported by the Ontario Geological Survey and the Canada First Research Excellence Fund's Metal Earth program. Thanks to staff at the Ontario Geological Survey for guidance and support, community engagement, aid with drafting figures, editorial assistance and sample preparation. The authors thank Batchewana First Nation, Brunswick House First Nation, Chapleau Cree First Nation, Chapleau Ojibwe First Nation, Garden River First Nation, Michipicoten First Nation and Missanabie Cree First Nation for allowing the Ontario Geological Survey to map their traditional land-use area. Special thanks to Sean at Wabatong Lodge, as well as Rod and the Missanabie community at Dog Lake Cottages and Campground for their hospitality throughout all our field seasons.

REFERENCES

Arias, Z.G. and Heather, K.B. 1987. Regional structural geology related to gold mineralization in the Goudreau–Lochalsh area, District of Algoma; *in* Summary of Field Work and Other Activities, 1987, Ontario Geological Survey, Miscellaneous Paper 136, p.146-154.

Arias, Z.G. and Helmstaedt, H. 1990. Structural evolution of the Michipicoten (Wawa) Greenstone belt, Superior Province: Evidence for Archean fold and thrust belt; *in* Geoscience Research Grant Program, Summary of Research 1989–1990, Ontario Geological Survey, Miscellaneous Paper 150, p.107-114.

Bleeker, W., Kamo, S.L., Ames, D.E. and Davis, D.W. 2015. New field observations and U-Pb ages in the Sudbury area: Toward a detailed cross-section through the deformed Sudbury Structure; *in* Targeted Geoscience Initiative 4: Canadian Nickel-Copper-Platinum Group Elements-Chromium Ore Systems – Fertility, Pathfinders, New and Revised Models, Geological Survey of Canada, Open File 7856, p.151-156.

Campos, I.C. 2023. Structural evolution, geochemistry, and geochronology of the Magino Gold Deposit, Michipicoten greenstone belt, northern Ontario; unpublished MSc thesis, Department of Earth Sciences, Laurentian University, Sudbury, Ontario, 323p.

Corfu, F. and Sage, R.P. 1992. U-Pb age constraints for deposition of clastic metasedimentary rocks and late-tectonic plutonism, Michipicoten Belt, Superior Province; Canadian Journal of Earth Sciences, v.29, p.1640-1651.

Craig, S. 2023. Mineralogical, textural, and geochemical investigation of Conboy Lake base metal and gold mineralization in the Michipicoten greenstone belt, Wawa Subprovince, Ontario; unpublished BSc thesis, Department of Geological Sciences and Geological Engineering, Queen's University, Kingston, Ontario, 114p.

Davis, D.W. 2016. Geochronology of rocks from northwest Ontario 2015–2016. Part 2: LA-ICP–MS Geochronology; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, University of Toronto, Toronto, Ontario, 100p.

Goodwin, A.M. 1962. Structure, stratigraphy and origin of iron formations, Michipicoten area, Algoma District, Ontario, Canada; Geological Society of America, Bulletin, v.73, p.561-586.

Heather, K.B. and Arias, Z.G. 1987. Geological setting of gold mineralization in the Goudreau–Lochalsh area, District of Algoma; *in* Summary of Field Work and Other Activities, 1987, Ontario Geological Survey, Miscellaneous Paper 137, p.155-162.

——— 1992. Geological and structural setting of gold mineralization in the Goudreau–Lochalsh area, Wawa gold camp; Ontario Geological Survey, Open File Report 5832, 159p.

Heather, K.B. and Buck, S. 1988. The geological and structural setting of gold mineralization in the Missanabie–Renabie District of the Michipicoten greenstone belt, Wawa, Ontario; *in* Summary of Field Work and Other Activities, 1988, Ontario Geological Survey, Miscellaneous Paper 141, p.257-270.

Jellicoe, K., Ciufo, T.J., Lin, S., Wodicka, N., Wu, N., Mercier-Langevin, P. and Yakymchuk, C. 2022. Genesis of the Island Gold deposit, Ontario, Canada: Implications for gold mineralization in the Wawa subprovince of the Superior province; Economic Geology, v.117, no.7, p.1597-1612.

Kamo, S.L. 2016. Part A: Report on U-Pb ID-TIMS geochronology for the Ontario Geological Survey: Bedrock mapping projects, Ontario; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, University of Toronto, Toronto, Ontario, 48p.

——— 2024. Report on U-Pb ID-TIMS geochronology for the Ontario Geological Survey: Bedrock Mapping Projects, Ontario 2023–2024, Part 1: Internal U/Pb age; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 35p.

Ma, C., Vice, L.E.D., Nagy, C., Adam, Z.V., Shirriff, D., Lafrance, B. and Robichaud, L. 2023. Orogenic and intrusion-related gold deposits of the Michipicoten and Mishibishu greenstone belts in the Wawa region, with an emphasis on their structural timing and setting: A geological guidebook; Geological Association of Canada–Mineralogical Association of Canada–Society for Geology Applied to Mineral Deposits, Joint Annual Meeting, Sudbury, Ontario, May 25–27, 2023, Field Trip FT10 Guidebook, Ontario Geological Survey, Open File Report 6398, 57p.

Maity, B.K. and Adrianwalla, C.J. 2023. Timmins Regional Resident Geologist (Sault Ste. Marie District)—2022; *in* Report of Activities 2022, Resident Geologist Program, Timmins Regional Resident Geologist Report: Timmins and Sault Ste. Marie Districts; Ontario Geological Survey, Open File Report 6402, 157p.

McDivitt, J.A., Lafrance, B., Kontak, D.J. and Robichaud, L. 2017. The structural evolution of the Missanabie–Renabie gold district: Pre-orogenic veins in an orogenic gold setting and their influence on the formation of hybrid deposits; Economic Geology, v.112, no.8, p.1959-1975.

McGill, G.E. and Shrady, C.H. 1986. Evidence for a complex Archean deformational history; southwestern Michipicoten greenstone belt, Ontario; Journal of Geophysical Research, v.91, no.B13, p.E281-E289

Ontario Geological Survey 1999. Single master gravity and aeromagnetic data for Ontario, Geosoft® format; Ontario Geological Survey, Geophysical Data Set 1036.

——— 2003. Ontario airborne geophysical surveys, magnetic and electromagnetic data, grid and profile data (Geosoft® format), Wawa area; Ontario Geological Survey, Geophysical Data Set 1009b.

——— 2011. Ontario airborne geophysical surveys, magnetic and electromagnetic data, grid and profile data (ASCII and Geosoft® formats) and vector data, Magpie River–Missinaibi Lake area—Purchased data; Ontario Geological Survey, Geophysical Data Set 1237.

——— 2024. Ontario Mineral Inventory; Ontario Geological Survey, online database, September 2024 update, www.hub.geologyontario.mines.gov.on.ca. [accessed October 4, 2024]

Percival, J.A. and Card, K.D. 1983. Archean crust as revealed in the Kapuskasing Uplift, Superior Province, Canada; Geology, v.11, p. 323-326.

Robichaud, L. 2013. Geology and mineral potential of Marsh and Lang townships, Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2013, Ontario Geological Survey, Open File Report 6290, p.3-1 to 3-10.

Robichaud, L. and McDivitt, J.A. 2014. Geology and mineral potential of Brackin Township, Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2014, Ontario Geological Survey, Open File Report 6300, p.5-1 to 5-11.

Robichaud, L., McDivitt, J.A. and Trevisan, B.E. 2015. Geology and mineral potential of Rennie and Leeson townships, Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.5-1 to 5-11.

Robichaud, L., Walker, J., West, S.M. and Nywening, A. 2016. Geology and mineral potential of Stover Township, Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p.5-1 to 5-10.

Sage, R.P. 1994. Geology of the Michipicoten greenstone belt; Ontario Geological Survey, Open File Report 5888, 592p.

Sage, R.P. and Heather, K.B. 1991. The structure, stratigraphy and mineral deposits of the Wawa area; Geological Association of Canada–Mineralogical Association of Canada–Society of Economic Geologists, Joint Annual Meeting, Toronto 1991, Field Trip A6, 118p.

Turek, A., Heather, K.B., Sage, R.P. and Van Schmus, W.R. 1996. U/Pb zircon ages for the Missanabie–Renabie area and their relation to the rest of the Michipicoten greenstone belt, Superior Province, Ontario, Canada; Precambrian Research, v.76, p.191-211.

Turek, A., Smith, P.E. and Van Schmus, W.R. 1982. Rb–Sr and U–Pb ages of volcanism and granite emplacement in the Michipicoten belt, Wawa, Ontario; Canadian Journal of Earth Sciences, v.19, p.1608-1626.

——— 1984. U–Pb zircon ages and the evolution of the Michipicoten plutonic–volcanic terrane of the Superior Province, Ontario; Canadian Journal of Earth Sciences, v.21, p.457-464.

Turek, A., Van Schmus, W.R. and Sage, R.P. 1988. Extended volcanism in the Michipicoten greenstone belt, Wawa, Ontario; abstract *in* Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, St. John's 1988, Program with Abstracts, v.13, p.A127.

Vice, L.E.D. 2022. Preliminary geology of Meath Township, northeastern Michipicoten greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.7-1 to 7-10.

Vice, L.E.D., Perrouty, S. and Pelletier, S.G. 2023. Preliminary geology of Riggs and Glasgow townships, Michipicoten greenstone belt, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.6-1 to 6-10.

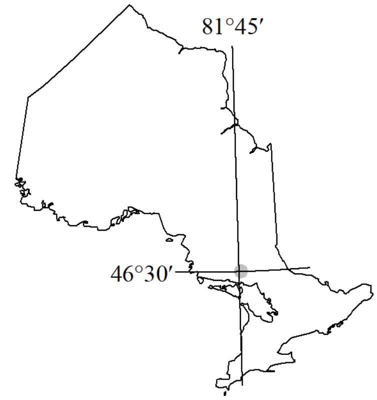
Vice, L.E.D., Perrouty, S. and Robichaud, L. 2022. Introduction to a geochronological and structural study of supracrustal assemblages in the northeastern Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.8-1 to 8-8.

Walker, J. 2017. Geology and mineral potential of Bruyere Township, Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p.6-1 to 6-10.

Walker, J. and Robichaud, L. 2016. Geology and mineral potential of Copenace Township, Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p.6-1 to 6-9.

——— 2018. Geology and mineral potential of West Township, Michipicoten greenstone belt; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.5-1 to 5-10.

8. Project NE-24-005. Precambrian Geology and Mineral Potential of Totten Township, Superior Province, Sudbury District, Northeastern Ontario



N.T. Carter[1] and R.M. Easton[1]

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

INTRODUCTION

Totten Township is located on the west side of the Sudbury Structure, approximately 20 km north of the community of Nairn Centre (Figure 8.1). The township encompasses approximately 100 km^2 (NTS 41 I/5, 12) and is bounded by latitudes 46°27′30″ N to 46°32′30″ N and longitudes 81°34′W to 81°41′W. Access is provided by Old Chicago Mine Road, located approximately 2 to 3 km east of the township, and by numerous logging roads present throughout the township. Totten Township was last mapped more than 40 years ago (Choudhry 1983a, 1984). The township is underlain mainly by granitoid rocks of the Archean Ramsey–Algoma terrane (Card 1979), which consist mainly of quartz monzonite of the Birch Lake batholith or monzogranite to syenogranite of the Cartier granite (Figure 8.2). In the northeast corner of the township, in and around Armstrong Lake, older felsic gneisses and migmatitic rocks of the Levack gneiss complex crop out (Choudhry 1983a) (*see* Figure 8.2).

Although a granitoid-dominated area like Totten Township would not normally be a priority mapping target, interest in remapping the township is a result of 1) the discovery of the mineralized Trill quartz diorite offset dike in the southeastern part of the township (e.g., Golightly, Pattison and Lightfoot 2010, p.30-38) and 2) the acquisition of high-resolution aeromagnetic and gamma-ray spectrometric data over the township (Ontario Geological Survey 2019a, 2019b). In addition, the mapping of Totten Township represents a continuation of a program of detailed mapping of the southwestern and western part of the Sudbury area initiated by the Ontario Geological Survey in 2015 (e.g., Gordon, Simard and Généreux 2018; Gordon 2018, 2022).

GEOLOGY

Quaternary cover is thick across much of Totten Township, especially along the 3 main southerly drainage systems present in the township, namely, John Creek, Armstrong Creek and Ministic Creek. In the northeast corner of the township, sandy to bouldery till is capped by numerous, closely-spaced, large boulders (1 to 5 m in size), consisting predominantly of Cartier granite and minor mafic intrusive rocks (*see* Figure 8.2, marked as the southern extent of boulder till). In areas of thick vegetation and atop hills, it can be difficult to distinguish material that is in place (outcrop) from transported material, and it is suspected that some of the outcrops shown on the map of Choudhry (1983a) may have been boulders. Any planned exploration work in the northeastern part of the township needs to take the distribution of this boulder till into account.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.8-1 to 8-12.

Archean Rocks

LEVACK GNEISS COMPLEX

Langford (1960) and Dressler (1984a) described the Levack gneiss complex as consisting of migmatites; however, subsequent work by Card (1979), as summarized in the legend for the Sudbury compilation map of Ames et al. (2005), expands the definition of the Levack gneiss complex to include older mafic and ultramafic gneiss, tonalitic to granodioritic gneiss which may locally be xenolith-rich, as well as somewhat younger foliated granodiorite rocks. In addition, Ames et al. (2005) recognized 2 types of migmatitic rocks, those with less than 30% mobilizate and those with greater than 30% mobilizate. The timing of the Levack gneiss complex formation is not well constrained, in part because of the proximity of these rocks to the Sudbury Structure and related shock-metamorphic effects on zircon. The oldest tonalitic gneiss unit yielded ages of 2711 Ma (Krogh, Kamo and Bohor 1996), with early migmatization interpreted as occurring at *circ*a 2661 Ma (Wodicka *in* Ames et al. 1997). Later migmatization has been interpreted as occurring at *circa* 2647 Ma (Krogh, Davis and Corfu 1984; Krogh, Kamo and Bohor 1996); however, this timing is based on zircons from pegmatite veins crosscutting the migmatitic rocks, not the migmatitic rocks themselves, and thus may represent a minimum age for migmatization.

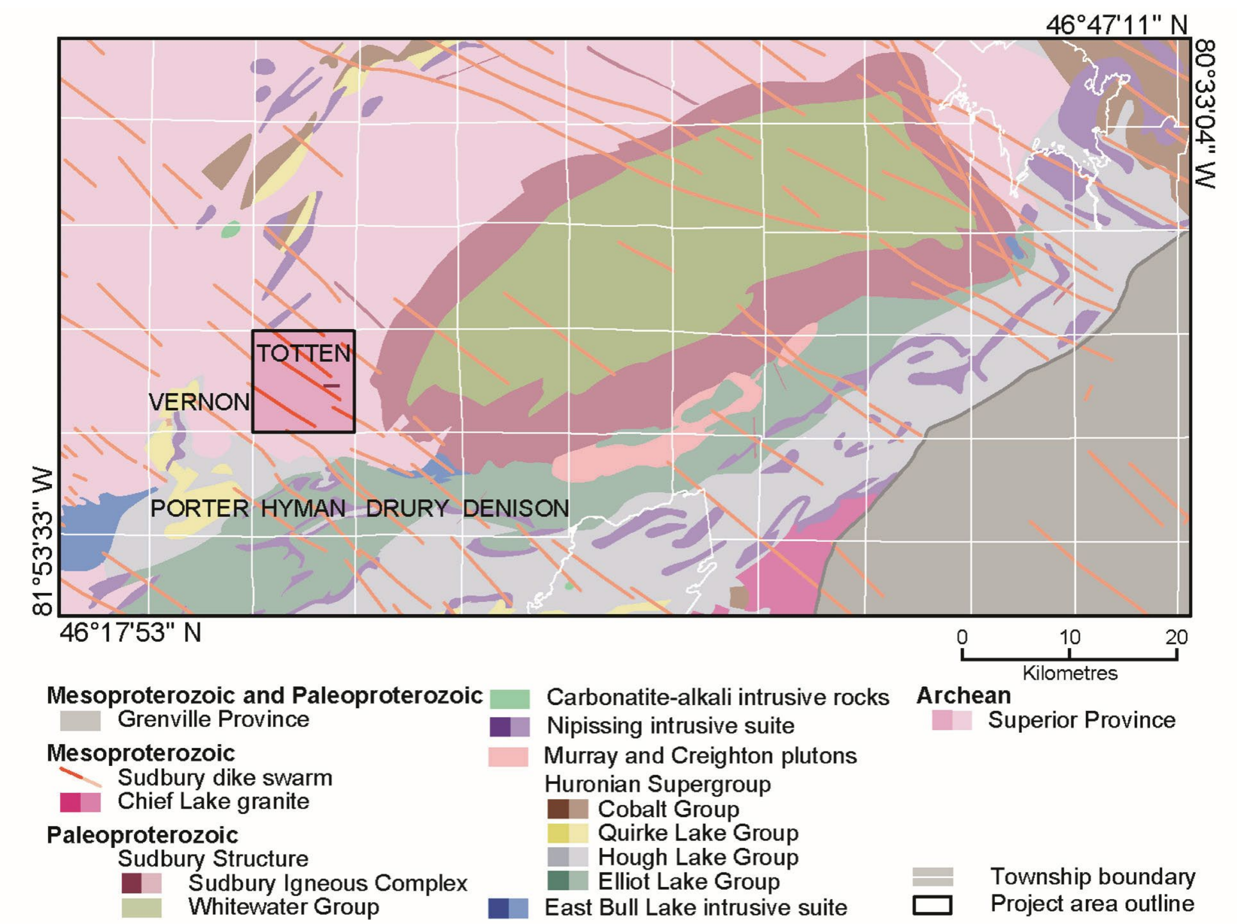


Figure 8.1. Simplified geological map of the Sudbury area. Geology *modified from* Ontario Geological Survey (2011). Note, darker colours indicate geological units in Totten Township, which is outlined in black. Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 17.

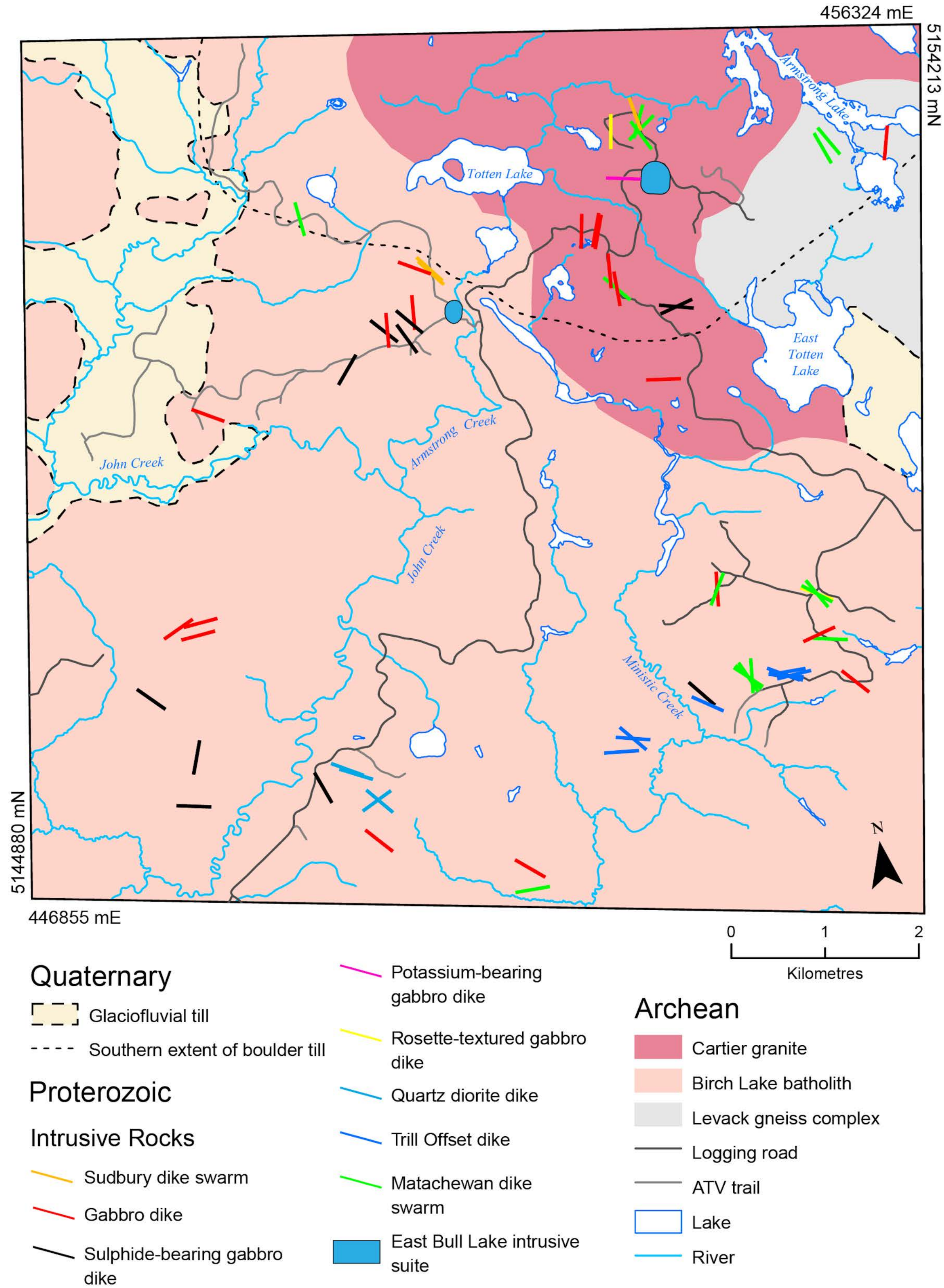


Figure 8.2. Simplified geological map of Totten Township, based on mapping in 2024 and *modified from* Choudhry (1983a). A heavy dashed line indicates the southern extent of the boulder-rich till in northeastern Totten Township. All UTM co-ordinates are provided using NAD83 in Zone 17.

In Totten Township, foliated granodioritic rocks and tonalitic to granodioritic gneisses with boudinaged xenoliths are the most common rock types present in the Levack gneiss complex, although migmatites are locally present, especially near Armstrong Lake (*see* Figure 8.2). Epidote-filled fractures occur locally throughout the Levack gneiss complex. Heterogeneous gneisses (Photo 8.1A) and migmatites (Photo 8.1B) of the Levack gneiss complex are composed of leucosome and melanosome that typically can be described as fine to medium grained, granitic, white, slightly foliated, and locally hosting minor fine-grained garnets (*see* Photo 8.1B); and fine grained, dioritic, black to dark grey, granoblastic, and weakly to moderately boudinaged, respectively.

An area approximately 1 km southwest of East Totten Lake, *see* Figure 8.2, was initially described by Choudhry (1983a) as consisting of felsic gneisses and migmatites of the Levack gneiss complex; however, it was found during mapping in the 2024 field season that this area consisted of foliated quartz monzonites with a patchy, fracture-controlled, potassic and chloritic alteration. Pending petrological and geochemical results, rocks in this area have been tentatively assigned to the Cartier granite.

BIRCH LAKE BATHOLITH

Approximately three-quarters of Totten Township is underlain by 2 phases of the Birch Lake batholith 1) porphyritic granite and 2) medium-grained, weakly foliated, equigranular quartz monzonite, quartz syenite and monzogranite. The Birch Lake batholith (*circa* 2651 Ma: Kamo 2006) is intruded by fine- to medium-grained dikes of the Matachewan and Sudbury dike swarms that trend northwest, north and northeast. Additionally, there are several dikes of unknown affinity composed of sulphide-bearing and non-sulphide-bearing quartz diorite, sulphide-bearing and non-sulphide-bearing gabbro, and rosette-textured gabbro that cut the Birch Lake batholith (*see* Figure 8.2).

Rocks of the Birch Lake batholith were observed to be weakly to moderately foliated and typically contain an abundance of irregular fractures (5 to 30%) that were not the result of glaciation. Quartz monzonite is the dominant rock type in the Birch Lake batholith. The quartz monzonites are medium- to coarse-grained, equigranular, white to white-pink rocks, with approximately equal amounts of modal plagioclase and potassium feldspar (~35% each), angular quartz (~15%) and minor mafic minerals (~10%) that are partially altered to chlorite (Photo 8.1C). Gamma-ray spectrometric readings for most rocks of the Birch Lake batholith have low equivalent thorium (generally between 5–25 ppm; Easton and Kamo, this volume, Table 11.2). Rocks mapped as quartz syenites are similar to the quartz monzonites in texture and mineralogy; however, they are redder, either because of more potassium feldspar and/or increased alteration (possibly hematization). They typically have higher equivalent thorium readings (>40 ppm; Easton and Kamo, this volume, Table 11.2). Monzogranites in the batholith are not common and are difficult to distinguish from the quartz monzonites; generally, the monzogranites contain at least 20 to 25% modal quartz whereas the quartz monzonites contain up to 15% quartz. The granitic rocks locally contain a variety of xenoliths, notably diorite, gabbro, tonalite, and mafic rocks of unknown affinity, with xenolith size ranging from 10 cm to 2 m in diameter.

CARTIER GRANITE

Rocks of the Cartier granite (see Figure 8.2) consist of medium- to coarse-grained, equigranular, locally potassium feldspar megacrystic, high thorium (>30 ppm), nonfoliated monzogranite (Photo 8.1D) to syenogranite. The rocks range from white-light grey to pink-red depending on the degree of alteration. Biotite, the most common mafic mineral, is typically chloritized. Small bodies of potassium feldspar-dominated pegmatite occur sporadically throughout the Cartier granite. Aplite veins also occur locally, are relatively narrow (<10 cm), and typically cut the pegmatite bodies. Epidote-filled interstitial spaces and fractures occur locally. The Cartier granite has yielded a U/Pb zircon age of 2642±1 Ma

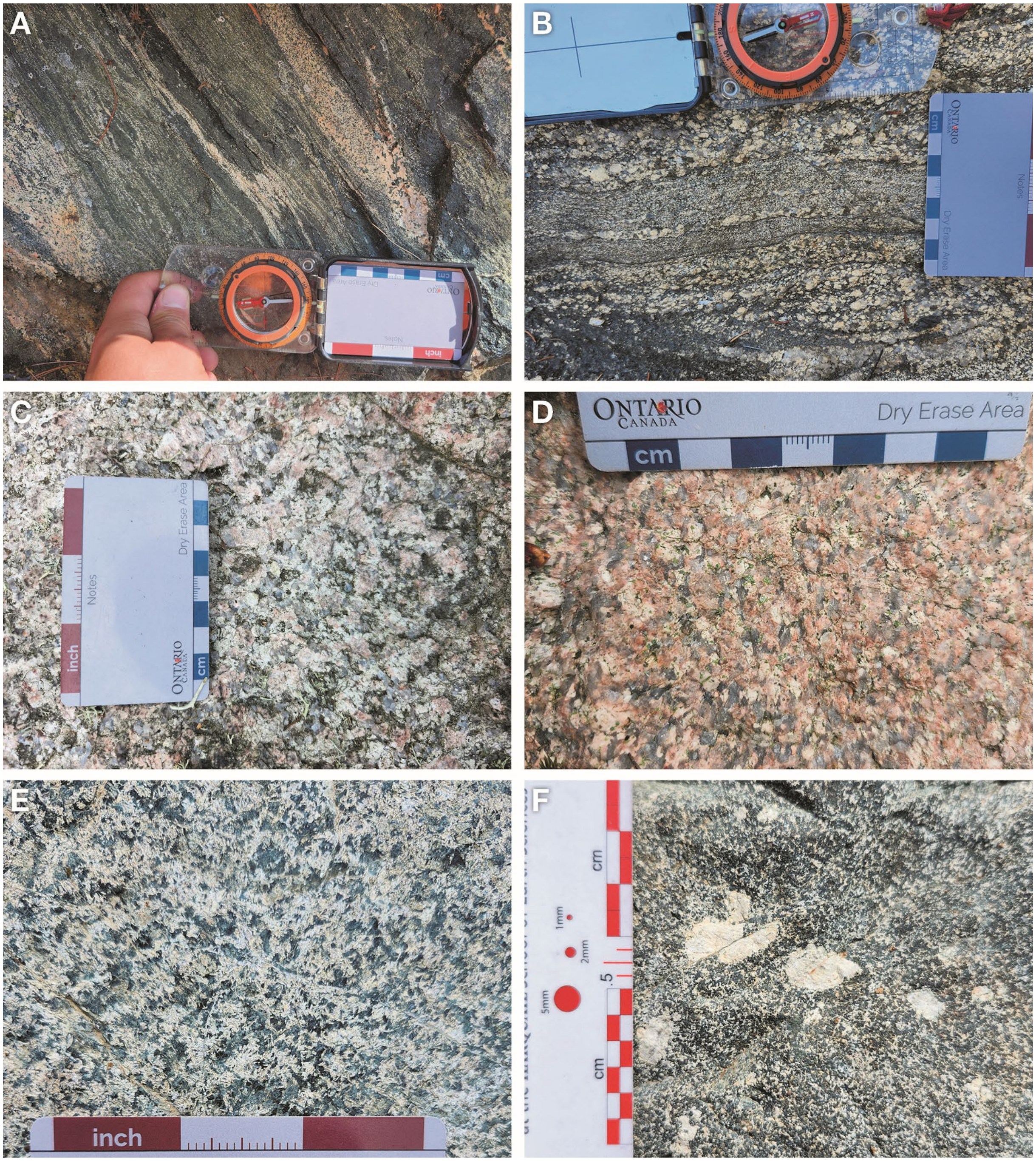


Photo 8.1. **A)** Mafic to intermediate gneiss, Levack gneiss complex. Strongly gneissic textured with leucocratic and melanocratic bands and laminations (UTM 455453E 5153450N). **B)** Migmatite, Levack gneiss complex. Leucosome is fine to medium grained, granitic, weakly foliated, and locally contains fine-grained garnets. Melanosome is fine grained, dioritic and granoblastic (UTM 455968E 5153232N). **C)** Quartz monzonite, Birch Lake batholith. Typical equigranular, white to faint pink, speckled, medium-grained, plagioclase, orthoclase and quartz rock. Mafic minerals are partially altered to chlorite (UTM 453235E 5146620N). **D)** Monzogranite, Cartier granite. Equigranular, medium-grained, pink-red orthoclase and plagioclase grains alongside light grey quartz and pistachio green interstitial fine-grained epidote (UTM 453769E 5152472N).
E) Leucogabbro, East Bull Lake intrusive suite. Fine- to medium-grained leucogabbro with acicular to stellate plagioclase and amphibole (UTM 453482E 5152687N). **F)** Plagioclase-phyric gabbro dike, Matachewan dike swarm. Photo is of a plagioclase-phyric, fine-grained, salt-and-pepper-textured gabbro (UTM 455226E 5148136N). Scale card in all images is 9 cm wide. All UTM co-ordinates are provided using NAD83 in Zone 17.

(Meldrum et al. 1997). Geochemically, it is metaluminous to peraluminous, with high barium (700–1400 ppm), zirconium (200–450 ppm), light rare earth element, thorium, and uranium contents (Meldrum et al. 1997). The Cartier granite is intruded by mafic dikes of the Matachewan and Sudbury dike swarms as well as by numerous fine-grained gabbro dikes of unknown affinity. Dikes can trend northwest, north, northeast and east, with no trend being consistently related to a particular dike swarm (see Figure 8.2).

Proterozoic Rocks

Proterozoic rocks in Totten Township consist entirely of mafic intrusive rocks. Numerous mafic intrusive suites and mafic dike swarms occur in the Southern Superior Province and include the 1) Matachewan dike swarm (2480–2460 Ma: Heaman 1997; Bleeker et al. 2015); 2) East Bull Lake intrusive suite (2480 Ma: Krogh, Davis and Corfu 1984; James et al. 2002), 3) Nipissing intrusive suite (2219–2210 Ma: Davey et al. 2019); 4) North Channel dikes associated with the Marathon dike swarm (2125–2105 Ma: Halls, Stott and Davis 2005; Bleeker et al. 2015); 5) Blind River dikes (*circa* 1935 Ma: Bleeker et al. 2015); 6) Trap dike swarm (1750 Ma: Bleeker et al. 2015); and 7) Sudbury dike swarm (1238 Ma: Krogh et al. 1987). Assigning mafic rocks in the field to these various intrusive suites or dike swarms is not always easy, especially if the dikes are narrow (<10 m wide) or outcrop areas are small. Furthermore, no trend is consistently related to a particular dike swarm (*see* Figure 8.2). Geochemical analyses of samples collected during the field season may aid in better characterizing these mafic units.

EAST BULL LAKE INTRUSIVE SUITE

Intrusions of the East Bull Lake intrusive suite (*circa* 2475 Ma) can consist either of layered mafic intrusions or more homogeneous sill or dike-like bodies (Easton, James and Jobin-Bevans 2010). Both types of intrusions occur in Totten Township. A characteristic feature of all the East Bull Lake intrusive suite bodies is their low radiometric signature (typically <0.3 wt% K, 0 ppm U, <3 ppm Th; Easton and Kamo, this volume, Table 11.2). Rocks of the East Bull Lake intrusive suite were not identified previously in Totten Township (*see* Figure 8.2).

At least 3 unidentified bodies of gabbro, leucogabbro and/or anorthositic gabbro in Totten Township are interpreted to be of the East Bull Lake intrusive suite (*see* Figure 8.2). The largest body, exposed along a logging road approximately 1.3 km east of Totten Lake, consists of gabbro, leucogabbro and anorthositic gabbro (Photo 8.1E) that is hosted by the Cartier granite (*see* Figure 8.2). Another unidentified leucogabbro body, 15 m long and 10 m wide, is located approximately 1 km south of Totten Lake along a logging road and is hosted in the Birch Lake batholith (*see* Figure 8.2). Finally, rosette-textured gabbro dikes, located 2 km south of East Totten Lake, are crosscut by a northwest-trending Matachewan dike and thus are interpreted to be part of the East Bull Lake intrusive suite. Thick glacial and vegetation cover in the township has obscured the full extent of these bodies, all of which could be much larger than is currently visible.

Approximately 1 km east of John Creek in the northwestern corner of Totten Township, a previously known lenticular body of gabbro (5 km long, up to 700 m wide) assigned to the Nipissing intrusive suite (Choudhry 1983a, 1983b) is likely an East Bull Lake intrusive suite body, akin to the Stone Ridge intrusion in the Elliot Lake area (Easton, James and Jobin-Bevans 2010). Another more extensive (5 km long, up to 1 km wide) homogeneous East Bull Lake intrusive suite body, also previously assigned to the Nipissing intrusive suite (Choudhry 1983b), occurs farther north in Ermatinger Township to the west of Weequed Lake. This larger body is cut by mafic dikes of the Matachewan swarm (Choudhry 1983b), which confirms that it cannot be a Nipissing suite intrusion.

DIKE SWARMS

Apart from dikes of the northwest-trending Sudbury dike swarm, it is difficult to distinguish dike swarms in Totten Township based solely on trend. For example, dikes of the Matachewan dike swarm may trend north-northeast, north, or north-northwest. Furthermore, the presence of numerous rotated fault blocks in Totten Township (Choudhry 1983a) hampers the use of trend to distinguish dike swarms from one another. Hand-held gamma-ray spectrometric measurements are locally helpful in distinguishing between some dike swarms (Easton and Kamo, this volume, Table 11.2), but given the geochemical similarity of many of the dike swarms present in Totten Township, it is not a foolproof tool.

Matachewan Dike Swarm

Fine- to medium-grained, typically greenish grey weathering, plagioclase-phyric (Photo 8.1F) and nonphyric varieties of Matachewan swarm dikes occur throughout Totten Township, cutting rocks of the Birch Lake batholith, the Cartier granite, the Levack gneiss complex and the East Bull Lake intrusive suite (*see* Figure 8.2). The dikes most commonly observed in Totten Township are Matachewan dikes. The Matachewan dikes in Totten Township typically have low magnetic susceptibility, consistent with the observation from the Elliot Lake area that south of approximately 46°42″ N, Matachewan swarm dikes lose their magnetic character, with magnetic susceptibility changing from 20 to 60 $\times 10^{-3}$ SI units in the north to 0.7 to 0.9 $\times 10^{-3}$ SI units in the south (Easton 2010). This change in magnetic character can be attributed to low-temperature alteration of the basement rocks to low-temperature fluid movement through the Huronian Supergroup during the Yavapai Orogeny (1720 to 1680 Ma). Nearer to the Sudbury Structure, a few of the Matachewan dikes in Totten Township have higher magnetic susceptibility (26.2 to 31.8 $\times 10^{-3}$ SI), although the reason for this increase in magnetism has yet to be determined.

Mafic Dikes of Unknown Affinity

Dikes that cannot easily be assigned to any particular dike swarm include the following: 1) medium-grained dikes with small rosettes of plagioclase that are not as epidotized or chloritized as the plagioclase-phenocrysts in Matachewan swarm dikes; 2) fine-grained, dense, green- to grey-black, cross-hatch fractured dikes with disseminated sulphide minerals; 3) fine- to medium-grained dikes that have high potassium contents (typically >1.6 wt %); and 4) fine-grained, medium grey, homogeneous gabbro dikes.

Sudbury Dike Swarm

At least 4 large Sudbury swarm dikes cut across Totten Township based on aeromagnetic data (Ontario Geological Survey 2019a, 2019b); however, few surface exposures of these dikes were encountered during the 2024 field season (*see* Figure 8.2). Where observed, they are light grey to patchy rusty brown, "onion-layer"-fractured, olivine gabbros that trend to the northwest.

SUDBURY BRECCIA

All map units within Totten Township that are older than *circa* 1850 Ma contain varied amounts of impact breccia known locally as Sudbury Breccia. Sudbury Breccia has been defined as veins and irregular bodies that consist of subrounded clasts, mainly derived from adjacent host rocks, set in a very fine-grained to aphanitic matrix (Dressler 1984a, 1984b). In Totten Township, Sudbury Breccia occurs as a moderately to strongly foliated, fine-grained (pseudotachylite), dark green to greenish yellow chloritic rock that occurs as veinlets and veins of varied thicknesses (0.5 cm to >1 m) and orientation. There are both clast-poor and clast-rich varieties, and the matrix occasionally hosts fine-grained euhedral pyrite.

Clasts are subrounded to rounded and typically sourced from the adjacent host rock. Thicker breccia veins, usually clast rich, are concentrated in corridors along major lithologic contacts and structures. Most host rock units contain up to 5% of thin Sudbury Breccia veinlets, but the amount varies considerably from one area to another, and identification is strongly affected by the quality of the outcrop exposure.

TRILL OFFSET DIKE

The most economically important rock type related to the Sudbury Structure is quartz diorite (QD) (Photo 8.2A), of which all Offset dikes of the Sudbury Igneous Complex are composed. Exposures of this rock type were mapped for the first time in Totten Township in the fall of 2004 by Wallbridge Mining Company Ltd. as part of a ground follow-up of an AeroTEM anomaly (Golightly, Pattison and Lightfoot 2010, p.31). Subsequent work, including trenching and stripping, traced the Trill Offset dike over an east-trending distance of approximately 1.85 km (Golightly, Pattison and Lightfoot 2010, p.31) (*see* Figure 8.2). The dike is cut in several places by crosscutting faults, which displace it by several tens of metres. As described by Golightly, Pattison and Lightfoot (2010), the silicate components in the Offset dike consist of euhedral plagioclase and amphibole (Photo 8.2A), with minor amounts of biotite, titanite, and apatite. The texture is varied; very fine-grained to glassy chill margins locally occur along the wall rock contacts, and stellate or acicular amphibole crystal aggregates (after pyroxene) (Photo 8.2B) characterize the fine-grained sections of the dike, with coarser, interlocking igneous textures typifying the core of the dike. Xenoliths of various rock types, including amphibolite, anorthosite and granite, occur in some parts of the dike, in which case this rock type is called inclusion-rich quartz diorite (IQD) (Photo 8.2D). The inclusions range from a few centimetres to almost a metre and are subrounded (*see* Photo 8.2D). According to Golightly, Pattison and Lightfoot (2010), in the area of the discovery site, the offset dike appears to widen and split into branches, possibly encircling large monzonite xenoliths. The mineralization (e.g., Photo 8.2C) occurs along the southern branch of the dike. The offset dike is hosted in quartz monzonite of the Birch Lake batholith. Preliminary mapping of the extent of the Trill Offset dike, in the summer of 2024, illustrates a sinistrally displaced branch of the dike extending approximately 2 km southeasterly from the original discovery site (*see* Figure 8.2). These rocks are composed of sulphide-bearing quartz diorite and unmineralized and sulphide-poor inclusion-rich quartz diorite dikelets.

A few quartz diorite dikes were mapped farther west of the Trill Offset dike (*see* Figure 8.2), with 2 varieties identified: sulphide bearing and nonsulphide bearing. The trend of the 2 subtypes appears to be perpendicular to one another, with the sulphide-bearing dike trending 110° and 54° and the non-sulphide dike trending 130°. Currently, these quartz diorite dikes are not considered part of the Trill Offset dike; however, this may change following petrographic and geochemical study of these dikes.

ECONOMIC GEOLOGY

There are no mineral deposit occurrences within Totten Township listed in the Ontario Mineral Inventory (Ontario Geological Survey 2024a, 1988); however, numerous drill holes are recorded in and near the Trill Offset dike (Ontario Geological Survey 2024b).

Trill Offset Dike

In 2022, Archer Exploration Corp. acquired the Trill Offset dike property from Wallbridge Mining Company Ltd. In April 2024, Archer Exploration Corp. changed their name to NorthX Nickel Corp. No substantive work has been done on the Trill property since 2022. Mineralization in the Trill Offset dike occurs in a sulphide and inclusion-rich core zone (*see* Photo 8.2C) flanked by sulphide- and inclusion-poor quartz diorite, which is the typical geometric arrangement of mineralization within quartz diorite offset dikes (Golightly, Pattison and Lightfoot 2010).

The mineralization is contained in a zone that is approximately 65 m long and 5 m wide and dips steeply to the north (Golightly, Pattison and Lightfoot 2010, p.32). Major economic minerals include pentlandite and chalcopyrite. According to Golightly, Pattison and Lightfoot (2010, p.32), merenskyite and michenerite were identified as platinum group element (PGE)-bearing phases by electron microprobe. Gangue minerals include pyrrhotite, pyrite and magnetite. The mineralization in the Trill Offset dike is crudely zoned (Golightly, Pattison and Lightfoot 2010). The core contains massive or inclusion-bearing, nickel-rich sulphide, whereas the flanks contain copper-rich, vein- and disseminated-style mineralization. The margins of the offset dike are not mineralized. The mineralization, based on borehole intersections, channel samples and surface mapping, has an average grade estimated at 1.2% nickel, 1% copper, 2 g/t platinum, 5g/t palladium, 0.4 g/t gold and 4.3 g/t silver (Golightly, Pattison and Lightfoot 2010, p.32).

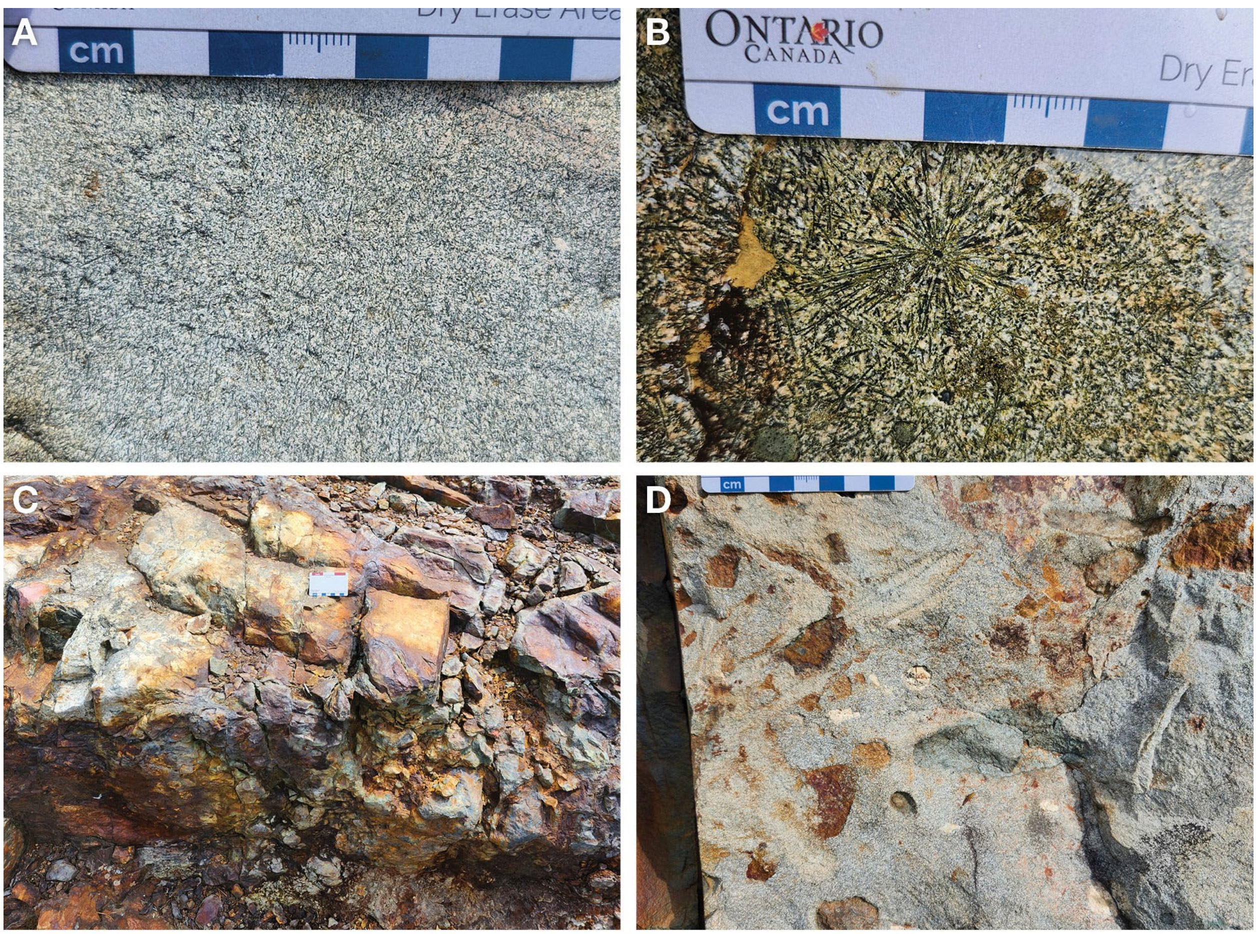


Photo 8.2. **A)** Quartz diorite, Trill Offset dike. Fine-grained, acicular amphibole crystal aggregates in a matrix of finer grained plagioclase (UTM 454896E 5147263N). **B)** Stellate amphibole crystals (2 cm) in quartz diorite, Trill Offset dike (UTM 454982E 5147273N). **C)** Sulphide-lens in the inclusion-rich quartz diorite of the Trill Offset dike. Heavily oxidized portion of the inclusion-rich quartz diorite is representative of the sulphide-rich portions of the Trill Offset dike (UTM 454896E 5147263N). **D)** Close-up view of the inclusion-rich quartz diorite showing subrounded amphibolite, quartz monzonite, sulphide minerals and anorthosite inclusions in a plagioclase and amphibole-dominated matrix (UTM 454896E 5147263N). Scale card in all images is 9 cm wide. All UTM co-ordinates are provided using NAD83 in Zone 17.

East Bull Lake Intrusive Suite Rocks

Mineralization in the East Bull Lake intrusive suite consists of copper-nickel-platinum group element mineralization in breccia zones located near the contacts of the layered mafic intrusions (Easton, James and Jobin-Bevans 2010). To date, mineralization has not been reported from the homogeneous sill or dike-like intrusions. Consequently, the layered mafic intrusion east of Totten Lake, especially its western flank, has greater exploration potential than the body in the northwestern corner of the township (*see* Figure 8.2).

ACKNOWLEDGMENTS

Special thanks are extended to Atikameksheng Anishnawbek First Nation, Sagamok Anishnawbek First Nation, Whitefish River First Nation and Métis Nation of Ontario for allowing the Ontario Geological Survey to map their traditional land-use area. The authors would like to thank J. Lauzon, P. Beals, J. Creppin, and N. Szumylo for their assistance during the 2024 field season. M. Duguet and C.A. Gordon (OGS) are thanked for their ongoing guidance and assistance on this project; and J.E. Chartrand, K.H. Yeung, S.A. Evers and P. Gervais, for all the assistance with databases, software logistics, sample preparation and drafting.

REFERENCES

Ames, D.E., Bleeker, W., Heather, K.B. and Wodicka, N. 1997. Timmins to Sudbury transect: New insights into the regional geology and setting of mineral deposits; Geological Association of Canada–Mineral Association of Canada, Joint Annual Meeting, Ottawa 1997, Field Trip Guidebook B6, 133p.

Ames, D.E., Davidson, A., Buckle, J.L. and Card, K.D. 2005. Geology, Sudbury bedrock compilation, Ontario; Geological Survey of Canada, Open File 4570, scale 1:50 000.

Bleeker, W., Kamo, S.L., Ames, D.E. and Davis, D. 2015. New field observations and U-Pb ages in the Sudbury area: Toward a detailed cross-section through the deformed Sudbury Structure; *in* Targeted Geoscience Initiative 4: Canadian Nickel-Copper-Platinum Group Elements-Chromium Ore Systems – Fertility, Pathfinders, New and Revised Models, Geological Survey of Canada, Open File 7856, p.151-156.

Card, K.D. 1979. Regional geological synthesis, central Superior Province; *in* Current Research, Geological Survey of Canada, Paper 79-1A, p.87-90.

Choudhry, A.G. 1983a. Precambrian geology of Totten Township, Sudbury District; Ontario Geological Survey, Preliminary Map P.2601, scale 1:15 840.

——— 1983b. Precambrian Geology of Ermatinger Township, Sudbury District; Ontario Geological Survey, Preliminary Map P.2600, scale 1:15 840.

——— 1984: Geology of Hart, Ermatinger and Totten townships; Ontario Geological Survey, Open File Report 5525, 70p.

Davey, S., Bleeker, W., Kamo, S.L., Davis, D.W., Easton, R.M. and Sutcliffe, R.H. 2019. Ni-Cu-PGE potential of the Nipissing sills as part of the ca. 2.2 Ga Ungava large igneous province; *in* Targeted Geoscience Initiative: 2018 Report of Activities; Geological Survey of Canada, Open File 8549, p.403-419.

Dressler, B.O. 1984a. General geology of the Sudbury area; *in* The Geology and Ore Deposits of the Sudbury Structure; Ontario Geological Survey, Special Volume 1, p.57-82.

——— 1984b. The effects of the Sudbury Event and the intrusion of the Sudbury Igneous Complex on the footwall rocks of the Sudbury Structure; *in* The Geology and Ore Deposits of the Sudbury Structure, Ontario Geological Survey, Special Volume 1, p.97-136.

Easton, R.M. 2010. Compilation mapping, Pecors–Whiskey Lake area, Superior and Southern provinces; *in* Summary of Field Work and Other Activities, 2010, Ontario Geological Survey, Open File Report 6260, p.8-1 to 8-12.

Easton, R.M., James, R.S. and Jobin-Bevans, S.L. 2010. Geological guidebook to the Paleoproterozoic East Bull Lake intrusive suite plutons at East Bull Lake, Agnew Lake and River Valley, Ontario: A Field Trip for the 11th International Platinum Symposium; Ontario Geological Survey, Open File Report 6253, 108p.

Golightly, J.P., Pattison, E.F. and Lightfoot, P.C. 2010. Ni-Cu-PGE mineralization in the South Range of the Sudbury Igneous Complex: A field trip for the 11th International Platinum Symposium; Ontario Geological Survey, Open File Report 6252, 41p.

Gordon, C.A. 2018. Precambrian geology of Denison Township, southwest Sudbury Structure; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.13-1 to 13-10.

——— 2022. Preliminary geology of Hyman Township, Southern and Superior provinces, Sudbury District, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.13-1 to 13-10.

Gordon, C.A., Simard, R-L. and Généreux, C-A. 2018. Precambrian geology of Drury Township, southwest Sudbury Structure: Explanatory notes for Preliminary Map P.3823; Ontario Geological Survey, Open File Report 6346, 49p.

Halls, H.C., Stott, G.M. and Davis, D.W. 2005. Paleomagnetism, geochronology and geochemistry of several Proterozoic mafic dike swarms in northwestern Ontario; Ontario Geological Survey, Open File Report 6171, 59p.

Heaman, L.M. 1997. Global mafic magmatism at 2.45 Ga: Remnants of an ancient large igneous province?; Geology, v.25, p.299-302.

James, R.S., Easton, R.M., Peck, D.C. and Hrominchuk, J.L. 2002. The East Bull Lake intrusive suite: Remnants of a ~2.48 Ga large igneous and metallogenic province in the Sudbury area of the Canadian Shield; Economic Geology, v.97, p.1577-1606.

Kamo, S.L. 2006. Report on U-Pb geochronological data from the southern Abitibi Subprovince, Bannockburn–Montrose and Vernon townships, and the Grenville Front region, Thistle–Sisk townships, Ontario; internal U/Pb age report prepared for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 20p.

Krogh, T.E., Corfu, F., Davis, D.W., Dunning, G.R., Heaman, L.M., Kamo, S.L., Machado, N., Greenough, J.D. and Nakamura, E. 1987. Precise U-Pb isotope ages of diabase dikes and mafic to ultramafic rocks using trace amounts of baddeleyite and zircon; *in* Mafic Dike Swarms, Geological Association of Canada, Special Paper 34, p.147-152.

Krogh, T.E., Davis, D.W. and Corfu, F. 1984. Precise U-Pb zircon and baddeleyite ages for the Sudbury area; *in* The Geology and Ore Deposits of the Sudbury Structure; Ontario Geological Survey, Special Volume 1, p.431-446.

Krogh, T.E., Kamo, S.L. and Bohor, B.F. 1996. Shock metamorphosed zircons with correlated U-Pb discordance and melt rocks with concordant protolith ages indicate an impact origin for the Sudbury structure; *in* Earth Processes: Reading the Isotopic Code; American Geophysical Union, Geophysical Monograph 95, p.343-353.

Langford, F.F. 1960. Geology of Levack Township and the northern part of Dowling Township, District of Sudbury; Ontario Department of Mines, Preliminary Report 1960-5, 78p.

Meldrum, A., Abel-Rahman, A.M., Martin, R.F. and Wodicka, N. 1997. The nature, age and petrogenesis of the Cartier Batholith, northern flank of the Sudbury Structure, Ontario; Precambrian Research, v.82, p.265-285.

Ontario Geological Survey 1988. Totten Township, District of Sudbury, Geological Data Inventory Folio 417; compiled by the staff of the Resident Geologist's office, Sudbury, 16p.

——— 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

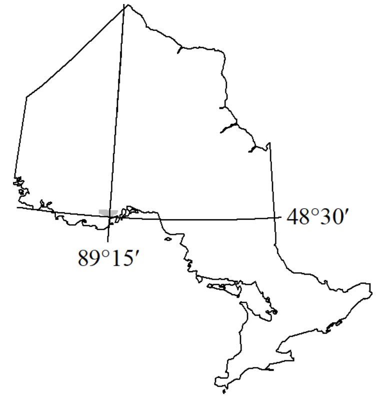
——— 2019a. Ontario airborne geophysical surveys, magnetic gradiometer and gamma-ray spectrometric data, grid and profile data (ASCII format) and vector data, Ramsey–Algoma area; Ontario Geological Survey, Geophysical Data Set 1086a.

——— 2019b. Ontario airborne geophysical surveys, magnetic gradiometer and gamma-ray spectrometric data, grid and profile data (Geosoft® format) and vector data, Ramsey–Algoma area; Ontario Geological Survey, Geophysical Data Set 1086b.

——— 2024a. Ontario Mineral Inventory; Ontario Geological Survey, online database, July 2024 update, www.hub.geologyontario.mines.gov.on.ca. [accessed October 21, 2024]

——— 2024b. Ontario Drill Hole Database; Ontario Geological Survey,online database, July 2024 update, www.hub.geologyontario.mines.gov.on.ca. [accessed October 21, 2024]

9. Project NW-19-001. Mapping Regional Fractionation Patterns in S-type Peraluminous Granite and Pegmatite Intrusions in the Southern Quetico Subprovince



G. Launay[1] and R.T. Metsaranta[1]

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

INTRODUCTION

Peraluminous granites and peraluminous granitic pegmatites form a significant component of the Quetico Subprovince (e.g., Percival 1989). Locally, highly fractionated lithium–cesium–tantalum (LCT)–type pegmatites in the Quetico Subprovince host lithium mineralization, most notably in the Georgia Lake pegmatite field (e.g., Pye 1965). Bedrock geology mapping that is in progress in the southern Quetico Subprovince and adjacent northern Wawa Subprovince, north of Thunder Bay, has delineated several peraluminous granite intrusions with spatially associated granitic pegmatites (Metsaranta 2015; Metsaranta and Walker 2019; Metsaranta 2022; Launay and Metsaranta 2023). Although no known economic lithium mineralization is present in the area being mapped, some LCT-type pegmatites host rare-element mineralization in the form of pegmatites containing beryl and niobium–tantalum oxide minerals (Breaks, Selway and Tindle 2003; Launay and Metsaranta 2023). In conjunction with bedrock geology mapping, a regional-scale evaluation of spatial fractionation patterns in peraluminous granites and associated LCT-type pegmatites, based on lithogeochemical and mineral chemical data, has been initiated. Preliminary results of this work are summarized in this article, with comparisons to published data sets from the Georgia Lake area (Breaks, Selway and Tindle 2008; Tindle, Selway and Breaks 2002; Tindle, Breaks and Selway 2008).

This work is part of a multi-year bedrock geology mapping project to produce new 1:50 000 scale maps of a large part of the Quetico Subprovince and its contacts with the Wawa and Wabigoon subprovinces in an area north of the city of Thunder Bay (Metsaranta 2015). During the summer of 2024, field work in the northern part of the project area commenced and field work in the southern part of the project area was completed. For the remainder of this article, "project area" refers to the southern portion of the multi-year project and corresponds to the area shown on Figure 9.1.

GEOLOGY OF PERALUMINOUS GRANITES AND PEGMATITES IN THE PROJECT AREA

A more detailed description of the geology of peraluminous granites and granitic pegmatites in the project area is found in Launay and Metsaranta (2023). However, to provide some context for the discussion of fractionation patterns that follows, a brief discussion of salient features of the distribution, field characteristics and age of peraluminous magmatism in the southern Quetico Subprovince is provided below.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.9-1 to 9-11.

Peraluminous granite intrusions in the project area include the Voutilainen intrusion (VI, Photos 9.1A and 9.1B), the Hilma Lake granite (HLG, Photos 9.1C and 9.1D), and the Hadwen Lake intrusion (HLI, Photos 9.1E and 9.1F) and their distribution is shown on Figure 9.1. The VI, HLG, and HLI are syntectonic with respect to transpressive, dextral deformation along the Quetico deformation zone (QDZ) and are commonly foliated or sheared. All 3 intrusions are characterized by low magnetic susceptibility (typically less than approximately 0.1 x 10^{-3} SI units) and comprise mixtures of biotite, biotite-muscovite and biotite±muscovite±garnet leucocratic granite. The intrusions locally contain metagreywacke xenoliths and, in places, contain abundant biotitic schlieren.

Peraluminous granitic pegmatites in the project area include the Onion Lake pegmatites (OLP, Photos 9.2A and 9.2B), the Walkinshaw Lake pegmatites (WLP, Photo 9.2C), those in and around the margins of the HLG (Photos 9.1C and 9.1D), and the Highway 17 pegmatites (Photos 9.2D and 9.2E). The OLP, those around the HLG and many of the Highway 17 pegmatites have a close association with potential parent granites. The WLP have no nearby peraluminous granite intrusion. The general location of these intrusions and pegmatite fields are shown on Figure 9.1.

Preliminary geochronology and field observations indicate that there are 2 generations of peraluminous granitic pegmatites in the project area. These can be recognized in the field based on deformation intensity and crosscutting relationships with respect to the QDZ. Most pegmatites are deformed and comprise an older group. A less common group of granitic pegmatites clearly postdates the QDZ and forms approximately north-northeast trending dikes (Photo 9.2F).

Most of the peraluminous granitic pegmatites in the area consist of mixtures of quartz, potassium feldspar, plagioclase, biotite, muscovite and garnet. More fractionated pegmatites are characterized by quartz-, potassium feldspar-, muscovite- and garnet-dominated compositions that locally contain columbite-tantalite group oxides, tourmaline, apatite and beryl. Andalusite-bearing pegmatites are present locally. In one instance (Photo 9.2E), a narrow muscovite-garnet-rich pegmatite dike, belonging to the Highway 17 pegmatites, contains alluaudite. Alluaudite is a sodium-rich phosphate that can be formed by sodic metasomatism of lithium-rich pegmatites (Moore 1971).

A preliminary laser ablation inductively couple plasma mass spectrometer (LA-ICP–MS) U/Pb zircon age for the Voutilainen intrusion suggests the emplacement occurred at 2667±1 Ma (this study; Sutcliffe 2020). A similar LA-ICP–MS monazite age of 2667±9 Ma (this study; Davis and Sutcliffe 2017) derived from a sample of a foliated garnet-muscovite pegmatite collected in the Onion Lake area supports a parent granite-pegmatite type relationship for the older group of foliated peraluminous granites and pegmatites. A preliminary LA-ICP–MS monazite age of 2646.4±0.5 Ma (this study; J.H. Marsh, Mineral Exploration Research Centre Isotope Geochemistry Laboratory, Laurentian University, personal communication, 2024) for a north-northeast-striking quartz-rich, garnet- and andalusite-bearing pegmatite dike cutting highly strained paragneiss further supports subdivision of pegmatites in the project area into 2 groups.

These field relationships and preliminary ages suggest that a classical parent granite-pegmatite relationship may be valid for the VI, HLG and HLI and foliated pegmatites in their vicinity, such as the Onion Lake pegmatites and Highway 17 pegmatites. However, a clear “parent” granite related to the second generation, posttectonic pegmatites, has not been identified thus far. It is not clear which pegmatite group the Walkinshaw pegmatites belong to because they occur to the south of the main zone of high strain associated with the QDZ. A sample of a tourmaline-muscovite-bearing granitic pegmatite was collected in the summer of 2024 for geochronology.

In the discussions below samples are not subdivided into these 2 distinct age groups, data from both types are considered together. The younger group of pegmatites forms only a very small component of the data collected so far.

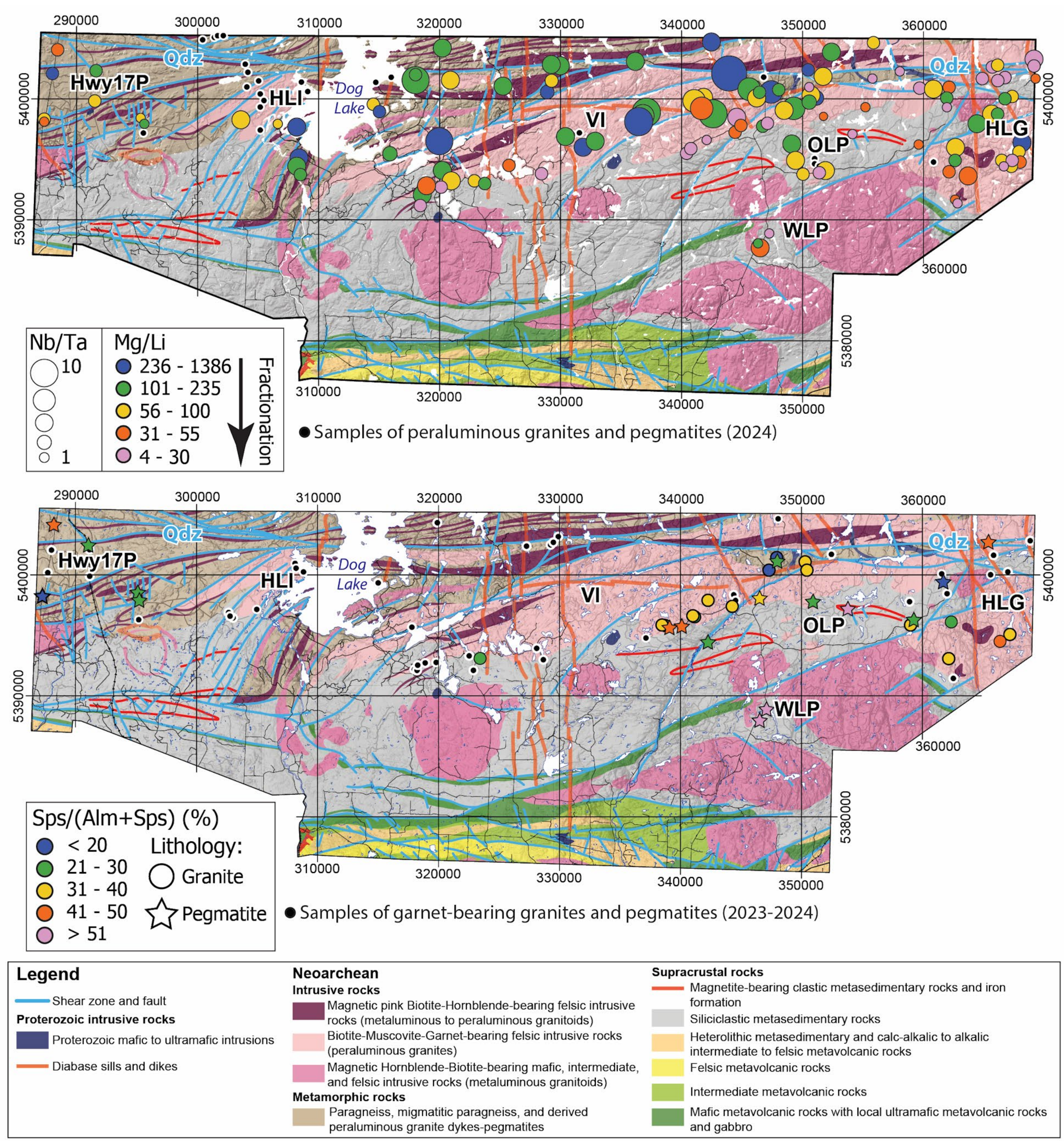


Figure 9.1. **A)** Preliminary geological map of the project area (*modified from* Launay and Metsaranta, 2023) displaying the Nb/Ta and Mg/Li values calculated from the lithogeochemical analysis of the peraluminous granites and pegmatites sampled throughout the project area from 2015 to 2023. The black dots correspond to the samples collected during the summer of 2024. **B)** Preliminary geological map of the project area displaying the proportion of the spessartine component in the garnets from the peraluminous granites and pegmatites sampled throughout the project area from 2015 to 2023. The black dots correspond to samples collected the summers of 2023 and 2024. Abbreviations: HLG, Hilma Lake granite; HLI, Hadwen Lake intrusion; Hwy17P, Highway 17 pegmatites; OLP, Onion Lake pegmatite; Qdz, Quetico deformation zone; VI, Voutilainen intrusion; WLP, Walkinshaw Lake pegmatite.

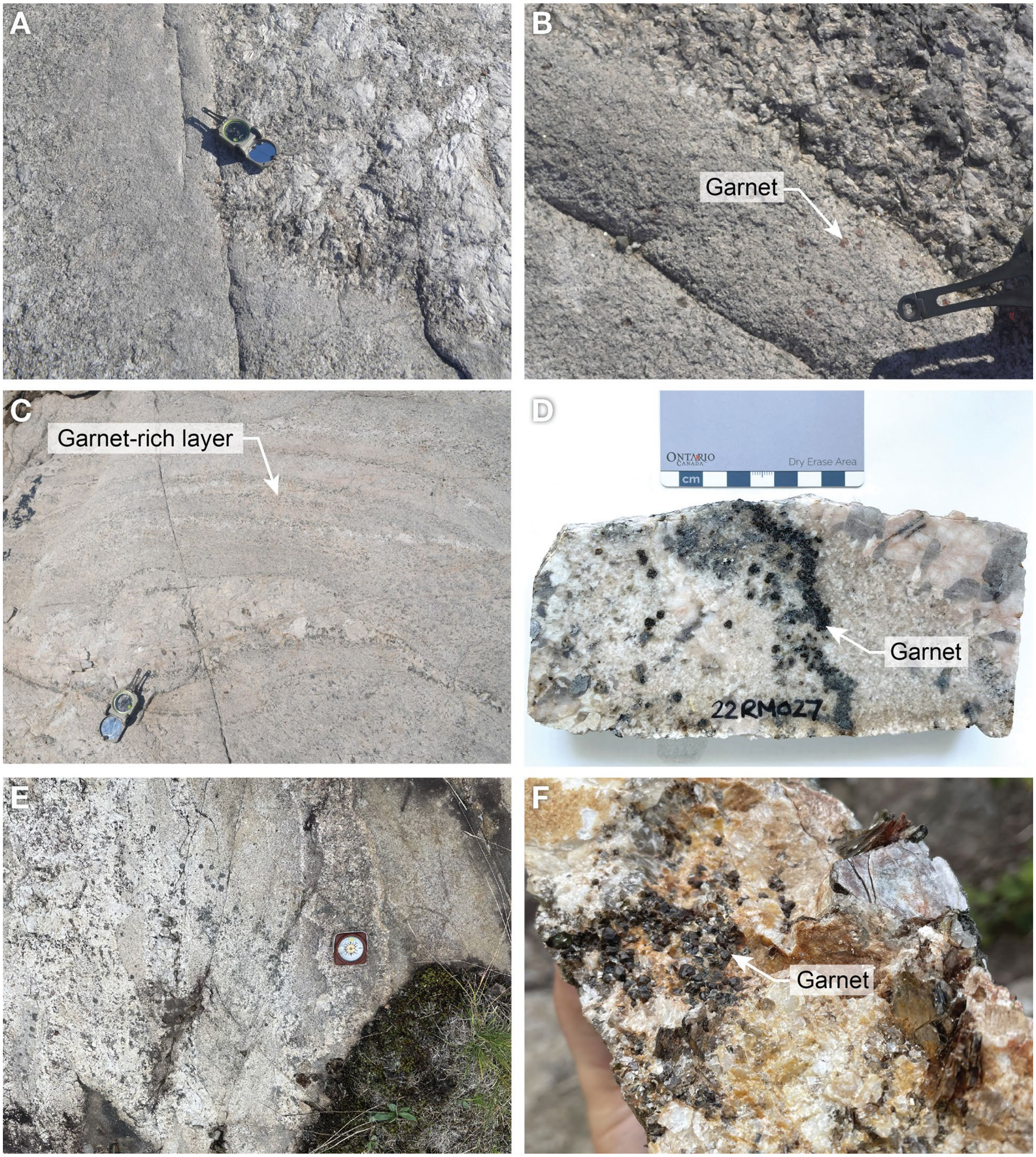


Photo 9.1. Representative photographs of the main peraluminous granite intrusions occurring in the project area.
A) Pegmatitic pocket in coarse-grained garnet-bearing two-mica granite composing the southern part of the Voutilainen intrusion (22RM015 UTM 358782E 5397850N), compass for scale is 22 cm in length. **B)** Close-up of the garnet-bearing two-mica granite at the same locality as Photo 9.1A. Approximately 6 cm from the compass sighting arm for scale. **C)** Typical exposure of the Hilma Lake granite showing layered granite–pegmatite marked by garnet-rich layers. **D)** Hand sample from the same locality as Photo 9.1C showing a close-up of the garnet-rich layer. **E)** Typical exposure of the Hadwen Lake intrusion showing medium-grained two-mica granite intruded by barren biotite-bearing pegmatites (23GAL669: UTM 302769E 5396584N), compass for scale is 10 cm in length. **F)** Hand sample of muscovite garnet-bearing pegmatite from the Hadwen Lake intrusion (23GAL669: UTM 302769E 5396584N).

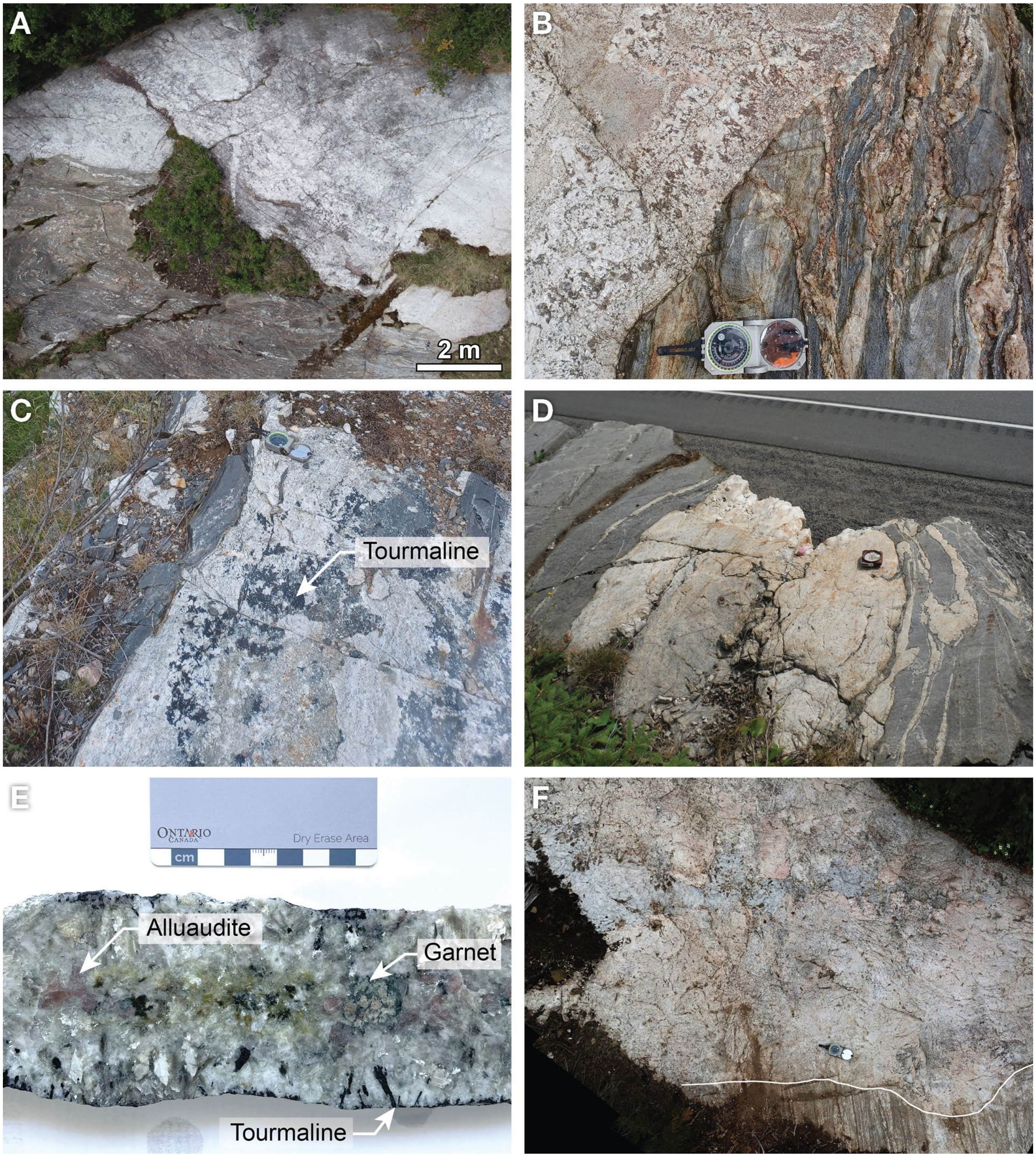


Photo 9.2. Representative photographs of the notable pegmatite fields occurring in the project area. **A)** Drone aerial photography displaying a sheared and foliated complex layered aplite–pegmatite dike from the Onion Lake area (22RM214: UTM 346817E 5398027N), compass for scale is 22 cm in length. **B)** Close-up of the contact between the pegmatite dike and the sheared metasedimentary host rock displayed in Photo 9.2A, the pegmatite is characterized by unidirectional solidification texture, compass for scale is 22 cm in length. **C)** Undeformed dike of tourmaline-bearing pegmatite from the Walkinshaw Lake area, (19RM155: UTM 346697E 5388265N), compass for scale is 22 cm in length. **D)** Dextrally sheared and boudinaged garnet–biotite–muscovite-bearing dike of layered pegmatite–aplite occurring along Highway 17 (23GAL384: UTM 287300E 5398121N), compass for scale is 10 cm in length. **E)** Hand sample of a north- to-northeast striking thin dike of garnet-alluaudite-muscovite-black tourmaline-bearing pegmatite from Highway 17 (23GAL384: UTM 287300E 5398121N). **F)** Undeformed north-to-northeast striking dike of garnet–andalusite-bearing pegmatite discordant with the regional foliation of the paragneiss (19RM221: UTM 340510E 5405271N), compass for scale is 22 cm in length with the sighting arm pointing north.

METHODS USED FOR EVALUATING GRANITE FRACTIONATION

Regional and internal fractionation of peraluminous granites and pegmatites are critical for concentrating rare elements (e.g., Li, Be, Nb, Ta) and ultimately developing economically viable rare-element deposits such as those in the Wodgina and the Tanco pegmatites (Černý 1991; London 2018). Through the fractionation processes of a parental granitic melt, volatiles and incompatible rare elements are contracted in residual melt and then crystallize in pegmatites as rare-element-bearing minerals (spodumene, pollucite, columbite-tantalite) (Černý 1991; London 2018). Analysis of the major and trace element compositions of granites and aplitic parts of pegmatites is a robust approach to identify fertile granites and pegmatites and to assess the degree of fractionation of the granitic melts (e.g., Breaks, Selway and Tindle 2003; Selway, Breaks and Tindle 2005). To investigate regional fractionation patterns of the peraluminous granites and pegmatites occurring in the southern part of the Quetico Subprovince, 163 samples of peraluminous granites or pegmatites were collected for lithogeochemical analysis (Figure 9.1A).

Because of potential issues of sample representativeness (e.g., heterogeneity and grain size) for the lithogeochemical analysis of pegmatites and granites, the chemistry of rock-forming or accessory minerals such as muscovite, tourmaline, garnet and potassium feldspar constitutes a good complementary tool to study fractional crystallization processes in granites and pegmatite fields (e.g., Černý 1991; Breaks, Selway and Tindle 2003; Garate-Olave et al. 2017). Garnet is common in fractionated peraluminous granitic systems and thus constitutes a good indicator of granite fertility. Garnet colour and composition changes are directly related to the degree of fractionation of the granitic melt from which they crystallized. The high resistance of garnet to alteration compared to feldspars and micas and its wide range of major element composition, make garnet a reliable mineral for identifying the most evolved pegmatites and mapping fractionation patterns. Numerous studies (Baldwin and von Knorring 1983; Černý 1989; Whitworth 1992; Selway, Breaks and Tindle 2005) have established that the manganese contents in garnets hosted by pegmatites increase with the degree of fractionation of the pegmatitic melts and toward the core zone of the complex pegmatitic dikes.

Garnet is a common accessory mineral in many peraluminous granite and granitic pegmatites observed in the project area (Launay and Metsaranta 2023). To expand the garnet composition database initiated by Breaks, Selway and Tindle (2003) in the project area, a total of 88 additional samples of garnet-bearing peraluminous granites or garnet-bearing pegmatites have been collected so far (Figure 9.1B). Scanning electron microscopy with energy-dispersive X-ray spectroscopy and electron microprobe analyses of garnets from these samples are ongoing.

PRELIMINARY ANALYSIS OF FRACTIONATION PATTERNS

Source and Fractionation Degree of the Peraluminous Granites and Pegmatites

S-type peraluminous granites and pegmatites are mainly considered to be the products of melting of metasedimentary rocks. Based on partial melting experiments of siliciclastic metasedimentary rocks, Sylvester (1998) demonstrated that Rb/Sr and Rb/Ba values in the whole-rock compositions of peraluminous granites can be used as a proxy for the source metasedimentary rocks from which granitic melts are derived. Peraluminous granites produced through the melting of clay-rich sedimentary rocks (i.e., metapelites) are characterized by higher Rb/Sr and Rb/Ba values than those generated from the melting of plagioclase-rich and clay-poor sedimentary rocks (i.e., psammitic rocks, greywackes). The peraluminous granite intrusions occurring in the project area (VI, HLI and HLG) are characterized by low values of Rb/Sr and Rb/Ba (Figure 9.2A) and were mainly produced by the partial melting of metagreywackes at depth. Some samples from the southern margin of the VI have higher Rb/Sr and Rb/Ba values suggesting a potential derivation from clay-rich sources (Figure 9.2A); however, this could also be the result of fractionation. These samples are also characterized by higher lithium concentrations (up to 244 ppm). Thus, granites produced by the partial melting of metapelites and/or have assimilated clay-rich rocks during their emplacement could be more fertile than those derived from the melting of greywackes.

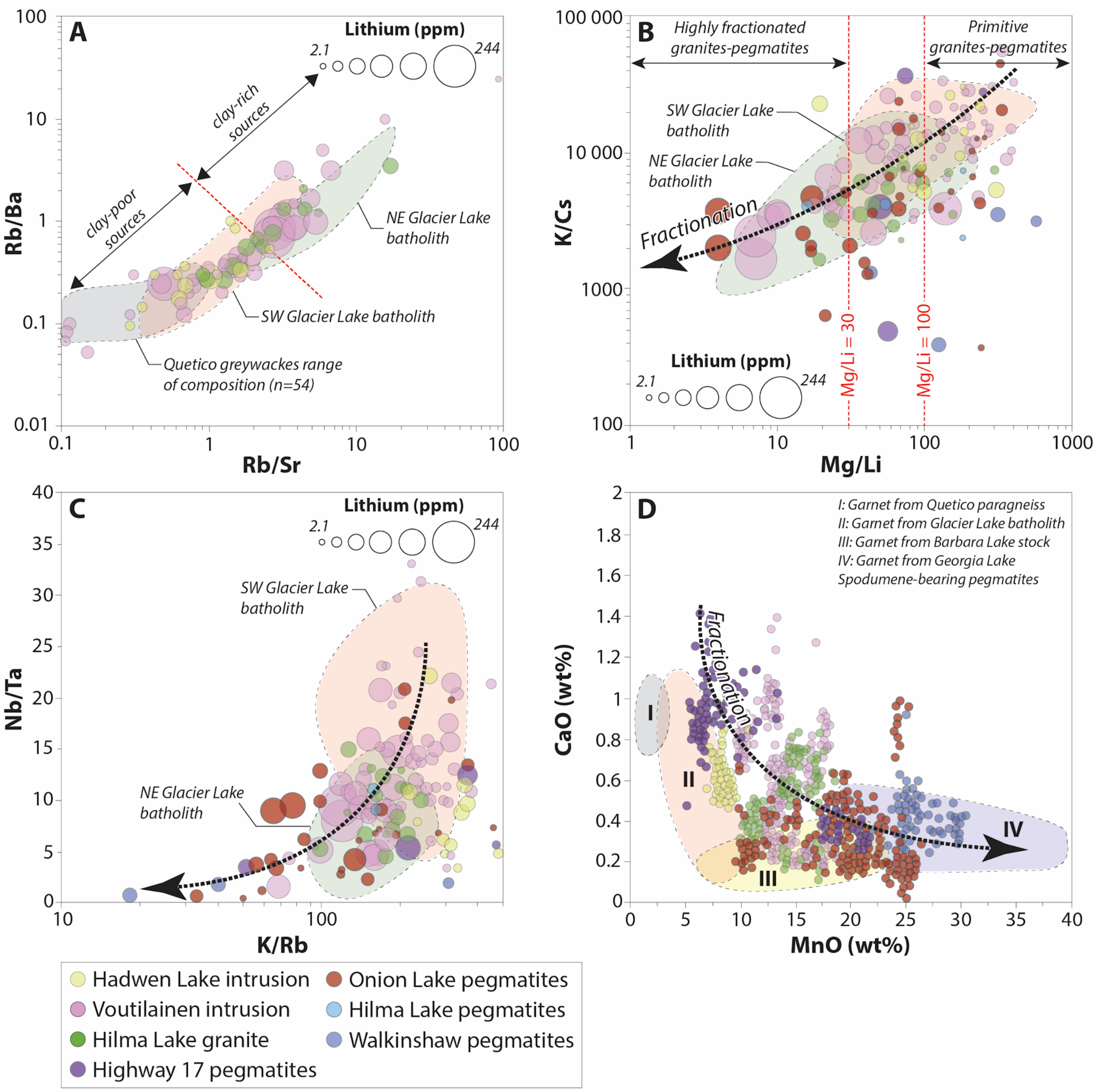


Figure 9.2. Summary of the whole-rock and garnet chemistry results obtained for the peraluminous granites and pegmatites of the project area along with comparisons to data from the Georgia Lake area. **A)** Plot of Rb/Ba values against Rb/Sr values showing the potential source rocks from which the peraluminous granites were derived (Sylvester 1998), symbol size proportional to lithium concentration in ppm. **B)** and **C)** Plots of K/Cs values against Mg/Li values and Nb/Ta values against K/Rb values showing the fractionation trends of the peraluminous granites and pegmatites of the project area, symbol size is proportional to lithium concentration in ppm **D)** Plot of CaO against MnO for garnet compositions from granites and pegmatites of the project area. The compositional fields displayed in these diagrams for the Glacier Lake batholith, the Barbara Lake stock, and the spodumene-bearing pegmatites of Georgia Lake were defined from the data published in Miscellaneous Release Data—111 (Tindle, Selway and Breaks 2002) and Miscellaneous Release Data—231 (Tindle, Breaks and Selway 2008).

The K/Cs, K/Rb, Mg/Li and Nb/Ta values are good indicators of the degree of fractionation and fertility of peraluminous granites and pegmatites (Černý 1989; Selway, Breaks and Tindle 2005; Ballouard et al. 2016). These studies demonstrated that the values of these different ratios decrease with the degree of fractionation. The most fractionated and fertile granites and pegmatites are characterized by significantly lower values than primitive granites (Breaks and Tindle 1997; Selway, Breaks and Tindle 2005). Figures 9.2B and 9.2C show that the compositions of granites and pegmatites from the project area follow fractionation trends. These fractionation trends suggest that the VI and the OLP are likely genetically related. They evolve from primitive barren compositions (Mg/Li >100 and Nb/Ta >10) to highly fractionated compositions (Mg/Li <30 and Nb/Ta <5) comparable with fertile pegmatite fields (Selway, Breaks and Tindle 2005). The HLI and the HLG and their associated pegmatites (i.e., Highway 17 pegmatites and pegmatites near margins of HLG) have primitive and intermediate compositions, respectively (Figures 9.2B and 9.2C). This suggests that HLI and HLG have experienced limited fractionation compared to the VI and OLP. In general, lithium concentration increases with the degree of fractionation, with the highest lithium concentrations observed in the most evolved granites and pegmatites (Figures 9.2B and 9.2C). Finally, the range of compositions and degree of fractionation of the peraluminous granites occurring in the project area are similar to those documented in the parental granites in the Georgia Lake area (i.e., northeastern and southwestern Glacier Lake batholiths: Breaks, Selway and Tindle 2008) from which the lithium-bearing pegmatite field originated by fractional crystallisation (*see* Figures 9.2A to 9.2C).

Regional Fractionation Trend of Granites and Pegmatites

Figure 9.1A shows that the fractionation patterns of the peraluminous granites and pegmatites occurring in the project area are mappable. The southern part of the VI is characterized by lower values of Mg/Li and Nb/Ta and thus by more evolved and fractionated compositions than the northern part of the intrusion. The granite injections and intrusions composing the HLI and the northern part of the project area likely constitute the most primitive part of the peraluminous magmatic system. This suggests a north to south trend of increasing fractionation perpendicular to the Quetico deformation zone (QDZ), which bounds the VI to the north. The QDZ could have acted as a feeder zone for the VI by extracting the peraluminous granitic melt produced at depth, which then evolved to the south through fractional crystallization processes. The southern edge of the HLG is also more fractionated than the central part of the intrusion (Figure 9.1A), which seems to suggest the same fractionation pattern as the VI.

Garnet Chemistry as an Indicator of Pegmatite Evolution

All garnets from granites and pegmatites sampled in the project area belong to the almandine–spessartine solid solution, with a higher proportion of spessartine in garnets from the most fractionated intrusions. Figure 9.2D shows that the compositions of these garnets follow a fractionation trend defined by decreases in the CaO (from 1.4 to 0.2 wt %) and increases in the MnO contents (from 5 to 30 wt %). Garnets from the HLI have primitive compositions (MnO <10 wt %) compared to garnets from the VI and HLG, which are characterized by intermediate compositions (10 < MnO < 20 wt %) (Figure 9.2D). Garnets from granites and pegmatites sampled along the southern margin of the VI seem to be more fractionated than those sampled in the northern part of the intrusion (*see* Figure 9.1B). This is consistent with the fractionation pattern derived from the lithogeochemical data described previously (*see* Figures 9.1A and 9.2A to C). The most fractionated garnets are observed in the OLP and WLP (Figures 9.1B and 9.2D) and are characterized by similar compositions (MnO >20 wt %) to those from the lithium-bearing pegmatites of the Georgia Lake area (Figure 9.2D). Some analyzed garnets from the OLP and WLP display chemical zoning characterized by core-rim enrichment of manganese and depletion of iron, suggesting *in-situ* fractionation of the pegmatitic melts. The garnets from the Highway 17 pegmatites form 2 distinctive groups of composition: a first group characterized by primitive compositions (5 < MnO < 10 wt %) and a second group with more fractionated compositions (17.5 < MnO < 22.5 wt %) (Figure 9.2D). No major differences can be observed between the compositions of garnets from the peraluminous intrusions occurring in the project area and those from the fertile granites (Glacier Lake batholith and Barabara Lake stock) and pegmatites of the Georgia Lake area (Figure 9.2D).

CONCLUSIONS

Preliminary analyses of the fractionation patterns in peraluminous granites and granitic pegmatites occurring in the southern part of the Quetico Subprovince suggest

- The VI is characterized by a trend of increasing fractionation from north to south perpendicular to its long elongation axis and the Quetico deformation zone to the north. This fractionation trend is consistent with the presence of the most fractionated pegmatites along the southern margin and south of the VI, such as the OLP and the WLP.
- Despite the lack of known occurrences of lithium mineralization, lithogeochemical and garnet chemistry fractionation indicators show that highly fractionated granites and granitic pegmatites, comparable to those in the Georgia Lake area, are present in the project area.
- The absence of significant differences in terms of composition, degree of fractionation, or sources of the peraluminous granitic melts between the Georgia Lake pegmatite field and the project area suggests that other factors must be considered to explain the differences in lithium mineralization across the Quetico Subprovince.
- The contrasting lithium mineralization distribution could have resulted from differences in volatile (F, Cl, and P) contents in the granitic melts, fluid-rock interaction histories during the late stage of crystallization of pegmatites (this could affect the saturation and crystallization of Li and Nb-Ta-bearing minerals), assimilation processes during the granite emplacement and/or the structural framework (which could affect the mechanism of melt extraction and emplacement of granites and pegmatites)

ACKNOWLEDGMENTS

We would like to again thank Alison Griffiths and Kate Moorhouse for another summer of excellent assistance in the field. Manuel Duguet (Earth Resources and Geoscience Mapping Section, OGS) and OGS editors (Publication Services, OGS) are thanked for their reviews and improvements to the article. Thanks also to Pat Gervais (ERGMS, OGS) for drafting assistance. Manuel Duguet and Justin Jonsson are thanked for discussions on the geology of the Quetico Subprovince.

We would also like to thank Fort William First Nation, Red Rock Indian Band, Lac Des Mille Lacs First Nation, Biinjitiwaabik Zaaging Anishinaabek (Rocky Bay First Nation), Kiashke Zaaging Anishinaabek (Gull Bay First Nation), Métis Nation of Ontario Region 2 Thunder Bay Métis Council and Red Sky Métis Independent Nation for allowing the Ontario Geological Survey to map in their traditional land-use area. Their co-operation is greatly appreciated.

REFERENCES

Baldwin, J.R. and von Knorring, O. 1983. Compositional range of Mn-garnet in zoned granitic pegmatites; The Canadian Mineralogist, v.21, p.683-688.

Ballouard, C., Poujol, M., Boulvais, P., Branquet, Y., Tartese, R. and Vigneresss, J.L. 2016. Nb-Ta fractionation in peraluminous granites: A marker of the magmatic-hydrothermal transition; Geology, v.44, no.3, p.231-234.

Breaks, F.W., Selway, J.B. and Tindle, A.G. 2003. Fertile peraluminous granites and related rare-element mineralization in pegmatites, Superior Province, northwest and northeast Ontario: Operation Treasure Hunt; Ontario Geological Survey, Open File Report 6099, 179p.

Breaks, F.W. and Tindle, A.G. 1997. Rare element exploration potential of the Separation Lake area: An emerging target for Bikita-type mineralization in the Superior province of northwest Ontario; *in* Summary of Field Work and Other Activities, 1997, Ontario Geological Survey, Miscellaneous Paper 168, p. 72-88.

——— 2008. The Georgia Lake rare-element pegmatite field and related S-type, peraluminous granites, Quetico Subprovince, north-central Ontario; Ontario Geological Survey, Open File Report 6199, 176p.

Černỳ, P. 1989. Exploration strategy and methods for pegmatite deposits of tantalum; *in* Lanthanides, Tantalum and Niobium, Springer, Berlin/Heidelberg, Germany, p.274-302.

——— 1991. Rare-element granitic pegmatites. Part I: Anatomy and internal evolution of pegmatitic deposits; Geoscience Canada, v.18, p.49-67.

Davis, D.W. and Sutcliffe, C.N. 2017. U-Pb geochronology by LA-ICPMS in samples from northern Ontario; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 131p.

Garate-Olave, I., Müller, A., Roda-Robles, E., Gil-Crespo, P.P. and Pesquera, A. 2017. Extreme fractionation in a granite-pegmatite system documented by quartz chemistry: The case study of Tres Arroyos (Central Iberian Zone, Spain); Lithos, v.286-287, p.162-174.

Launay G.A. and Metsaranta, R.T. 2023. Precambrian bedrock geology mapping in the Onion Lake and Sunshine areas, Quetico and Wawa Subprovinces, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.11-1 to 11-12.

London, D. 2018. Ore-forming processes within granitic pegmatites; Ore Geology Reviews, v.101, p.349-383.

Metsaranta, R.T. 2015. Preliminary results from geological mapping of the Quetico Subprovince, the Shebandowan greenstone belt and Proterozoic rocks north of Thunder Bay; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.15-1 to 15-20.

——— 2022. Highlights of bedrock geology mapping in the Quetico Subprovince, north of Thunder Bay, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6380, p.9-1 to 9-9.

Metsaranta, R.T. and Walker, J.A. 2019. Precambrian geology of western McGregor Township and adjacent areas, northeast of Thunder Bay; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.11-1 to 11-10.

Moore, P.B. 1971. Crystal chemistry of the alluaudite structure type: Contribution to the paragenesis of pegmatite phosphate giant crystals; The American Mineralogist, v.56, p.1955-1975.

Percival, J.A. 1989. A regional perspective of the Quetico metasedimentary belt, Superior Province, Canada; Canadian Journal of Earth Sciences, v.26, p.677-693.

Pye, E.G. 1965. Geology and lithium deposits of Georgia Lake area, District of Thunder Bay; Ontario Department of Mines, Geological Report 31, 113p.

Selway, J.B., Breaks, F.W. and Tindle, A.G. 2005. A review of rare-element (Li-Cs-Ta) pegmatite exploration techniques for the Superior Province, Canada, and large worldwide tantalum deposits; Exploration and Mining Geology, v.14, p.1-30.

Sutcliffe, C.N. 2020. Preliminary U-Pb geochronology report for samples 19RM023GC and 19RM173GC by LA-ICPMS; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 8p.

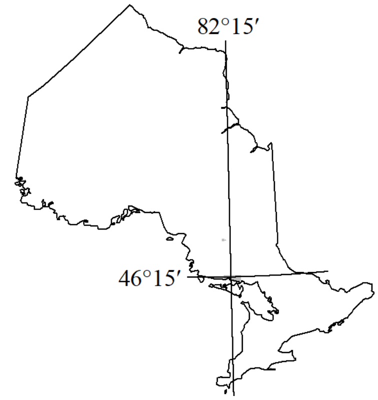
Sylvester, P.J. 1998. Post-collisional strongly peraluminous granites; Lithos, v.45, p.29-44.

Tindle, A.G., Breaks, F.W. and Selway, J.B. 2008. Electron microprobe and bulk rock and mineral compositions from S-type, peraluminous granitic rocks and rare-element pegmatites, Georgia Lake pegmatite field, Quetico Subprovince, north-central Superior Province of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 231.

Tindle, A.G., Selway, J.B. and Breaks, F.W. 2002. Electron microprobe and bulk analyses of fertile peraluminous granites and related rare-element pegmatites, Superior Province, northwest and northeast Ontario: Operation Treasure Hunt; Ontario Geological Survey, Miscellaneous Release—Data 111.

Whitworth, M. 1992. Petrogenetic implications of garnets associated with lithium pegmatites from SE Ireland; Mineralogical Magazine, v.56, p.75-83.

10. Newly Identified Magmatic and Metamorphic Events in the Southern Province near Walford, Ontario



R.M. Easton[1], E.C.G. Hastie[1], S.L. Kamo[2] and M. Duguet[1]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, Ontario P3E 6B5
[2]Jack Satterly Geochronology Laboratory, Department of Earth Sciences, University of Toronto, Toronto, Ontario M5S 3B1

INTRODUCTION

In the summer of 2022, portions of a 75 m long roadcut on the north side of Highway 17, approximately 850 m west of the community of Walford (centre of roadcut UTM[3] 404170E 5117685N, NAD83, Zone 17), were sampled for U/Pb geochronology. The roadcut is in a belt of amphibolite-facies metasedimentary and meta-intrusive rocks between 6 and 10 km wide, that is located immediately south of the Murray fault and which extends from Spragge to Worthington (~100 km) (Figure 10.1). This belt will be referred to herein as the Walford belt. This is the same package of rocks that contains the *circa* 2258 Ma May Township sills (Bleeker et al. 2023) (*see* Figure 10.1), which previously had been mapped as Nipissing gabbros (*circa* 2217 Ma: Davey et al. 2019). The regional extent of the May Township sills was not known at the time of sampling the Walford roadcut. Approximately 4 km to the west of the Walford roadcut, this belt of rocks is cut by the *circa* 1740 Ma Cutler granite (Davidson, van Breemen and Sullivan 1992) (*see* Figure 10.1).

From west to east, the roadcut contains a 25 m wide medium-grained amphibolite dike or sill, which is cut on its eastern side by a 20 m wide undeformed Sudbury swarm diabase dike (*circa* 1240 Ma: Krogh et al. 1987). The eastern 30 m of the roadcut consists of a whitish, medium-grained, porphyroblastic to lepidoblastic, garnet–staurolite–sillimanite metapelite that has been previously mapped as the McKim Formation of the Elliot Lake Group of the Huronian Supergroup (Robertson 1975) (Photo 10.1A). Most significantly, the metapelite is cut by a thin, irregular band of breccia that has the appearance of Sudbury breccia (*see* Photos 10.1A and 10.1B). It could not be determined in outcrop if the breccia had been metamorphosed along with the pelite or not. If the former, that would suggest that metamorphism of the metapelite, the breccia, and probably the amphibolite, occurred after the Sudbury impact event at 1850 Ma (Krogh, Davis and Corfu 1984), but before Sudbury swarm dike injection at *circa* 1240 Ma.

To better understand the geological history observed in the roadcut, the deformed amphibolite and the metapelite were sampled for U/Pb geochronology. In part, this was done to determine which regional orogenic event the metamorphism might be associated with: the Blezardian (2460–2300 Ma; Raharimahefa, Lafrance and Tinkham 2014), the Penokean (1870–1835 Ma; Zi et al. 2022), or a previously undocumented event.

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

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.10-1 to 10-12.

URANIUM–LEAD GEOCHRONOLOGY METHODS

Chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS) and laser ablation inductively coupled plasma mass spectrometry (LA-ICP–MS) methods were used on the samples, with work being done at 3 separate laboratories.

Amphibolite Sample

Sample preparation and isotopic analyses on the amphibolite sample was done at the Jack Satterly Geochronology Laboratory (JSGL) at the University of Toronto. The sample was crushed and milled using standard methods (jaw crusher and Bico disk mill, respectively). Heavy mineral separation was done by reprocessing on a Wilfley table, with magnetic separation and heavy liquid (methylene iodide) methods used to produce a concentrate. Final sample selection was done by hand-picking under a microscope.

Chemical Abrasion Isotope Dilution Thermal Ionization Mass Spectrometry Analytical Method

Prior to analysis, zircon crystals were thermally annealed and chemically etched (chemical abrasion: Mattinson 2005). The pretreatment involved placing zircon grains in a muffle furnace at ~900°C for ~48 hours to repair radiation damage and anneal the crystal lattice, followed by a modified single-step partial dissolution procedure in ~0.10 mL of ~50% HF and 0.020 mL 8N HNO_3 in Teflon™ dissolution

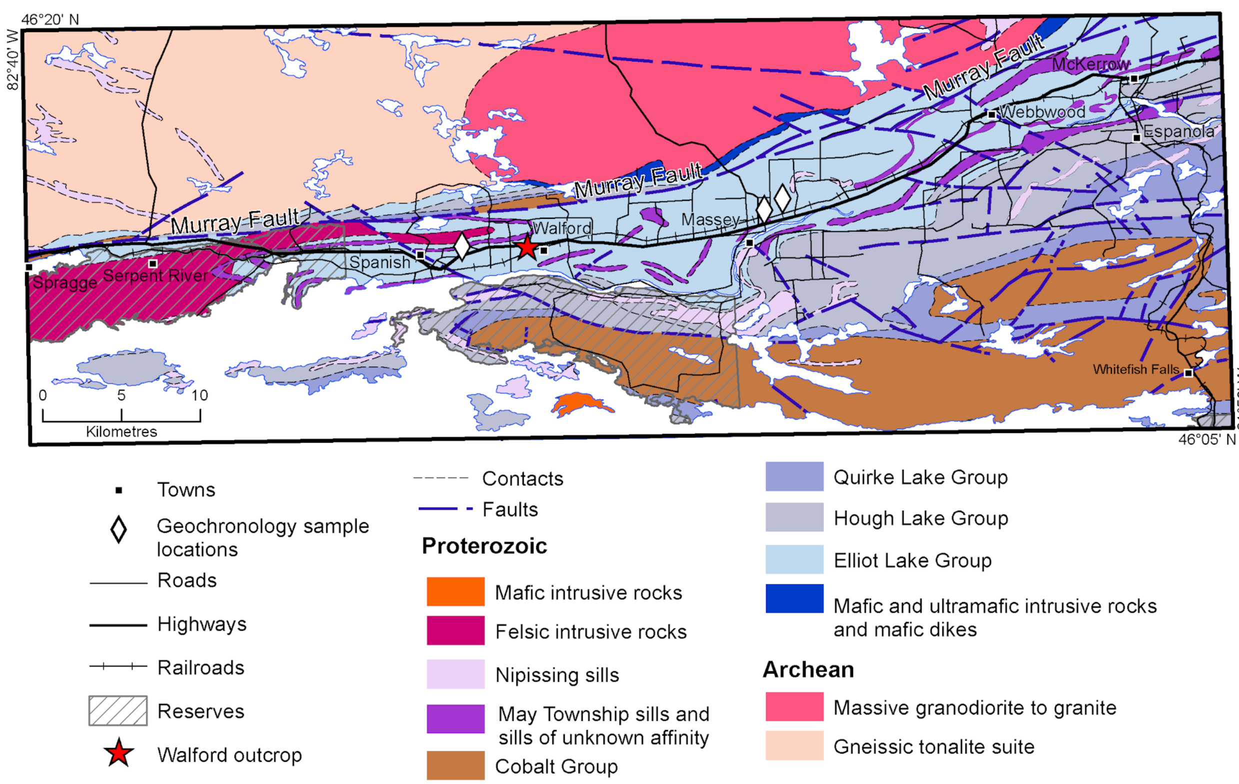


Figure 10.1. Geological sketch map for the area between Espanola and Serpent River showing the location of the Walford roadcut, known and probable May Township sills and their geochronology sample sites, and the Murray Fault. Geology *modified from* Ontario Geological Survey (2011). Figure *modified from* Bleeker et al. (2023).

vessels at 200°C for ~2 to 8 hours depending on the state of preservation of the grains. Zircon and baddeleyite were rinsed in 8N HNO_3 at room temperature prior to dissolution. A ^{205}Pb–^{235}U spike was added to the Krogh-type Teflon™ dissolution capsules during sample loading. The minerals were dissolved using ~0.10 mL of concentrated HF and ~0.02 mL of 8N HNO_3 at 200°C for 4 days. All samples were dried to a precipitate and redissolved in ~0.15 ml of 3N HCl overnight (Krogh 1973).

Photo 10.1. **A)** Photograph of the central part of the Walford roadcut, showing white-grey metapelite layers and more massive white psammite layers (S_0), cut by a veinlet interpreted as Sudbury breccia. Red dashed line highlights the lower contact of the interpreted Sudbury breccia veinlet (S_n). **B)** Close-up view of the Sudbury breccia veinlet showing a discrete clast that shows an older fabric (S_0?) at high-angle to the walls of the brecciated zone. Hammer handle in Photo 10.1A is 66 cm long. Location is UTM 404170E 5117685N NAD83, Zone 17.

Uranium and lead were isolated from zircon and baddeleyite using anion exchange columns and HCl, deposited onto outgassed rhenium filaments with silica gel (Gerstenberger and Haase 1997), and analyzed with a VG354 mass spectrometer using a Daly detector in pulse counting mode. Corrections to the ^{206}Pb–^{238}U ages for initial ^{230}Th disequilibrium have been made assuming a Th/U value in the magma of 4.2. All common lead was assigned to procedural lead blank for zircon and baddeleyite. Dead time of the measuring system for lead and uranium was 16 and 14 ns, respectively. The mass discrimination correction for the Daly detector is constant at 0.05% per atomic mass unit. Amplifier gains and Daly characteristics were monitored using the SRM 982 lead standard. Thermal mass discrimination corrections are 0.10% per atomic mass unit for both lead and uranium. Decay constants are those of Jaffey et al. (1971); a uranium isotopic composition of 137.88 was used (Steiger and Jäger 1977). All age errors quoted in the text, and error ellipses in Figure 10.2A, are given at the 95% confidence interval. VG Sector software was used for data acquisition. In-house data reduction software in Visual Basic by D.W. Davis was used. Plotting and age calculations used Isoplot 3.00 (Ludwig 2003).

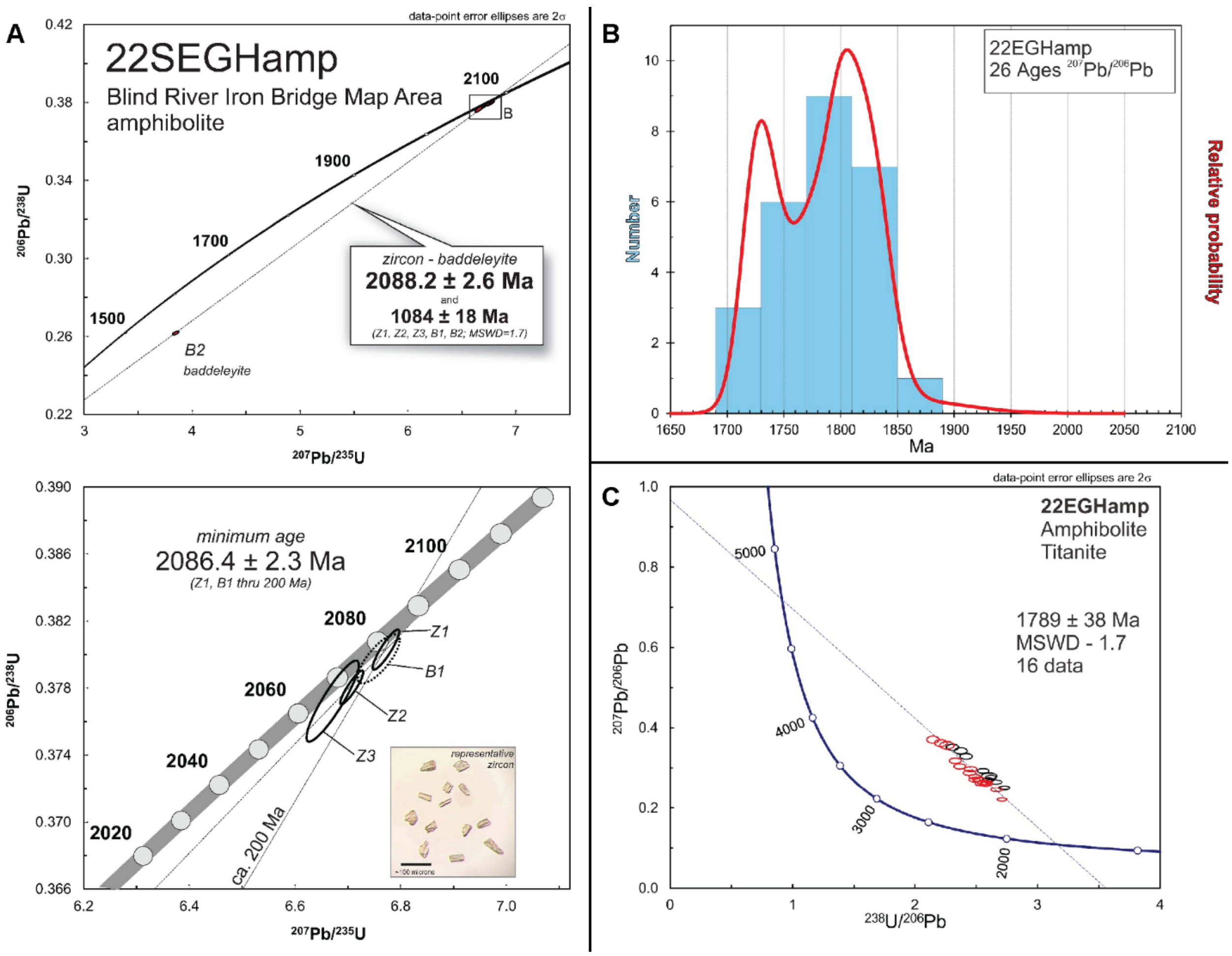


Figure 10.2. Geochronology results from the amphibolite sample from the Walford roadcut (sample 22EGHamp). **A) Upper plot:** Concordia plot for zircon and baddeleyite from sample 22EGHamp. **A) Lower plot:** Close-up view of upper intercept shown in Figure 10.2A showing the minimum age estimate of 2086.4±2.3 Ma based on zircon (Z1) and baddeleyite (B1). Inset shows representative zircon grains. **B)** Combined age relative probability density plot and histogram showing the distribution of $^{207}Pb/^{206}Pb$ ages on titanite grains from sample 22EGHamp. **C)** Tera–Wasserburg Concordia plot showing U/Pb isotopic data on titanite grains from sample 22EGHamp. Black ellipses were omitted from the average age calculation. See text for discussion.

Laser Ablation Inductively Coupled Plasma Mass Spectrometry Analytical Method

For LA-ICP–MS analysis at the JSGL, the freshest, least cracked grains of zircon and titanite were mounted in epoxy and polished. Polished grains were imaged with backscattered electrons (BSE) using a JEOL JSM6610-Lv scanning electron microscope (SEM) to detect phases of growth that may have different ages. Uranium–lead isotopic analyses were conducted using an Agilent Technologies Inc. 7900 ICP–MS and a New Wave Research Inc. NWR193 excimer laser system. Data were collected using spots analyses and were conducted with laser wavelength of 193 nm, fluence of about 4.5 J/cm^2 and frequency of 10 Hz at a rate of 20 µm/s with typical beam diameter of 15 to 30 µm, depending on the sample. Data were collected on ^{88}Sr (10 ms), ^{206}Pb (30 ms), ^{207}Pb (70 ms), ^{208}Pb (10 ms) and ^{238}U (20 ms). Prior to analyses, spots were pre-ablated with a larger beam diameter for 1 s (5 pulses) to clean the surface. Following a 10 s period of baseline accumulation, the laser sampling beam was turned on and data were collected for 20 s followed by a washout period of 10 s.

Laser ablation data were edited and reduced using custom VBA software (UtilLAZ program) written by D.W. Davis. The ^{206}Pb/^{238}U values show increasing fractionation for zircon caused by loss of refractory uranium with increasing penetration depth through the run, whereas the ^{207}Pb/^{206}Pb profile is usually flat. For zircon, ^{88}Sr and ^{232}Th were monitored to detect intersection of the beam with alteration zones or inclusions. Data with high strontium signal and discordance or irregular time resolved profiles were either averaged over restricted time windows or rejected. In some cases, high strontium occurs from ablation of small apatite inclusions that does not significantly affect the U/Pb analysis or age. Laser ablation titanite data were plotted on a Tera–Wasserburg diagram. Average age errors in the text and error ellipses on Figures 10.2A to 10.2C are given at 2 sigma. Data were calculated and plotted using Isoplot (Ludwig 1998, 2003) with the uranium decay constants of Jaffey et al. (1971). For Paleoproterozoic and Archean samples, ^{207}Pb/^{206}Pb ages are more precise than ^{206}Pb/^{238}U ages and are less susceptible to fractionation biases between samples and standards. Therefore, interpreted ages are based on ^{207}Pb/^{206}Pb.

Metapelite Sample

This sample was analyzed using LA-ICP–MS at 2 different laboratories. Detrital zircon data were obtained from the Pacific Centre for Isotopic and Geochemical Research at the University of British Columbia (PCIGR), whereas monazite data, and some detrital zircon data, were obtained from the Mineral Exploration Research Centre Isotope Geochemistry Lab (MERC–IGL) at Laurentian University. Methods used at PCIGR are described in Easton, Marich and Wall (2023) and are not repeated herein.

For the samples analyzed at MERC–IGL, rock chips were prepared and assembled into molds at the Ontario Geological Survey. Following the pouring of epoxy into the molds, the molds were heated to 60ºC in an oven overnight and for 2 hours the next day in a 120ºC oven. Epoxy pucks were then polished and subsequently carbon coated. These pucks were supplied to MERC–IGL for imaging for internal structure using a Tescan Vega 3 field emission SEM. Imaging at MERC–IGL is a three-step process, involving the phase identification of all high-density (BSE bright) phases by automated energy dispersive spectrometry (EDS) analysis, medium (60–100×) magnification, high-resolution BSE and cathodoluminescence (CL) imaging and finally high (200–1000×) magnification, high-resolution BSE and CL imaging of the individual representative grains of interest for spot targeting.

The LA-ICP–MS analyses at MERC–IGL were performed using a Photon Machine Analyte G2 ArF excimer laser, with the ablated aerosol split downstream of the sample cell, so that U/Pb and trace element measurements could be conducted simultaneously. The U/Pb isotope measurements were conducted using a Thermo Scientific™ Neptune Plus multi-collector ICP–MS. The following parameters were used: spot size of 15 µm; fluence rate of 2 J/cm^2; repetition rate of 7 Hz; carrier gases: He (cup) = 0.6 L/min, He (cell) = 0.10 L/min, Ar = 0.725 L/min, N_2 = 0.008 L/min; ablation duration of 30 s; ablation depth of 15 µm; and ablation rate of 0.5 µm/s. For the analytical uncertainty of individual analyses, the within-run variance in the measured ratios for the primary reference material OG1 for zircon and KM03 for monazite and xenotime) was propagated into the measured (internal) uncertainty to obtain the total propagated 2 sigma uncertainty. No additional uncertainty was added to the $^{207}Pb/^{206}Pb$ ages, as the verification reference materials that are consistently analyzed along with the unknowns in the MERC–IGL have no long-term excess variance in their measured $^{207}Pb/^{206}Pb$ values (mean square weighted deviation (MSWD) <1). Multiple verification reference materials were analyzed during each session to ensure accuracy of the U/Pb values and to demonstrate that the propagated uncertainty is adequate to account for dispersion of the measured ratios (i.e., MSWD ≤1 for the reference materials).

URANIUM–LEAD GEOCHRONOLOGY RESULTS

Amphibolite

Two baddeleyite and 3 zircon analyses indicate a primary age by CA-ID-TIMS of 2088±3 Ma for the amphibolite sample (*see* Figure 10.2A). Baddeleyite showed no indication of metamorphic effects, neither on its crystal faces nor in the U/Pb results, suggesting that the deformational event was a relatively low-temperature one.

A probable time of metamorphism has been determined on pale-coloured titanite at *circa* 1800 Ma by LA-ICP–MS (Rochin-Banaga 2024). Colourless titanite selected for LA-ICP–MS was placed into 2 groups: small, clear titanite grains from which an age could not be obtained because of the null content of uranium, and a second group of large-granular grains with dark inclusions. Backscattered electron microscope images showed granular texture and cracks in all grains, which had uranium concentrations between 3 and 9 ppm U. These granular titanite grains were mounted in epoxy, polished and imaged on a SEM. U/Pb analyses showed diverse ages ranging from 1729 Ma to 1828 Ma. A relative probability density plot of $^{207}Pb/^{206}Pb$ ages reveals a resolved age peak at *circa* 1780 Ma (Figure 10.2B).

Minerals such as titanite contain a common lead component so the Tera–Wasserburg diagram is often more appropriate. In this diagram, undisturbed samples analyses that share the same age and initial lead isotopic ratios should be collinear. In the Tera–Wasserburg diagram, the lower intercept of the mixing line gives the age of the radiogenic component, whereas the upper intercept gives the $^{207}Pb/^{206}Pb$ value of the common lead component. Excluding the outliers, the age regression model for the amphibolite sample suggests an age of 1789±38 Ma (2δ, MSWD = 1.7) with a $^{207}Pb/^{206}Pb$ value of the initial common lead component of 0.950 (Figure 10.2C). The $^{207}Pb/^{206}Pb$ value of the initial common lead component for an age of 1800 Ma is 0.985 as predicted by the lead evolution model for average crust of Stacey and Kramers (1975). The $^{207}Pb/^{206}Pb$ ages of 16 spots scatter within error, resulting in an average age, using the $^{207}Pb/^{206}Pb$ ratio of the initial common lead component from Stacey and Kramers (1975), of 1806±11 Ma (2δ, MSWD = −1.8). This age agrees, within error, with the age regression model, but the error is smaller because the upper intercept is anchored to a “known value”, even though this might not be as accurate as the free-fit regression model.

Metapelite

For the detrital zircon grains analyzed at PCIGR, of the grains that were less than 5% discordant (94 of 122), Geon 26 grains (62 of 94) were much more abundant than Geon 27 grains (17 of 94), a feature characteristic of sandstones from the Elliot Lake and Hough Lake groups of the Huronian Supergroup (Easton 2019). Peaks are present at *circa* 2930, 2881, 2830, 2790, 2730, 2705 Ma and

2575-2590 Ma with the youngest grains at 2407.2 Ma and 2370.6 Ma. Zircons analyzed at MERC–IGL showed a similar relationship, with a peak at 2671±1.3 Ma (26 of 60 grains). Monazite analyzed at MERC-IGL revealed 2 population peaks: 1761±2.5 Ma and 1747±1.9 Ma (J.H. Marsh, Mineral Exploration Research Centre Isotope Geochemistry Lab, Laurentian University, written communication, 2024).

DISCUSSION

The metamorphic ages from both the amphibolite and the metapelite samples confirm that the metamorphism represents a previously undocumented event in the Southern Province that is not associated with either of the Blezardian or Penokean orogenies. Furthermore, the emplacement age of 2088±3 Ma for the amphibolite is distinctly younger than the ages on the Marathon dike swarm (2101 to 2121 Ma: Halls, Stott and Davis 2005) that occur in the Southern and southern Superior provinces. As such, it represents a newly recognized magmatic event in Ontario.

Mafic Magmatism at *Circa* 2090 Ma

Although mafic magmatism at *circa* 2090 Ma has not been reported previously in Ontario, it has been described from both the Wyoming and Baltic cratons, which were in close proximity to the Superior Craton at *circa* 2090 Ma (e.g., Ernst and Bleeker 2010, their Figure 8). In Wyoming, these include a metagabbro plug emplaced at 2092±9 Ma (Premo and Van Schmus 1989) and the Bennett Creek mafic sill emplaced at 2094.3±1.6 Ma (Mammone et al. 2022), both of which were intruded into the Deep Lake Group of the Snowy Pass Supergroup (equivalent to the Elliot Lake and Hough Lake groups of the Huronian Supergroup). Ages on possible correlative mafic intrusions in Finland are less precise, mainly based on Nd–Sm isochrons or older generation LA-ICP–MS ages, but they do record a distinct mafic magmatic event between 2100 and 2050 Ma related to extensional break-up of Baltica (Nironen 2017; Huhma et al. 2018; and references therein), confirming that Walford roadcut amphibolite is part of a widespread magmatic event, including the Marathon dike swarm, that occurred along the southern margin of the Wyoming, Superior and Baltic cratons at *circa* 2090 Ma.

Metamorphism During Geon 17

The titanite ages from the amphibolite and the monazite ages from the metapelite suggest the presence of at least 2 distinct metamorphic events in the Walford belt: an older event between *circa* 1800 and 1760 Ma and a somewhat younger event at *circa* 1750 to 1740 Ma (Table 10.1). Only the younger population may be related to emplacement of the Cutler granite, as discussed below. Work on establishing the metamorphic conditions present during each of the 2 events is ongoing.

Both events are younger than the peak of metamorphism (*circa* 1835 Ma) for the Penokean Orogeny in the United States (Holm et al. 2001; Zi et al. 2022); however, multiple metamorphic events between 1800 and 1680 Ma have been reported from high-grade schist and paragneiss sequences in the Wyoming craton in Utah (Yonkee 2024) and Wyoming (Whitmeyer and Karlstrom 2007), suggesting that the metamorphism observed in the Walford belt rocks may be part of a broader regional deformational event along the southern margin of the Wyoming and Superior cratons. Both metamorphic events are older than the Yavapai orogeny (1710–1680 Ma: Whitmeyer and Karlstrom 2007).

The older titanite and monazite ages from the metapelite sample are consistent with metamorphic ages on monazite and xenotime from 5 separate iron formations in Michigan (Rasmussen et al. 2016), as well as 3 electron microprobe (EMPA) $^{207}Pb/^{206}Pb$ ages from the Walford belt in Ontario (Piercey, Schneider and Holm 2007) (*see* Table 10.1).

Table 10.1. Argon–argon (Ar/Ar) hornblende and mica ages, electron microprobe $^{207}Pb/^{206}Pb$ monazite and xenotime ages, and LA-ICP–MS titanite and monazite ages from the Spragge to Massey area and from the Marquette Range Supergroup in Michigan.

Age (in Ma)	Error (in Ma)	Mineral	Method	Comment	Source
1810–1760 Ma Metamorphism					
1810	10	Monazite	EMPA	N=14	Rasmussen et al. (2016)
1806	11	Titanite	LA-ICP–MS	Amphibolite sample	This study, Rochin-Banaga (2024)
1803	11	Monazite	EMPA	Sample CLR-13, altered mica schist, Mississagi Formation, near the Eden Lake batholith, high Y, low Th cores, 18 spots	Piercey, Schneider and Holm (2007)
1796	17	Monazite	EMPA	N=13	Rasmussen et al. (2016)
1779	9	Xenotime	EMPA	N=10	Rasmussen et al. (2016)
1774	8	Monazite	EMPA	Sample 17-01, greenschist-facies biotite schist, McKim Formation adjacent to the Cutler granite; 37 of 43 spots, 5 grains	Piercey, Schneider and Holm (2007)
1766	4	Monazite	EMPA	N=37	Rasmussen et al. (2016)
1761	2.5	Monazite	LA-ICP–MS	Metapelite sample	This study, Marsh (2024)
1761	3	Monazite	EMPA	N=50	Rasmussen et al. (2016)
1760	3	Monazite	EMPA	Sample 17-02, amphibolite facies garnet-biotite schist, McKim Formation near the Cutler granite; 86 spots, 8 grains	Piercey, Schneider and Holm (2007)
<1750 Ma Metamorphism					
1747	1.9	Monazite	LA-ICP–MS	Metapelite sample	This study, Marsh (2024)
>1704 <1744		Zircon	LA-ICP–MS	Granite dike cutting Pecors Formation	Raharimahefa, Lafrance and Tinkham (2014)
1740	4	Monazite	EMPA	Sample 17-04, amphibolite-facies garnet-biotite-muscovite schist, McKim Formation, 4 km northwest of the Walford roadcut; 79 spots, 5 grains	Piercey, Schneider and Holm (2007)
1732	3	Hornblende	Ar/Ar plateau	Sample 17C, gabbro, adjacent to the Cutler granite	Piercey, Schneider and Holm (2007)
1714	11	Monazite	EMPA	Sample CLR-13, altered mica schist, Mississagi Formation, near the Eden Lake pluton, low Y rims, 22 spots	Piercey, Schneider and Holm (2007)
<1450 Ma Metamorphism					
1432	6	Muscovite	Ar/Ar plateau	Sample 17-04, garnet-biotite-muscovite schist, McKim Formation, 4 km northwest of the Walford roadcut	Piercey, Schneider and Holm (2007)

Abbreviations: EMPA, electron microprobe analysis; LA-ICP–MS, laser ablation inductively coupled plasma mass spectrometry.

The age of *circa* 1747 Ma from the Walford roadcut metapelite is similar to the ages reported for the Cutler granite (*circa* 1740 Ma, titanite: Davidson, van Breemen and Sullivan 1992; 1753±18 Ma, zircon: W. Bleeker, Geological Survey of Canada, written communication, 2024; *see* Figure 10.1) and the Eden Lake granite (1743±3 Ma, monazite: Sullivan and Davidson 1993; 1744±29 Ma, zircon: Raharimahefa, Lafrance and Tinkham 2014) approximately 25 km south of Sudbury. Both plutons occur northwest of the more voluminous Killarney Magmatic Belt, which is transected by the Grenville Front and which underlies much of the northern Grenville Province in Ontario (e.g., Easton 2014; Slagstad et al. 2024). Plutonism in the Killarney Magmatic Belt ranges from 1754 to 1736 Ma (Easton 2014; Slagstad et al. 2024; Easton and Kamo, this volume). Metamorphic ages between 1744 and 1704 Ma have been reported from the McKim Formation within the Walford belt by Piercey, Schneider and Holm (2007) and Raharimahefa, Lafrance and Tinkham (2014) (*see* Table10.1).

The Murray Fault

Previous researchers have suggested that the Huronian Supergroup rocks were buried to mid-crustal levels south of the Murray fault as a result of a collisional event typically assigned to the Penokean orogeny (e.g., Bennett, Dressler and Robertson 1991; Zolnai, Price and Helmstaedt 1984). This burial to mid-crustal levels resulted in tectonic thickening by folding, with an overriding allochthonous terrane subsequently leading to ductile deformation and high-grade metamorphism.

An unexplained aspect of the deep burial model of Zolnai, Price and Helmstaedt (1984) is the presence of the highest metamorphic grade rocks immediately adjacent to the Murray fault. Jackson (1993) suggested a more complex history for the Massey to Walford area, with the main foliation development occurring during 2 periods: prior to peak metamorphism and during peak metamorphism. This was followed by the development of east-northeast- and west-northwest-striking faults, folds, and an axial-planar crenulation cleavage that were superimposed upon the early mica foliation and folds. The east-northeast- and west-northwest-striking folds are those shown commonly on the township-scale geological maps of the Walford belt (Jackson 1993). If Jackson's (1993) interpretation is correct, then the main foliation development may have been coincident with the *circa* 1800 to 1760 metamorphic event, with the superimposed faults, folds and cleavage perhaps coincident with the *circa* 1747 Ma event.

Regardless, the data presented herein and in Bleeker et al. (2023) suggest that the rock package in the Walford belt has a different, distinct, magmatic, deformational and metamorphic history compared to the Huronian Supergroup rocks located to the north and to the south of the Walford belt. Fully understanding the origin of the Walford belt rocks, and the history of the Murray fault, will likely require examination of the tectonic history along the entire length of the southern margin of the Wyoming, Superior and Baltic cratons during the Paleoproterozoic, not just additional work in Ontario.

SUMMARY

The following conclusions arise from this reconnaissance study of the Walford belt.

- The Walford belt consists of a distinct package of rocks that includes the May Township mafic sills emplaced at *circa* 2260 Ma, mafic dikes emplaced at *circ*a 2090 Ma, and which was subjected to middle amphibolite-facies metamorphism at *circa* 1800 to 1760 and *circa* 1747 Ma.
- The Walford belt rocks have similarities with magmatic and deformational events that occurred in both the Wyoming and Baltic cratons. Rocks of the Walford belt may also be present east of the Grenville Front in the Wanup area south of Sudbury (Easton 2023) and possibly elsewhere in the Grenville Province in Ontario, north of the French River.
- The distinctive nature and metamorphic history of the Walford belt rock package suggests that the Murray fault may be a much more significant crustal structure than has been previously recognized. Consequently, more work to understand the history of the Walford belt and the evolution of the southern margin of the Superior Craton south of the Murray fault is warranted.

ACKNOWLEDGMENTS

J.E. Chartrand and P. Gervais assisted in the production of Figure 10.1. S.L. Kamo and P. Gervais produced Figure 10.2.

REFERENCES

Bennett, G.B., Dressler, B.O. and Robertson, J.A. 1991. The Huronian Supergroup and associated intrusive rocks; Chapter 14 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.549-591.

Bleeker, W., Kamo, S.L., Easton, R.M. and Davis, D.W. 2023. New mafic sill complex identified in the lower Huronian Supergroup succession: The May Township sills; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.14-1 to 14-13.

Davey, S., Bleeker, W., Kamo, S[.L.], Davis, D.[W], Easton, [R.]M. and Sutcliffe, R.H. 2019. Ni-Cu-PGE potential of the Nipissing sills as part of the ca. 2.2 Ga Ungava large igneous province; *in* Targeted Geoscience Initiative: 2018 Report of Activities; Geological Survey of Canada, Open File 8549, p.403-419.

Davidson, A., van Breemen, O. and Sullivan, R.W. 1992. *Circa* 1.75 Ga ages for plutonic rocks from the Southern Province and adjacent Grenville Province: What is the expression of the Penokean orogeny?; *in* Radiogenic Age and Isotopic Studies: Report 6, Geological Survey of Canada, Paper 92-2, p.107-118.

Easton, R.M. 2014. Geology and mineral potential of the Nepewassi domain, Central Gneiss Belt, Grenville Province; *in* Summary of Field Work and Other Activities, 2014, Ontario Geological Survey, Open File Report 6300, p. 16-1 to 16-12.

——— 2019. What do detrital zircon studies of the Huronian Supergroup tell us? An analysis of all published data; abstract *in* 65th Institute on Lake Superior Geology, Proceedings, v.65, pt.1, p.38-39.

——— 2023. Geology of the Grenville Front Tectonic Zone near Sudbury, northeastern Ontario: An update; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.18-1 to 18-7.

Easton, R.M., Marich, A.S. and Wall, C.J. 2023. Geochronological study of a saprolite atop the Grenvillian Mulock pluton near Redbridge, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.17-1 to 17-7.

Ernst, R. and Bleeker, W. 2010. Large Igneous Provinces (LIPs), giant dyke swarms, and mantle plumes: Significance for break-up events within Canada and adjacent regions from 2.5 Ga to the present; Canadian Journal of Earth Sciences, v.47, p.695-739.

Gerstenberger, H. and Haase, G. 1997. A highly effective emitter substance for mass spectrometric Pb isotope ratio determinations; Chemical Geology, v.136, p.309-312.

Halls, H.C., Stott, G.M. and Davis, D.W. 2005. Paleomagnetism, geochronology and geochemistry of several Proterozoic mafic dike swarms in northwestern Ontario; Ontario Geological Survey, Open File Report 6171, 59p.

Holm, D.K., Schneider, D.A., O'Boyle, C., Hamilton, M.A., Jercinovic, M.J. and Williams, M.L. 2001. Direct timing constraints on Paleoproterozoic metamorphism, southern Lake Superior region: Results from SHRIMP and EMP U-Pb dating of metamorphic monazites; abstract *in* Geological Society of America, Abstracts with Program, v.33, no.6, p.A-401.

Huhma, H., Hanski, F., Kontinen, A., Vuollo, J., Mänttäri, I. and Lahaye, Y. 2018. Sm-Nd and U-Pb isotope geochemistry of the Palaeoproterozoic mafic magmatism in eastern and northern Finland; Geological Society of Finland, Bulletin 405, 150p.

Jackson, S.L. 1993. Structural styles in the Aberdeen and Massey–Webbwood areas of the Southern Province; *in* Canadian Tectonics Group, Fall Workshop and Field Trip, October 15–17, 1993, program with abstracts and field guide, p.23 (unnumbered), available from www.canadiantectonicsgroup.ca/workshops.html. [accessed October 1, 2024]

Jaffey, A.H., Flynn, K.F., Glendenin, L.E., Bentley, W.C. and Essling, A.M. 1971. Precision measurement of half-lives and specific activities of ^{235}U and ^{238}U; Physical Review, Part C, v.4, p.1889-1906.

Krogh, T.E. 1973. A low contamination method for hydrothermal decomposition of zircon and extraction of U and Pb for isotopic age determinations; Geochimica et Cosmochimica Acta, v.37, p.485-494.

Krogh, T.E., Corfu, F., Davis, D.W., Dunning, G.R., Heaman, L.M., Kamo, S.L., Machado, N., Greenough, J.D. and Nakamura, E. 1987. Precise U-Pb isotopic ages of diabase dykes and mafic to ultramafic rocks using trace amounts of baddeleyite and zircon; *in* Mafic Dyke Swarms, Geological Association of Canada, Special Paper 34, p.147-152.

Krogh, T.E., Davis, D.W. and Corfu, F. 1984. Precise U-Pb zircon and baddeleyite ages for the Sudbury Structure; *in* Geology and Ore Deposits of the Sudbury Structure, Ontario Geological Survey, Special Volume 1, p.431-446.

Ludwig, K.R. 1998. On the treatment of concordant uranium-lead ages; Geochimica et Cosmochimica Acta, v.62, p.665-676.

——— 2003. User's manual for Isoplot 3.00: A geochronological toolkit for Microsoft® Excel®; Berkeley Geochronology Center, Special Publication No. 4, 71p.

Mammone, N., Bekker, A., Chamberlain, K. and Kuznetso, A.B. 2022. Testing the early Paleoproterozoic connection of the Superior and Wyoming cratons with geochronology and geochemistry; Precambrian Research, v.381, article 106818, 29p. doi.org/10.1016/j.precamres.2022.106818

Mattinson, J.M. 2005. Zircon U-Pb chemical abrasion ("CA-TIMS") method: Combined annealing and multi-step partial dissolution analysis for improved precision and accuracy of zircon ages; Chemical Geology, v.220, p.47-66.

Nironen, M. 2017. Guide to the geological map of Finland – Bedrock 1:1 000 000; *in* Bedrock of Finland at the Scale 1:1 000 000 – Major Stratigraphic Units, Metamorphism and Tectonic Evolution, Geological Survey of Finland, Special Paper 60, p.41-75.

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Piercey, P., Schneider, D.A. and Holm, D.H. 2007. Geochronology of Proterozoic metamorphism in the deformed Southern Province, northern Lake Huron region, Canada; Precambrian Research, v.157, p.127-143.

Premo, W. and Van Schmus, W. 1989. Zircon chronology of Precambrian rocks in southeastern Wyoming and northern Colorado; *in* Proterozoic Geology of the Southern Rocky Mountains, Geological Society of America, Special Paper 235, p.13-32.

Raharimahefa, T., Lafrance, B. and Tinkham, D.K. 2014. New structural, metamorphic, and U-Pb geochronological constraints on the Blezardian orogeny and Yavapai orogeny in the Southern Province, Sudbury, Canada; Canadian Journal of Earth Sciences, v.51, p.750-774.

Rasmussen, B., Zi, J-W., Sheppard, S., Krapež, B. and Muhling, J.R. 2016. Multiple episodes of hematite mineralization indicated by U-Pb dating of iron-ore deposits, Marquette Range, Michigan, USA; Geology, v.44, p.547-550. doi.org/10.1130/G37783.1

Robertson, J.A. 1975. Victoria and Salter townships, District of Sudbury; Ontario Department of Mines, Map 2308, scale 1:31 680.

Rochin-Banaga, H. 2024. Report on U-Pb LA-ICPMS geochronology for the Ontario Geological Survey, Bedrock Mapping Projects, Ontario 2023–2024, Part 3; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, University of Toronto, Toronto, Ontario, 29p.

Slagstad, T., Easton, R.M., Huyskens, M. and Culshaw, N. 2024. Complementarity of Lu–Hf isotopes from detrital and igneous zircon: An example from the Central Gneiss Belt, Grenville Province, Ontario; Canadian Journal of Earth Sciences, v.61, 19p., available online June 10, 2024. doi.org/10.1139/cjes-2024-0017 [accessed November 27, 2024]

Stacey, J.S. and Kramers, J.D. 1975. Approximation of terrestrial lead isotope evolution by two stage model; Earth and Planetary Science Letters, v.26, p.207-221.

Steiger, R.M. and Jäger, E., compilers. 1977. Subcommission on Geochronology: Convention on the use of decay constants in geo- and cosmochronology; Earth and Planetary Science Letters, v.36, p.359-362.

Sullivan, R.W. and Davidson, A. 1993. Monazite age of 1747 Ma confirms post-Penokean age of the Eden Lake Complex, Southern Province, Ontario; *in* Radiogenic Age and Isotopic Studies, Report 7, Geological Survey of Canada, Paper 93-2, p.45-48.

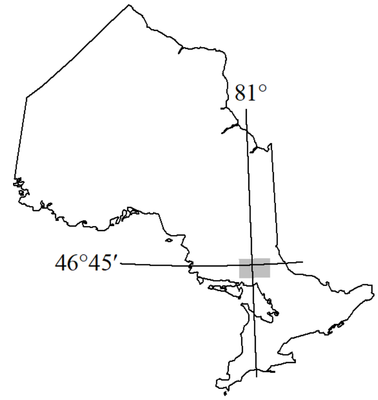
Whitmeyer, S. and Karlstrom, K.E. 2007. Tectonic model for the Proterozoic growth of North America; Geosphere, v.3, no.4, p.220-259. doi.org/10.1130/GES00055.1

Yonkee, A. 2024. Petro-tectonic analysis of the Farmington Canyon Complex, Utah: Implications for Paleoproterozoic rifting of Superia and assembly of Laurentia; abstract *in* Virtual Seminars in Precambrian Geology, April 25, 2024., Presentation available from https://sites.google.com/ucr.edu/vs-pg/home. [accessed July 5, 2024]

Zi, J-W., Sheppard, S., Muhling, J.R. and Rasmussen, B. 2022. Refining the Paleoproterozoic tectonothermal history of the Penokean Orogen: New U-Pb age constraints from the Pembine-Wausau terrane, Wisconsin, USA; Geological Society of America, Bulletin, v.134, p.776-790.

Zolnai, A.I., Price, R.A. and Helmstaedt, H. 1984. Regional cross-section of the Southern Province adjacent to Lake Huron, Ontario: Implications for the tectonic significance of the Murray fault zone; Canadian Journal of Earth Sciences, v.21, p.447-456.

11. Projects SO-22-003, NE-24-005, AS-19-002. Geoscience Studies in the Sudbury Area, Northeastern Ontario



R.M. Easton[1] and S.L. Kamo[2]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, Ontario, P3E 6B5
[2]Jack Satterly Geochronology Laboratory, Department of Earth Sciences, University of Toronto, Toronto, Ontario M5S 3B1

INTRODUCTION

The first author has been involved in several mapping projects in the Sudbury area since 2022. This article briefly summarizes some of the results from laboratory and field studies conducted in 2024 related to 3 of these projects. Figure 11.1 shows the location of the study areas.

PROJECT SO-22-003

To fill information gaps on the 1:50 000 scale geological compilation map of the Sudbury area of Ames et al. (2005), a mapping project, focussed on the area around Wanup (*see* Figure 11.1), was initiated in September 2021 (Easton 2022a, 2022b, 2023a, 2023c). Access to this study area is provided by highways 69 and 537, Estaire Road (old Highway 69) and several local roads. The study area is underlain by rocks of the Grenville Front tectonic zone and the Nepewassi domain of the Grenville Province.

An important aspect of this mapping project has been to understand the geological history of the study area by the use of geochemistry and geochronology. The reader is referred to Easton (2022b, 2023c) for more detailed geological summaries of the study area and geochemical results. In this article, a listing of new geochronological results is presented, which, in conjunction with data presented in Slagstad et al. (2024), demonstrate that Killarney Magmatic Belt rocks are abundant throughout Nepewassi domain (Table 11.1). These new data also spurred examination of the Badgerow complex (Lumbers 1974, 1975), located east of the Wanup area, north of the community of Verner.

Geological Overview

KILLARNEY MAGMATIC BELT

The Killarney Magmatic Belt crops out west of the Grenville Front, and consists mainly of intrusive rocks of granodiorite, diorite and granite composition (cf. van Breemen and Davidson 1988), emplaced between 1749 and 1742 Ma (*see* Table 11.1). Volcanic rocks are present with the intrusive rocks and are interpreted as coeval with caldera development during Killarney magmatism (van Breemen and Davidson 1988). Granodiorite and diorite intrusions are slightly older than the granitic intrusions (*see* Table 11.1). West of the Grenville Front, the Chief Lake Granite (*circa* 1465 Ma), as well as granite pegmatite dikes of similar age, cut the older intrusive rocks of the Killarney Magmatic Belt (*see* Table 11.1).

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.11-1 to 11-16.

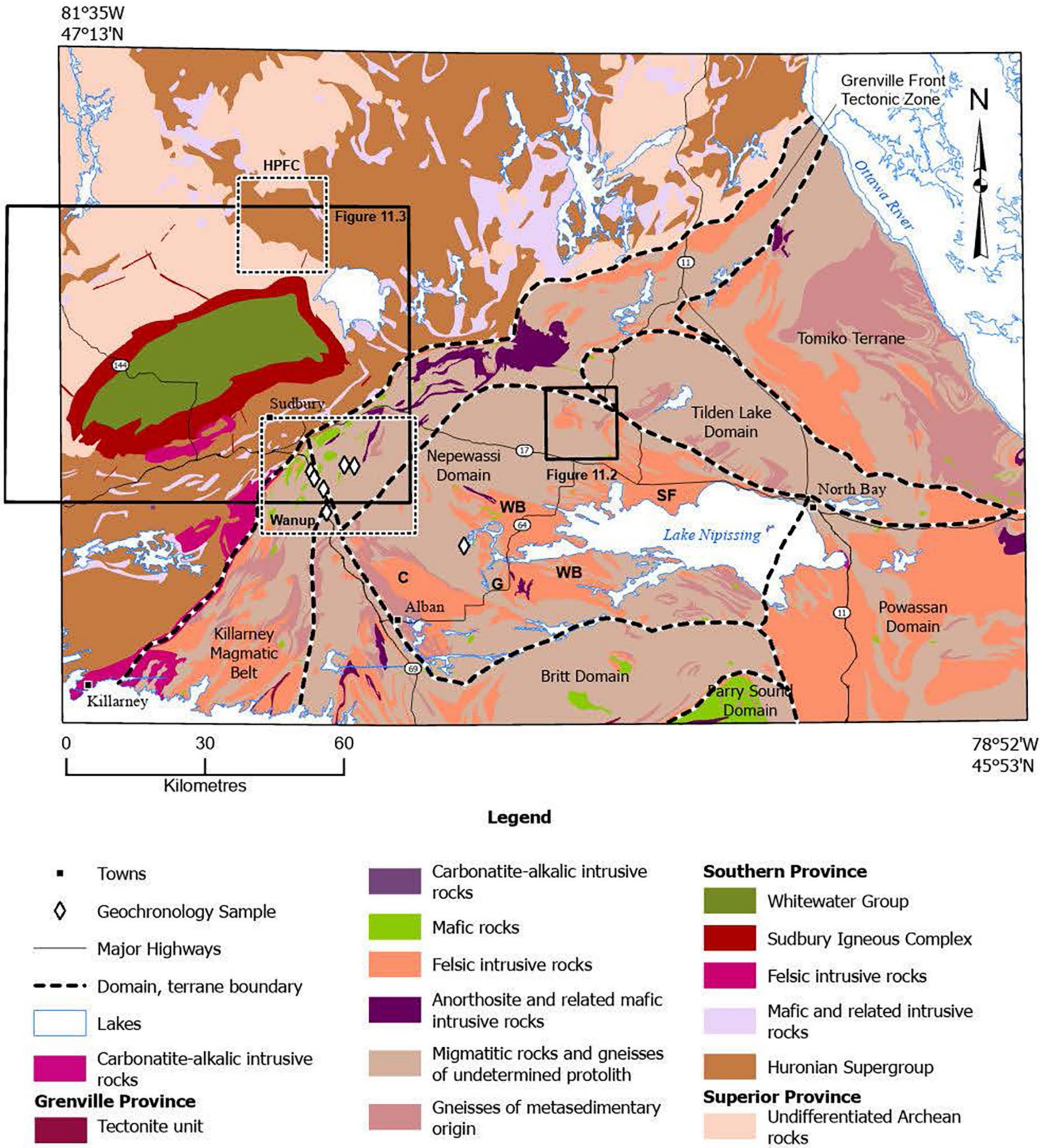


Figure 11.1. Geology of the northern Central Gneiss Belt of the Grenville Province and the Grenville Front region in Ontario. Locations of Figures 11.2 and 11.3 indicated by solid-line boxes; mapping areas described in this article are indicated by dashed-line boxes. Geochronology sample locations discussed in the text are also shown. Abbreviations: C, Cosby pluton; G, gabbro body on Highway 64; HPFC, Hutton–Parkin–Fraleck–Creelman townships; SF, Sturgeon Falls batholith; WB, West Bay batholith. Figure *modified from* Easton (1992, p.755), Easton (2014) and Ontario Geological Survey (2011).

Table 11.1. Summary of geochronological data for Killarney area magmatic rocks, the Grenville Front tectonic zone and the Nepewassi domain.

Age (in Ma)	Unit	Comment	U/Pb Method	Source
Killarney Area Magmatic Rocks				
$1749^{+12}/_{-8}$	Biotite granodiorite	North of Chief Lake granite	TIMS zircon	Davidson and van Bremen (1994)
1747±3	Granodiorite	Eden Lake complex	TIMS monazite	Sullivan and Davidson (1993)
1744±29	Granodiorite	Eden Lake complex	LA-ICP–MS zircon	Raharimahefa, Lafrance and Tinkham (2014)
1704±13	Granitic dike	Cuts fabric and shear zone in Huronian Supergroup rocks near McFarlane Lake	LA-ICP–MS zircon	Raharimahefa, Lafrance and Tinkham (2014)
1596±39	Granitic dike	Cuts fabrics in Eden Lake complex	LA-ICP–MS zircon	Raharimahefa, Lafrance and Tinkham (2014)
$1746^{+16}/_{-6}$	Granodiorite	Cutler batholith	TIMS zircon	Davidson, van Breemen and Sullivan (1992)
1742±1.4	Granite	Killarney granite	TIMS zircon	van Breemen and Davidson (1988)
1464±2	Granite	Chief Lake granite	TIMS zircon	Davidson and van Bremen (1994)
1467±18	Granite	Chief Lake granite	LA-ICP–MS zircon	Raharimahefa, Lafrance and Tinkham (2014)
1429	Pegmatite dike	South of GF, Chief Lake area	TIMS zircon	Krogh (1994)
1447	Pegmatite dike	South of GF, Chief Lake area	TIMS titanite	Krogh (1994)
1464	Pegmatite dike	South of GF, Chief Lake area	TIMS monazite	Krogh (1994)
Grenville Front tectonic zone, east of Wanapitei River				
1746.4±3.3	Diorite dike	GFTZ, 21RME-095	CA-ID-TIMS zircon	This study, Kamo (2024)
$1746^{+12}/_{-6}$	Quartz monzonite dike	Wanapitei complex, cuts metagabbro	TIMS zircon	Davidson, p.39 *in* Easton, Davidson and Murphy (1999)
1707±17	Quartz monzonite dike	Wanapitei complex, cuts metagabbro	LA-ICP–MS zircon	Rousell et al. (2012)
$1746^{+6}/_{-5}$, 996	Hornblende metanorite	Wanapitei complex, lower intercept age of metamorphism	TIMS zircon	Prevec (1995, 1992)
1735±3	Garnet metagabbro	Wanapitei complex	LA-ICP–MS zircon	Rousell et al. (2012)
1725±6 1614±9	Monzogranite	GFTZ, 21RME-075	LA-ICP–MS zircon	This study, Rochin-Banaga (2024)
1694±7, 1640±10	Garnetiferous mafic dike	Wanapitei complex, cuts other units, 2 populations	LA-ICP–MS zircon	Rousell et al. (2012)
Grenville Front tectonic zone, west of Wanapitei River				
1471±3	Calc-silicate gneiss	GFTZ, 21RME-067	CA-ID-TIMS zircon	This study, Kamo (2024)
1397±11, 1385±27 1391±24	Calc-silicate gneiss	GFTZ, 21RME-067	CA-ID-TIMS zircon, zircon, titanite	This study, Kamo (2024)
1746.5±1.8 1393±3	Garnet-bearing leucosome	GFTZ-Nepewassi domain boundary zone; 21RME-080	CA-ID-TIMS, zircon ID-TIMS monazite	This study, Kamo (2023, 2024)
1429±8	Pegmatite dike	GFTZ, dike P1	LA-ICP–MS zircon	This study, data from Pfister (2023)
1430±9	Pegmatite dike	GFTZ, dike P3	LA-ICP–MS zircon	This study, data from Pfister (2023)
1458±7	Pegmatite dike	GFTZ, dike P47	LA-ICP–MS monazite	This study, data from Pfister (2023)

Table 11.1. *continued*.

Age (in Ma)	Unit	Comment	U/Pb Method	Source
Nepewassi Domain				
1754±2	Diorite pluton	Highway 535, Cherriman Township, 22RME-1011	CA-ID-TIMS zircon	This study, Kamo (2024)
1755±9	Tonalite gneiss	Highway 64, sample 200458	LA-ICP–MS zircon	Slagstad et al. (2024)
1743±10	Grey migmatitic gneiss	Highway 64, sample 200459	LA-ICP–MS zircon	Slagstad et al. (2024)
1739±4	Estaire pluton	Nelson Road near Estaire, 21RME-022	CA-ID-TIMS zircon	This study, Kamo (2023)
1738±6	Estaire pluton	Nelson Road near Estaire	LA-ICP–MS zircon	This study, data from Pfister (2023)
1744±11	French River “paragneiss”	Near western boundary of Cosby subdomain, 2 sample sites, single population	TIMS zircon	Krogh (1989)
1741±7 1615±34	Quartzite, upper plate	Sample NEP434	LA-ICP–MS zircon	Culshaw et al. (2023)
1736±5	Mafic dike	Estaire Road, dike cuts metaquartzite, 21RME-102B	CA-ID-TIMS zircon	This study, Kamo (2024)
circa 1700, 1689±16	French River “granite”	Near western boundary of Cosby subdomain, migmatitic, cuts French River “paragneiss”	TIMS zircon, Rb/Sr whole rock	Krogh and Davis (1969, 1972)
1476±4	Cosby pluton	Sample 200462	LA-ICP–MS zircon	Slagstad et al. (2024)
1420	Cosby pluton	Cosby subdomain, no location given	TIMS zircon	Lumbers (1975)
1446±9	Pegmatite dike	Nelson Road, dike P48	LA-ICP–MS zircon	This study, data from Pfister (2023)
1445±8	Pegmatite dike	Highway 69, dike P51	LA-ICP–MS zircon	This study, data from Pfister (2023)
1443±9	Pegmatite dike	Nelson Road, dike P23	LA-ICP–MS zircon	This study, data from Pfister (2023)
1441±9	Pegmatite dike	Nelson Road, dike P24	LA-ICP–MS zircon	This study, data from Pfister (2023)
1438±8	Pegmatite dike	Nelson Road, dike P53	LA-ICP–MS zircon	This study, data from Pfister (2023)
1425±8	Pegmatite dike	Nelson Road, dike P49	LA-ICP–MS zircon	This study, data from Pfister (2023)
1062±15	French River quartzite	Cosby subdomain, quartzite only had Archean zircons	TIMS monazite	Krogh (1989)
1245±48	Mercer anorthosite	Southern subdomain, 1222±2 Ma *in* Prevec (1992)	TIMS zircon	Prevec (2004, 1992)
1244±100	St. Charles anorthosite	Southern subdomain, 1206±36 Ma *in* Prevec (1993)	SHRIMP zircon	Prevec (2004, 1993)
1236±10	West Bay pluton, monzogranite	Sample 200460	LA-ICP–MS zircon	Slagstad et al. (2024)
2696±10	Tonalite gneiss	NEPS-3	LA-ICP–MS zircon	Culshaw et al. (2023)
2695±20	Tonalite gneiss	NEPS-1	LA-ICP–MS zircon	Culshaw et al. (2023)
2695±11	Quartzite	NEPQ, main population	LA-ICP–MS zircon	Culshaw et al. (2023)
2677±9	Tonalite gneiss	Sample 200457	LA-ICP–MS zircon	Slagstad et al. (2024)
2673±11	Quartzite	NEP493A, main population	LA-ICP–MS zircon	Culshaw et al. (2023)
2678 to 2683	Tonalite, granodiorite	Northern subdomain, range from 7 sample sites	TIMS zircon	Chen, Krogh and Lumbers (1995)
975 to 996	Tonalite, granodiorite	Northern subdomain, age of metamorphism, range from 6 sample sites	TIMS zircon, lower intercept	Chen, Krogh and Lumbers (1995)

Abbreviations: *GF, Grenville Front; GFTZ, Grenville Front tectonic zone; CA-ID-TIMS, chemical abrasion isotope-dilution thermal ionization mass spectrometry; LA-ICP–MS, laser ablation inductively coupled plasma mass spectrometry; SHRIMP, sensitive high-resolution ion microprobe; TIMS, thermal ionization mass spectrometry.*

GRENVILLE FRONT TECTONIC ZONE

As described in detail in Easton (2022b), a linear, north-northwest–trending structure almost coincident with the Wanapitei River divides the study area into 2 parts. East of the Wanapitei River, host migmatitic gneisses are mostly quartzofeldspathic and contain garnet in both melasome and leucosome. Several large ovoid plutonic bodies are present, likely related to the Killarney Magmatic Belt (*circa* 1740 Ma), including the Wanapitei Complex (6 by 2 km). East Bull Lake intrusive suite rocks form larger, more continuous, and better-preserved bodies, including the Red Deer Lake intrusion (11 km long, up to 1 km wide). West of the Wanapitei River, the Grenville Front tectonic zone (GFTZ) is only 8 km wide, and rock units consist mainly of highly strained grey gneisses, typically migmatitic, that form thin, near-continuous belts interlayered with migmatitic amphibolite, amphibolite and garnet amphibolite. These grey gneisses could represent highly strained Archean bedrock (Easton 2022b). Possible metasedimentary units, including schists with aluminosilicate minerals, locally form thin, lenticular, discontinuous bands in the package of highly strained gneissic and amphibolitic rocks. Rocks of the East Bull Lake intrusive suite (*circa* 2475 Ma) are present and form thin, discontinuous units. Sudbury swarm (*circa* 1240 Ma) mafic dikes are large, with strike lengths of 50 to 100 m, but are discontinuous.

NEPEWASSI DOMAIN

To the south, the GFTZ has been overthrust by the Nepewassi domain that contains Killarney Magmatic Belt plutons, some of which are metamorphosed at granulite facies, and lenticular belts of quartzite (*see* Figure 11.1; Easton 2014, 2022b). The Nepewassi domain (Easton 1992) was discriminated from its neighbours on the basis of structural trends and rock types. The Nepewassi domain is underlain by compositionally heterogeneous migmatitic gneisses, many of which are Archean in age (*see* Table 11.1). These migmatitic gneisses have a polycyclic history. Plutonic rocks in the domain form 2 suites that are less deformed than their migmatitic host rocks: an older, granite-monzogranite suite (*circa* 1740 Ma) and a younger, non-migmatitic suite (*circa* 1450 to 1420 Ma), that includes the Cosby pluton (*see* Table 11.1). Near Alban, the Cosby pluton intruded a thick sequence of quartzite, known as the French River quartzite (cf. Lumbers 1975).

Methods and Results

Geochronological results of 3 samples from the GFTZ and 2 from the Nepewassi Domain are discussed below. Geochronological analyses were conducted by S.L. Kamo at the Jack Satterly Geochronology Laboratory at the University of Toronto Department of Earth Sciences (Kamo 2023, 2024). Most of the work was conducted using isotope dilution thermal ionization mass spectrometry (ID-TIMS) on zircon, monazite and titanite; however, 1 sample was examined using laser ablation inductively coupled plasma mass spectrometry (LA-ICP–MS) on zircon (Rochin-Banaga 2024). Full method descriptions and analytical details will be provided in a separate Ontario Geological Survey (OGS) publication that is in preparation.

GRENVILLE FRONT TECTONIC ZONE

21RME-067 Calc-silicate Gneiss, Dill Township

This calc-silicate gneiss sample is interlayered with migmatitic orthogneiss on the west side of Highway 69 (Universal Transverse Mercator (UTM) 510563E, 5138009N, North American Datum 1983 (NAD83), Zone 17). Three individual zircon fragments (each <1 µg) gave concordant results with $^{207}Pb/^{206}Pb$ ages of 1471±3 Ma, 1397±11 Ma and 1385±27 Ma (Kamo 2024). The very low Th/U values (~0.002) in all 3 fragments indicate a probable metamorphic origin. The low precision of the youngest

2 analyses is due to the small amount of material analysed and their low U concentrations. The oldest grain, at 1471 Ma, may indicate the primary age(?) or is a xenocryst. The other 2 zircons are collinear with titanite, which give approximate ages of 1391±24 Ma and 943±23 Ma. The *circa* 1470 Ma age is similar to the timing of granite pluton and granite pegmatite emplacement within the Killarney Magmatic Belt and the GFTZ (*see* Table 11.1), whereas the *circa* 1390 Ma age is similar to that of leucosome development in a migmatitic gneiss (sample 21RME-080) at the Nepewassi domain–GFTZ boundary located only 1 km to the south of where this sample was collected, as reported in Easton (2023c) (*see* Table 11.1).

21RME-075 Gneissic Monzogranite, Cleland Township

The sample is a medium-grained, pink to red, gneissic monzogranite collected on the north side of Red Deer Lake Road south in Cleland Township (UTM 520022E, 5139222N, NAD83, Zone 17). The sample is representative of many similar bodies throughout the GFTZ east of the Wanapitei River that Lumbers (1975) regarded as being of metasedimentary origin. The sample yielded abundant small well-rounded zircon grains with zoning but no clear evidence of rims or cores (Rochin-Banaga 2024). The 107 grains analyzed by LA-ICP–MS are seemingly organized into 3 groups: group 1 has an average age of 1725±6 Ma (42% of analyses), group 2 has an average age of 1614±9 Ma (36% of analyses), and group 3 has an average age of 987±9 Ma (Rochin-Banaga 2024). Groups 1 and 2 have a Th/U value greater than 0.1, suggesting that these are not metamorphic ages, whereas group 3 zircons have a low Th/U value of approximately 0.01, suggesting a metamorphic origin (Rochin-Banaga 2024).

21RME-095 Gneissic Diorite, Cleland Township

This non-migmatitic, medium-grained gneissic diorite was sampled from a roadcut on the north side of Highway 537 in Cleland Township (UTM 517848E, 5139441N, NAD83, Zone 17). This diorite is considered representative of many similar such bodies in Cleland Township, potentially associated with Killarney Belt magmatism (Easton 2023c). Two zircon grains gave $^{207}Pb/^{206}Pb$ ages of 1714±2 Ma (2.5% discordant) and 1705±2 Ma (3.2% discordant) (Kamo 2024). Two single grains of dark brown titanite have $^{207}Pb/^{206}Pb$ ages of 971±5 Ma and 970±23 Ma. If a line is fitted to all 4 results, intercept ages of 1746.4±3.3 Ma and 970±5 Ma are obtained (Kamo 2024). The upper and lower intercept ages are considered a good estimation of the time of diorite formation and later metamorphism, respectively.

NEPEWASSI DOMAIN

21RME-102B Biotite Amphibolite Layer in Quartzite, Secord Township

The amphibolite was sampled from a roadcut on the east side of Estaire Road (old Highway 69) within the northernmost part of the Nepewassi domain (UTM 513333E, 5134250N, NAD83, Zone 17). The amphibolite occurs as layers in quartzite, which may be correlative with the French River quartzite near Alban. Texturally, the sample is more altered than metamorphosed, with chlorite, sericitization of feldspar grains and iron oxide among mica cleavage. Two single zircons and a fraction of 4 small grains were variably discordant from 2.6 to 4.4% and collinear toward 1 Ga. A free-fit line through these points gives intercepts at 1736±16 Ma and 1005±100 Ma (Kamo 2024). If the line is then anchored at 1 Ga, the primary age for the intrusion is 1736±5 Ma (mean square weighted deviation (MSWD) = 0.14), which can be considered a good age estimate for this intrusion (Kamo 2024). This also provides a minimum age for quartzite deposition.

22RME-1011 Medium-grained Gneissic Diorite, Cherriman Township

A sample of this late-tectonic diorite pluton was collected from the east side of Highway 535, just south of the Island in the West Arm of Lake Nipissing (UTM 543697E, 5121981N, NAD83, Zone 17). It is a medium-grained gneissic diorite. Abundant large pale-yellow, irregular-shaped zircon fragments and equant zircon grains, and rare zircon laths, with slight rounding as a result of metamorphism and up to 250 µm in longest dimension, were recovered. Three analyses gave concordant to subconcordant overlapping results. A free-fit line through all grains gives ages of 1753.7±9.7 Ma and 933±600 Ma (Kamo 2024). The $^{207}Pb/^{206}Pb$ age of the oldest zircon is 1748.1±1.6 Ma and is considered a minimum age for the diorite. The weighted mean $^{207}Pb/^{206}Pb$ age of the 3 grains is 1746.1±5.6 but with an MSWD of 7.2, which indicates significant scatter as a result of Grenvillian lead loss. Kamo (2024) suggested that the upper intercept age of 1754±2 Ma, when anchored at the lower intercept age of *circa* 950 Ma, is the best age interpretation for this sample.

DISCUSSION

Four of the 5 new ages reported herein support the previous conjecture by Easton (2014) that Killarney Belt magmatism is more widespread throughout Nepewassi domain than previously documented. In addition, 2 new ages reported by Slagstad et al. (2024), as well as ages on the Estaire pluton reported by Kamo (2023) and Pfister (2023), further expand the known extent of Killarney Belt magmatism in Nepewassi domain, as summarized in Table 11.1. In addition, new ages reported herein and in Slagstad et al. (2024) and Pfister (2023) confirm the widespread occurrence of granite magmatism and pegmatite dike emplacement between 1467 Ma and 1425 Ma in both the GFTZ and the Nepewassi domain, with a possible localized high-grade metamorphic event at *circa* 1390 Ma.

The new data hint at the presence of slight age differences within the GFTZ on either side of the Wanapitei River. So far, no Killarney Magmatic Belt rocks (*circa* 1740 Ma) have been reported in the GFTZ west of the Wanapitei River; however, *circa* 1450 Ma magmatic rocks and *circa* 1390 Ma metamorphic rocks are present (*see* Table 11.1). In contrast, east of the Wanapitei River, Killarney-age rocks are well documented (*see* Table 11.1), and there appears to be evidence for a *circa* 1640 to 1620 Ma metamorphic and/or magmatic event not seen to the west (e.g., Rousell et al. 2012; this study) (*see* Table 11.1). The *circa* 1450 Ma magmatic and the *circa* 1390 Ma metamorphic events have yet to be documented in the GFTZ east of the Wanapitei River.

Badgerow Complex

The Badgerow complex (Lumbers 1975), located in Badgerow and eastern Hugel townships, lies within northern Nepewassi Lake domain of the Grenville Province (Easton 1992) (*see* Figure 11.1). The main part of the complex is roughly circular, approximately 4.5 by 3.5 km in size (Figure 11.2). 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 syenite with less than 5% mafic minerals. Near the eastern margin of the complex on Kipling Road, fine-grained syenite veins crosscut medium-grained gabbro containing relict pyroxene cores rimmed by amphibole. This relationship is similar to that observed in a roadcut on Highway 64 in Hartland Township in Nepewassi domain, east of Noelville (UTM 551321E, 5112388N, NAD83, Zone 17; *see* Figure 11.1, letter G), where a body of medium- to coarse-grained gabbro with relict mineralogy is cut by fine-grained leucogranite. Because of the relatively undeformed nature of the syenitic rocks of the Badgerow complex, the fact that it is the only near-circular pluton in northern Nepewassi domain, and the similarity to the body in southern Nepewassi domain, a syenite from the Badgerow complex was collected for U/Pb geochronology from an outcrop on Kipling Road (UTM 565131E, 5147631N; NAD83, Zone 17, 24RME3047; *see* Figure 11.2).

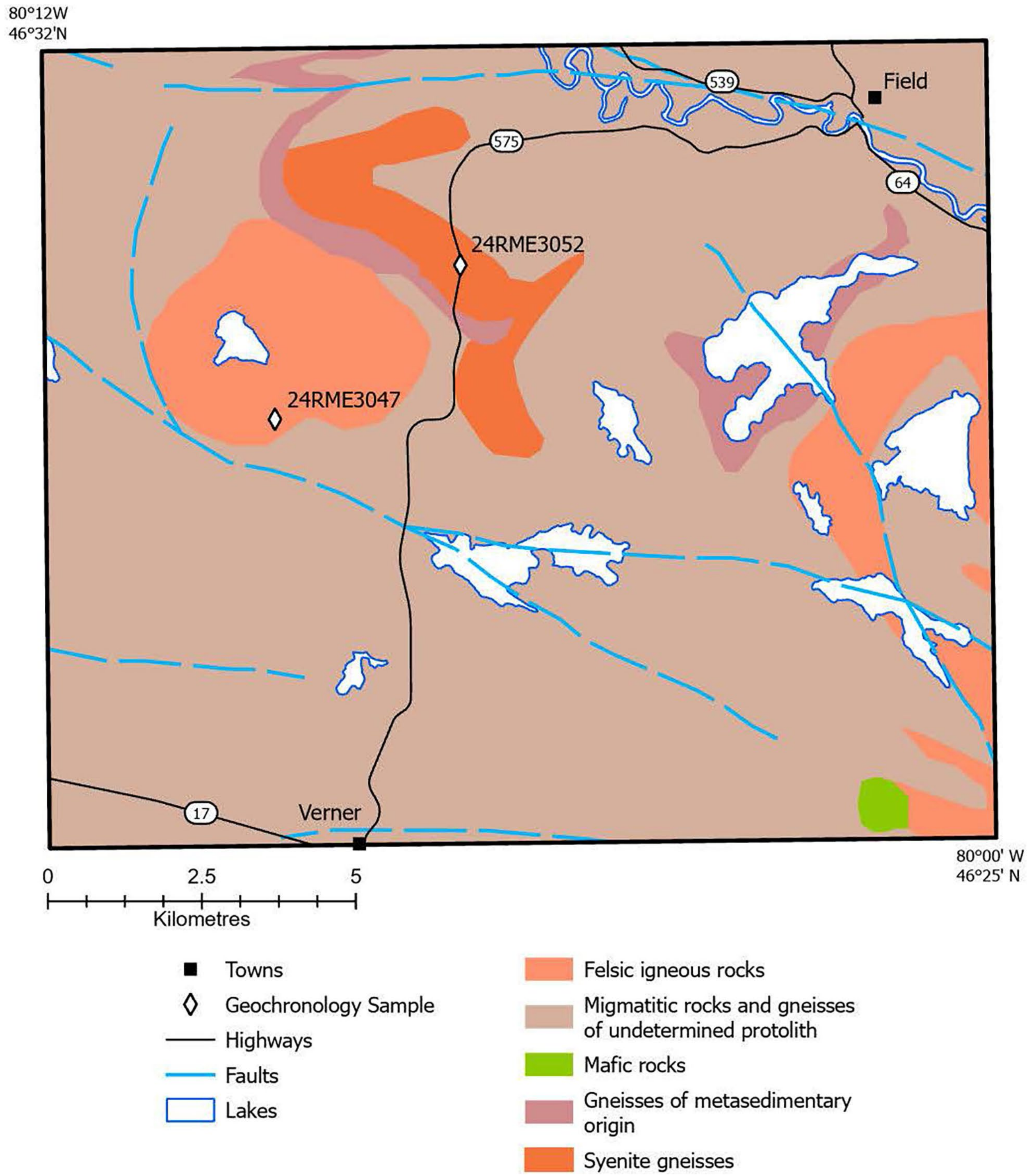


Figure 11.2. Simplified geological map of the Badgerow complex in the Grenville Province north of Verner. Sites sampled for U/Pb geochronology, as discussed in the text, are indicated. Geology *modified from* Ontario Geological Survey (2011).

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 syenite as part of the Badgerow complex (*see* Figure 11.2). This lens is well exposed on Highway 575, and is a medium-grained, slightly greenish, gneissic amphibole syenite. This unit is also much richer in thorium than is the undeformed syenite of the circular part of the Badgerow complex (Table 11.2). Given its mineralogy, and its much greater degree of deformation, it is unclear why Lumbers (1974) included it as part of the Badgerow complex. The gneissic syenite was also sampled for U/Pb geochronology from an outcrop on Highway 575 (UTM 568146E 5150140N, NAD83, Zone 17; 24RME3052; *see* Figure 11.2), because it is likely older than the Badgerow complex, yet it is still younger than its host migmatitic rocks.

PROJECT NE-24-005

Thorium and Uranium Depletion Zone

Hand-held gamma-ray spectrometric measurements made as part of a bedrock mapping program in Totten Township (Carter and Easton, this volume) have identified a large, previously undescribed, zone of equivalent thorium and equivalent uranium depletion in the Archean granitic rocks exposed in the central and eastern parts of Totten Township. This depletion zone is readily visible on airborne gamma-ray spectrometric maps of the Sudbury area, as illustrated for equivalent thorium and potassium–thorium ratio in Figures 11.3A and 11.3B, respectively. This depleted zone is approximately 5 to 7 km wide and occurs all along the western and northern sides of the Sudbury structure (*see* Figure 11.3A). The depletion zone corresponds approximately to the limit of abundant shatter-cone development (Dressler 1984). On the ground, the transition is relatively sharp, occurring over 100 to 250 m. As indicated in Table 11.2, within the depletion zone, equivalent thorium and uranium contents in both the Archean Birch Lake batholith and the Archean Cartier granite are less than half of what they are outside of the depletion zone. Potassium contents are reduced also, but not as markedly (*see* Table 11.2). In the field, there is no difference in physical appearance between rocks located within or outside of the depletion zone.

Meldrum et al. (1997) noted that thorium and uranium contents of their Cartier granite samples did not correlate well with differentiation or solidification indexes, nor with silica or potassium contents, and that the Th/U values showed considerable variation. This variation likely reflects the fact that Meldrum et al. (1997) collected samples from both within, and outside of, the equivalent thorium and equivalent uranium depletion zone. Thus, the geochemical data of Meldrum et al. (1997) are consistent with the field observations from this study.

It is not known if thorium and uranium depletion occurred in the mafic intrusive rocks in central and eastern Totten Township. Generally, the mafic rocks have low thorium and uranium contents (*see* Table 11.2), so any depletion would be harder to discern. This would also be true for potassium, since even if the approximately 15% depletion seen in the granitic rocks were present, it would be insufficient to change the observed differences in potassium content between units such as the East Bull Lake intrusive suite, the Nipissing intrusive suite, the Matachewan dike swam, or the Trill offset dike (*see* Table 11.2).

An unanswered question is whether the prominent radiometric highs in potassium, equivalent thorium (*see* Figure 11.3A), potassium-thorium ratio (*see* Figure 11.3B) and equivalent uranium that occur immediately west and north of the depletion zone represent unaltered background levels in the various rocks units (mainly the Birch Lake batholith and the Cartier granite), or whether potassium, equivalent thorium and equivalent uranium contents in the rock units have increased as a result of deposition of these elements from the adjacent depletion zone.

Table 11.2. Median scintillometer assay-mode values for major rock units in Totten Township and vicinity, the Nipissing intrusive suite, and from the Badgerow complex.

Unit	K (wt %)	K range	U (ppm)	Th (ppm)	Comment
Totten area					
Birch Lake batholith	4.0	3.7-4.8	6.2	34.3	N=14, outside of U-Th depletion zone
Birch Lake batholith	3.4	2.0-4.4	0.9	11.6	N=54, inside U-Th depletion zone
Cartier granite	4.1	3.0-5.9	4.2	49.8	N=21, outside of U-Th depletion zone
Cartier granite	3.3	2.9-4.2	1.1	26.7	N=10, inside U-Th depletion zone
Gneissic granodiorite	2.9	1.4-3.9	1.5	9.9	N-15, Levack gneiss complex, inside U-Th depletion zone
East Bull Lake intrusive suite	0.3	0.0-0.7	0.0	3.1	N=22, leucogabbros locally have higher potassium than do the gabbros
Matachewan dike swarm	0.9	0.5-1.6	0.0	5.8	N=28, plagioclase-phyric dikes
mafic dike, high K	1.6	1.0-2.5	0.0	4.4	N=24, unknown swarm(s)
Trill offset dike	1.9	1.1-2.3	0.2	8.5	N=8
Nipissing sills					
Nipissing intrusive suite	1.0	0.7-1.1	0.5	5.9	N=4, Ertaminger Township
Nipissing intrusive suite	0.4	0.0-0.6	0.0	2.1	N=5, Parkin Township,
Nipissing intrusive suite	0.4	0.2-1.3	0.0	1.6	N= 7, Fraleck Township, higher potassium values (>0.5 wt %) occur only in the coarse-grained upper part of the sill
Grenville Province					
granite	3.6	3.4-3.7	1.6	5.4	N=8, Highway 64, Nepewassi domain
syenite, Badgerow complex	3.7	3.1-3.8	1.2	6.1	N=5, Kipling Road, Nepewassi domain
gneissic syenite	4.5	4.3-5.7	2.9	22.9	N=5, Highway 575, Nepewassi domain

Abbreviation: *K, potassium; N, number; Th, thorium; U, uranium; ppm, parts per million; wt %, weight percent.*
Notes: *multiply K by 1.2046 for K_2O. All K, U and Th data were recorded using an Exploranium™ GR-135G MiniSpec gamma-ray spectrometer, serial number 4885, calibrated on March 25, 2019, using an NaI crystal and software version 501GEO. The instrument was stabilized daily, and data were recorded using the assay mode with a dead-time adjusted 5-minute count time. Quoted accuracy is 0.1% K, 0.4 ppm U, and 0.7 ppm Th for a sample with 2% K, 2 ppm U and 8 ppm Th. Reproducibility, accuracy and precision data for this particular instrument can be found in Easton (2009).*

The thorium and uranium depletion zone also corresponds to an area of total residual magnetic field highs and wormy-textured magnetic highs in the second vertical derivative of the magnetic field (Ontario Geological Survey 2024) that in the past have generally been attributed to the distribution of the Archean Levack gneiss complex. In Totten Township, this pattern is associated with surface exposures of the Birch Lake batholith and the Cartier granite, suggesting that the origin of this zone of magnetic highs might be more complex than previously thought, and may not be wholly diagnostic of the Levack gneiss complex.

The reason why the thorium and uranium depletion zone is not well expressed on the south side of the Sudbury Structure is unclear. It could be because of the presence of the more compositionally heterogeneous Paleoproterozoic Huronian Supergroup (metavolcanic and metasedimentary rocks) which would respond differently to the depletion process. Alternatively, it may be related to the more intense post-Sudbury Impact metamorphism and deformation that the South Range of the Sudbury Structure has undergone.

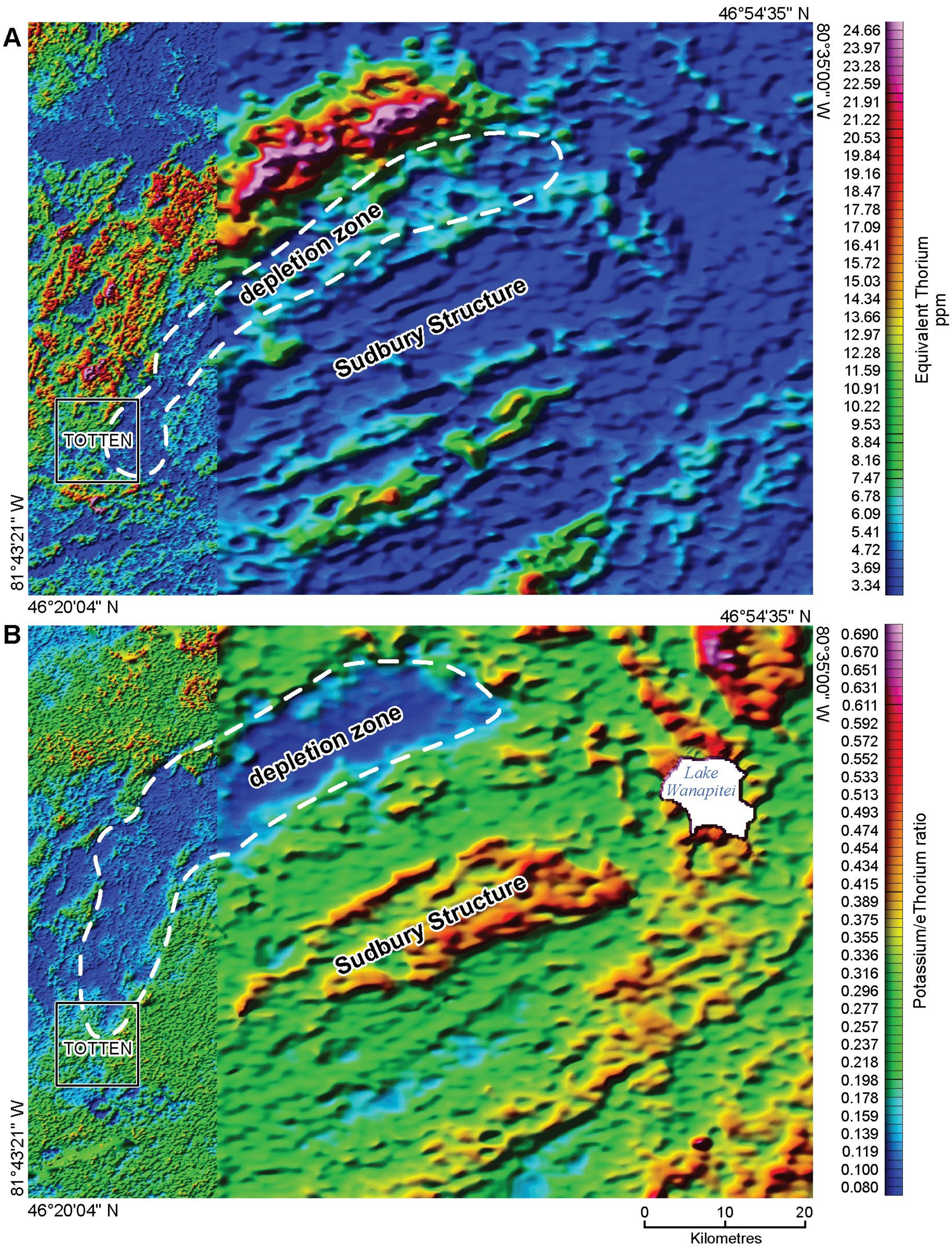


Figure 11.3. Airborne gamma-ray spectrometric data for equivalent thorium for the Sudbury area. Blue colours indicate areas of low thorium content, yellows and reds indicate higher contents. Area of Totten Township is outlined in black. Approximate outline of thorium (**A**) and potassium-thorium ratio (**B**) depletion zones adjacent to the Sudbury Structure is shown by white dashed lines. High-resolution data in the western part of the image are from Ontario Geological Survey (2019a, 2019b). Lower-resolution data *from* Hetu (1989).

EXPLORATION SIGNIFICANCE

The regional significance of the potassium, thorium and uranium depletion zone has yet to be determined. If significant leaching and/or redeposition of these 3 elements has occurred in a wide area around Sudbury (minimum 5 km wide, possibly 15 km wide or more), then it is possible that other elements may also have been mobilized and/or redeposited. Given its proximity to the Sudbury structure and spatial association with the limit of abundant shatter cones, it is likely that this depletion event was related to the Sudbury Impact Event. The Sudbury Impact could have easily superheated fluids in the surrounding host rocks causing dissolution, mobilization and redistribution of numerous elements. How significant this event was in aiding in the creation of mineralized zones in and around Sudbury has yet to be ascertained, but it will be the subject of ongoing study.

PROJECT AS-19-002

A reconnaissance petrographic and geochemical study of magnetic units from the Gowganda Formation was initiated in 2023 (Easton 2023b) to better understand the reason why parts of the Gowganda Formation are magnetic and any potential economic significance of these magnetic units. The next section reports briefly on additional field and laboratory work related to this project conducted in 2024, mostly in the Sudbury area (*see* Figure 11.1, area labelled HPFC). Full details will follow in a separate OGS publication that is in preparation.

Geochemistry and Mineralogy

Total iron contents of the magnetic Gowganda Formation mudstones from the Sudbury area (average magnetic susceptibility values of 16.0 to 48.75 $\times 10^{-3}$ SI units) range from 8.5 to 10.0 weight % Fe_2O_3. Thus, the mudstones are not ferruginous mudstones, which, according to the definition of James (1954), contain 10 to 15 weight % Fe_2O_3.

Total iron contents of the non-magnetic and weakly magnetic (average magnetic susceptibility values of 5.0 to 16.0 $\times 10^{-3}$ SI units) Gowganda Formation mudstones from the Sudbury area range from 5.0 to 7.2 weight % Fe_2O_3. In these less magnetic units, there is no clear correspondence between total iron content (or iron species, i.e., FeO versus Fe_2O_3) and magnetic susceptibility. Apart from total iron content, there do not appear to be any consistent geochemical differences between the magnetic and non-magnetic mudstones.

In the Sudbury area, in Hutton, Parkin and Creelman townships, samples collected north of latitude 46°53′N contain biotite and/or muscovite porphyroblasts and oligoclase, suggesting that they are more metamorphosed (greenschist facies) than samples to the south. The only prior report of this grade of metamorphism in this area comes from Meyn (1971a), who reported andalusite in the Lorrain Formation in Fraleck Township, to the north of Parkin Township. In addition, mudstones north of 46°53′N typically contain magnetite and ilmenite, and sulphide minerals are common. All these samples are non-magnetic or weakly magnetic (average magnetic susceptibility values of 0.5 to 16.0 $\times 10^{-3}$ SI units). In contrast, in the magnetic mudstones, only magnetite is present.

Other Observations

There are many similarities between the bedding characteristics of the Gowganda Formation mudstones present in Hutton, Parkin and Creelman townships and the glaciogenic muds of the Champlain Sea present in the Ottawa area. Thus, depositional models for the Champlain Sea muds proposed by Al-Mufti and Arnott (2023) and Al-Mufti et al. (2022) may be good analogs for how the Gowganda Formation mudstones were deposited.

While mapping in Parkin and Fraleck townships, it was observed that 2 separate Nipissing sills intruded into the Huronian Supergroup are likely high-magnesium sills (>9% MgO) based on their gamma-ray signatures (*see* Table 11.2). This is of exploration significance because the high-magnesium sills are more likely to be mineralized than are the typical Nipissing sills (5–7% MgO) (e.g., Easton and James 1997; Conrod 1989).

The Nipissing sill in Parkin Township was emplaced near the contact between the Espanola and Serpent formations, and Sudbury breccia is widespread along the contacts of the sill. The Nipissing sill in Fraleck Township is much larger in extent than is shown on the map of Meyn (1971b) and is emplaced near the contact between the Gowganda and the Lorrain formations. The sill appears to be facing northward, is approximately 300 m thick, and exhibits the typical internal stratigraphy of Nipissing sills (Lightfoot and Naldrett 1996, p.6).

ACKNOWLEDGMENTS

S.L. Kamo of the Jack Satterly Geochronology Laboratory at the University of Toronto performed or supervised the geochronological work related to Project SO-22-003 and contributed to the writing of that section of the article. As a whole, the article has benefited from discussions with N.T. Carter, M. Duguet and C.A. Gordon, as well as from a technical review by M. Duguet. J.E. Chartrand of the OGS was an excellent field assistant for all 3 projects and prepared figures 11.1 and 11.2 for publication. P. Gervais prepared Figure 11.3 using data supplied by D.R.B. Rainsford to the senior author in 2019.

REFERENCES

Al-Mufti, O.N. and Arnott, R.W.C. 2023. The origin of planar lamination in fine-grained sediment deposited by subaqueous sediment gravity flows; The Depositional Record, v.9, p.1-19. doi.org/10.1002/dep2.257. [accessed October 24, 2024]

Al-Mufti, O.N., Arnott, R.W.C., Hinto, M.J., Alpay, S. and Russell, H.A.J. 2022. Using computed tomography (CT) to reconstruct depositional processes and products in the subaqueous glaciogenic Champlain Sea basin, Ottawa, Canada; Geomorphology, v.403, article 108165, 17p.

Ames, D.E., Davidson, A., Buckle, J.L. and Card, K.D. 2005. Geology, Sudbury bedrock compilation, Ontario; Geological Survey of Canada, Open File 4570, scale 1:50 000.

Chen, Y.D., Krogh, T.E. and Lumbers, S.B. 1995. Neoarchean trondhjemitic and tonalitic orthogneiss identified within the northern Grenville Province in Ontario by precise U-Pb dating and petrologic studies; Precambrian Research, v.72, p.263-281.

Conrod, D.M. 1989. The petrology and geochemistry of the Duncan Lake, Beaton Bay, Milner Lake, and Miller Lake Nipissing intrusions within the Gowganda area, District of Timiskaming; Ontario Geological Survey, Open File Report 5701, 210p.

Culshaw, N., Van de Kerckhove, S., Slagstad, T., Marsh, J. and Easton, R.M. 2023. Crustal evolution of the Laurentian continental margin from the Paleo- through Mesoproterozoic: A zircon U–Pb and Hf transect through the western Grenville Province, Ontario, Canada; Precambrian Research, v.386, article 106963, 22p.

Davidson, A. and van Breemen, O. 1994. U-Pb ages of granites near the Grenville Front, Ontario; *in* Radiogenic Age and Isotopic Studies: Report 8, Geological Survey of Canada, Current Research 1994-F, p.107-114.

Davidson, A., van Breemen, O. and Sullivan, R.W. 1992. *Circa* 1.75 Ga ages for plutonic rocks from the Southern Province and adjacent Grenville Province: What is the expression of the Penokean Orogeny?; *in* Radiogenic Age and Isotopic Studies: Report 6, Geological Survey of Canada, Paper 92-2, p.107-118.

Dressler, B.O. 1984. The effects of the Sudbury Event and the intrusion of the Sudbury Igneous Complex on the footwall rocks of the Sudbury Structure; *in* The Geology and Ore Deposits of the Sudbury Structure, Ontario Geological Survey, Special Volume 1, Chapter 15, p.97-136.

Easton, R.M. 1992. The Grenville Province; Chapter 19 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.713-904.

——— 2009. Characterization of rock units in the Grenville and Southern Provinces by *in-situ* geophysical measurements and geochemistry; *in* Summary of Field Work and Other Activities, 2009, Ontario Geological Survey, Open File Report 6240, p.9-1 to 9-4.

——— 2014. Geology and mineral potential of the Nepewassi domain, Central Gneiss Belt, Grenville Province; *in* Summary of Field Work and Other Activities, 2014, Ontario Geological Survey, Open File Report 6300, p.16-1 to 16-12.

——— 2022a. Field Trip 2 – Geology of the Grenville Front and the Grenville Front tectonic zone in the Sudbury area; *in* 68th Institute on Lake Superior Geology, Sudbury, Ontario, Proceedings, v.68, pt.2, p.103-146.

——— 2022b. Geology of the Grenville Front tectonic zone near Sudbury, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.12-1 to 12-15,

——— 2023a. Critical Mineral potential in cataclastic rocks of the Grenville Front tectonic zone, southeast of Sudbury, Ontario; *in* Report of Activities 2022, Resident Geologist Program, Kirkland Lake Regional Resident Geologist Report: Sudbury District, Open File Report 6403, p.102-109.

——— 2023b. A study of why some fine-grained sedimentary rocks of the Gowganda Formation in northeastern Ontario are magnetic; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p. 15-1 to 15-12.

——— 2023c. An update on the geology of the Grenville Front Tectonic Zone near Sudbury, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.18-1 to 18-7.

Easton, R.M., Davidson, A. and Murphy, E.I. 1999. Transects across the Southern–Grenville Province Boundary near Sudbury, Ontario; Geological Association of Canada–Mineralogical Association of Canada, Sudbury '99 Annual Meeting, Guidebook A2, 52p.

Easton, R.M. and James, R.S. 1997. Revisiting the disappearance of the Huronian in the Sudbury–Crerar area: Insights from the geochemistry of amphibolites and paragneisses, 43rd Institute on Lake Superior Geology, Proceedings, v.43, pt.1, p.19-20.

Hetu, R. 1989. Airborne gamma ray spectrometric colour maps for Sudbury and District, northern Ontario; Geological Survey of Canada, Open File 2151, 11 maps, scale 1:50 000.

James, H.L. 1954. Sedimentary facies of iron-formation; Economic Geology, v.49, p.235-293.

Kamo, S.L. 2023. Report on U-Pb ID-TIMS geochronology for the Ontario Geological Survey: Bedrock Mapping Projects, Ontario 2022–2023; internal U/Pb age report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 22p.

——— 2024. Report on U-Pb ID-TIMS geochronology for the Ontario Geological Survey: Bedrock Mapping Projects, Ontario 2023–2024, Part 1; internal U/Pb age report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 35p.

Krogh, T.E. 1989. Provenance and metamorphic ages in the Grenville (NW); *in* The Abitibi–Grenville Lithoprobe Project: 1989 Transect Report and Updated Proposal, Lithoprobe Abitibi–Grenville Project Workshop, March 1989, Lithoprobe Secretariat, University of British Columbia, Vancouver, British Columbia, p.5-7.

——— 1994. Precise U-Pb ages for Grenvillian and pre-Grenvillian thrusting of Proterozoic and Archean metamorphic assemblages in the Grenville Front tectonic zone, Canada; Tectonics, v.13, p.963-982.

Krogh, T.E. and Davis, G.L. 1969. Old isotopic ages in the northwestern Grenville Province, Ontario; *in* Age relations in high-grade metamorphic terrains, Geological Association of Canada, Special Paper 5, p.189-192.

——— 1972. The effect of regional metamorphism on U-Pb systems in zircons and a comparison with Rb-Sr systems in the same whole rock; Carnegie Institution of Washington, Yearbook 71, p.564-571.

Lightfoot, P.C. and Naldrett, A.J. 1996. Petrology and geochemistry of the Nipissing Gabbro: Exploration strategies for nickel, copper, and platinum group elements in a large igneous province; Ontario Geological Survey, Study 58, 81p.

Lumbers, S.B. 1974. Burwash area, districts of Nipissing, Parry Sound and Sudbury; Ontario Department of Mines, Map 2271, scale 1:126 720.

——— 1975. Geology of the Burwash area, districts of Nipissing, Parry Sound, and Sudbury; Ontario Division of Mines, Report 116, 158p.

Meldrum, A., Abel-Rahman, A.M., Martin, R.F. and Wodicka, N. 1997. The nature, age and petrogenesis of the Cartier Batholith, northern flank of the Sudbury Structure, Ontario; Precambrian Research, v.82, p.265-285.

Meyn, H.D. 1971a. Geology of Roberts, Creelman and Fraleck townships; Ontario Department of Mines, Geological Report 91, 48p.

——— 1971b. Roberts, Creelman and Fraleck townships; Ontario Department of Mines, Map 2212, scale 1:31 680.

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

——— 2019a. Ontario airborne geophysical surveys, magnetic gradiometer and gamma-ray spectrometric data, grid and profile data (ASCII format) and vector data, Ramsey–Algoma area; Ontario Geological Survey, Geophysical Data Set 1086a.

——— 2019b. Ontario airborne geophysical surveys, magnetic gradiometer and gamma-ray spectrometric data, grid and profile data (Geosoft® format) and vector data, Ramsey–Algoma area; Ontario Geological Survey, Geophysical Data Set 1086b.

——— 2024. Ontario gravity and aeromagnetic data; Ontario Geological Survey, OGS Earth www.geologyontario.mndm.gov.on.ca/ogsearth.html. [accessed August 12, 2024].

Pfister, J.D. 2023. Assessing primary versus secondary features in two pegmatite swarms with implications for the nature of pegmatitic systems; unpublished PhD thesis, Laurentian University, Sudbury, Ontario, 302p.

Prevec, S.A. 1992. U-Pb age constraints on Early Proterozoic mafic magmatism from the southern Superior and western Grenville provinces, Ontario; *in* Radiogenic Age and Isotopic Studies, Report 6, Geological Survey of Canada, Paper 92-2, p.97-106.

——— 1993. An isotopic, geochemical and petrographic investigation of the genesis of Early Proterozoic mafic intrusions and associated volcanics near Sudbury, Ontario; unpublished PhD thesis, University of Alberta, Edmonton, Alberta, 223p.

——— 1995. Sm-Nd isotopic evidence for crustal contamination in the *ca.* 1750 Ma Wanapitei Complex, western Grenville Province, Ontario; Canadian Journal of Earth Sciences, v.32, p.486-495.

——— 2004. Basement tracing using Mid-Proterozoic anorthosites straddling a palaeoterrane boundary, Ontario, Canada; Precambrian Research, v.129, p.169-184.

Raharimahefa, T., Lafrance, B. and Tinkham, D.K. 2014. New structural, metamorphic and U-Pb geochronological constraints on the Blezardian Orogeny and Yavapai Orogeny in the Southern Province, Sudbury, Canada; Canadian Journal of Earth Sciences, v.51, p.750-774.

Rochin-Banaga, H. 2024. Report on U-Pb LA-ICPMS geochronology for the Ontario Geological Survey: Bedrock Mapping Projects, Ontario 2023-2024, Part 3; internal U/Pb age report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 29p.

Rousell, D.H., Petrus, J.A., Easton, R.M., Tinkham, D.K. and Napoli, M.G. 2012. The tectonometamorphic, magmatic and mineralization history of the Wanapitei Complex, Grenville Front tectonic zone, Ontario; 58th Institute on Lake Superior Geology, Proceedings, v.58, pt.1, p.75-76.

Slagstad, T., Easton, R.M., Huyskens, M. and Culshaw, N. 2024. Complementarity of Lu-Hf isotopes from detrital and igneous zircon: An example from the Central Gneiss Belt, Grenville Province, Ontario; Canadian Journal of Earth Sciences, v.61, 19p. e-first release June 10, 2024.

Sullivan, R.W. and Davidson, A. 1993. Monazite age of 1747 Ma confirms post-Penokean age of the Eden Lake Complex, Southern Province, Ontario; *in* Radiogenic Age and Isotopic Studies: Report 7, Geological Survey of Canada, Paper 93-2, p.45-48.

van Breemen, O. and Davidson, A. 1988. Northeast extension of Proterozoic terranes of mid-continental North America; Geological Society of America Bulletin, v.100, p.630-638.

12. Summary of Geophysical Projects and Activities

S. Biswas[1] and J. Evangelatos[1]

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

INTRODUCTION

During the past year, the Ontario Geological Survey (OGS) published 1 geophysical data set from the fixed-wing magnetic gradiometer survey flown in the Winisk River area (Ontario Geological Survey 2024). A 3394 station ground gravity survey in the Guelph area, commissioned by the OGS, was completed in October 2023. The gravity survey results are being prepared for publication. Data sets from 2 airborne gravity and magnetic surveys, donated by Nuclear Waste Management Organization (NWMO), have been reprocessed and are being prepared for publication (Figure 12.1).

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

SUPPORT FOR THE BEDROCK GEOLOGY MAPPING PROGRAM

The OGS mapping program for the 2024 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:

- Totten bedrock geology
- Denison bedrock geology
- Michipicoten greenstone belt
- Timmins bedrock geology
- Kirkland Lake bedrock geology
- Rowan–Kakagi bedrock geology

SUPPORT FOR THE GROUNDWATER PROGRAM

The 3394 station ground gravity survey in the Guelph area, in support of the Guelph three-dimensional (3-D) sediment mapping project (*see* Figure 12.1), was completed in October 2023. The survey complements existing ground gravity surveys in the Orangeville (Ontario Geological Survey 2013),

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.12-1 to 12-4.

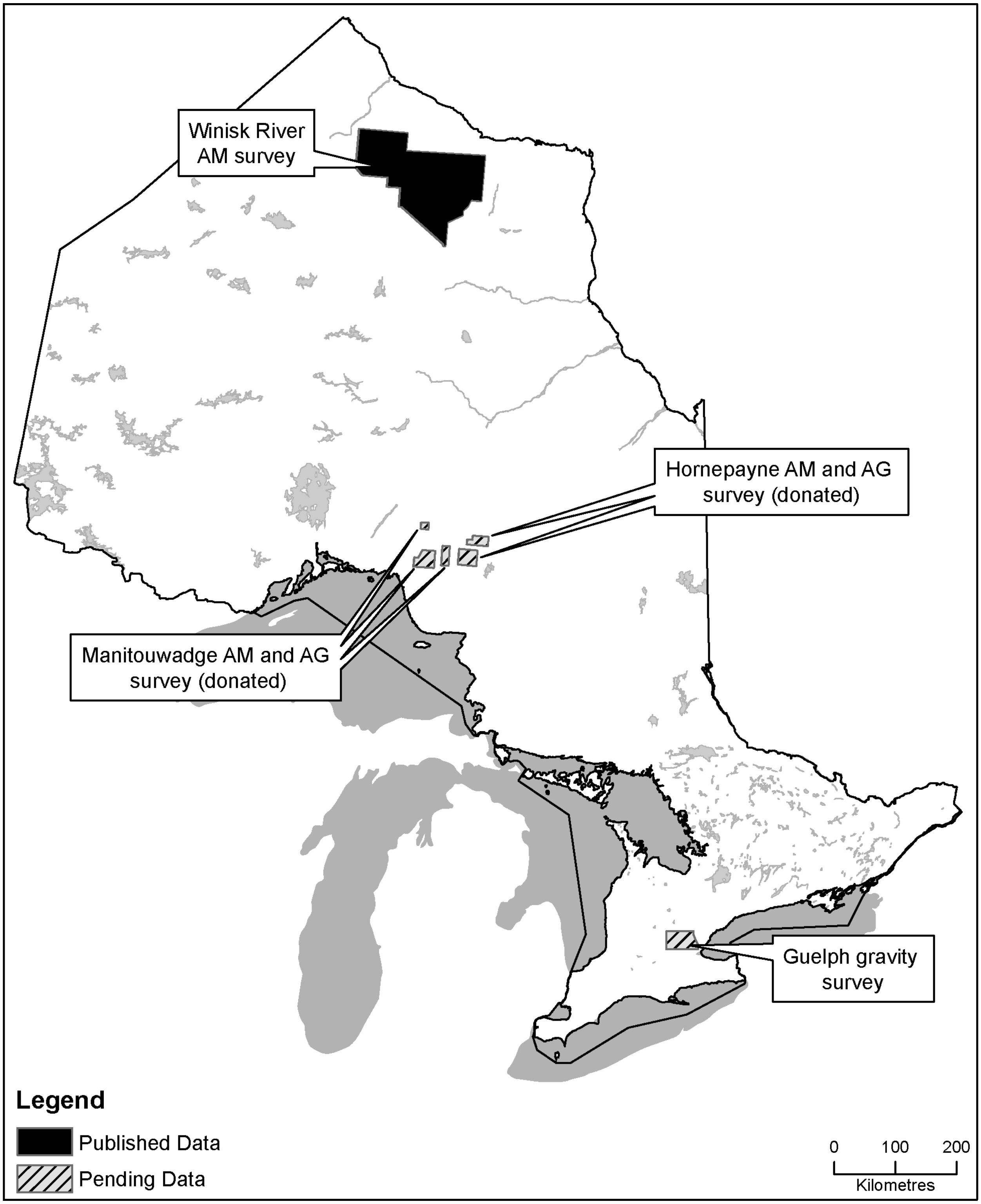


Figure 12.1. Locations of geophysical surveys (published and pending data). Abbreviations: AG, airborne gravity; AM, airborne magnetic.

Kitchener–Waterloo (Marich et al. 2011) and Niagara Peninsula (Ontario Geological Survey 2014) areas. The work was performed by Clearview Geophysics Inc., Brampton, Ontario, along a network of 17 road traverses with station spacing of 50 m. A density of 2.1 g/cm^3, the same value as in the Orangeville area survey, was used to calculate the Bouguer gravity for the Guelph area. A 2 km upward continuation of the regional gravity data was subtracted from the observed gravity to calculate the residual gravity for the Guelph survey. The preliminary results of the survey were presented at the OGS Showcase (Biswas, Evangelatos and Burt 2023) in November 2023 and at the Groundwater Open House (Burt, Biswas and Evangelatos 2024) in February 2024. These results will help identify potential thalwegs that can be investigated by drilling to characterize the 3-D subsurface sediments in the area. It is expected that the survey data and the accompanying map will be released as soon as the products are ready for publication.

NEW AIRBORNE GEOPHYSICAL DATA

In 2024, the OGS reprocessed 2 data sets donated by the NWMO. The airborne gravity and magnetic surveys were flown in 2015 in the Hornepayne and Manitouwadge areas (*see* Figure 12.1). The Hornepayne survey comprises 12 694 line-kilometres and covers 2 separate blocks with a total area of approximately 1240 km^2. The Manitouwadge survey consists of 13 957 line-kilometres over 3 blocks and extends over a total area of approximately 1340 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. It is expected that the survey data and the accompanying maps will be released as soon as the products are ready for publication.

GEOPHYSICAL DATA RELEASES FOR 2024

One airborne Geophysical Data Set (GDS 1069), containing the results of the Winisk River area survey flown between November 2011 and February 2012, was released in March 2024 (Table 12.1) (Ontario Geological Survey 2024). The survey location is shown in Figure 12.1.

Table 12.1. Summary of airborne geophysical data released by the Ontario Geological Survey in 2024.

Publication	Survey Name	Year of Survey	Survey Type	Line-Kilometres
GDS 1069	Winisk River area	2012	Airborne magnetic	76 744

Abbreviation: GDS, Geophysical Data Set.

OTHER ACTIVITIES

In 2024, 13 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 7 projects. As such, training on the proper use of the OGS spectrometers was provided to 7 field assistants accompanying the 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 uranium, thorium and potassium. The performance of these instruments is tested for consistency throughout the year at a convenient field location off Municipal Road 35 in Sudbury.

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 Mines. Furthermore, a virtual meeting was held with members of Thessalon First Nations to share knowledge of geophysics and to communicate the role of geophysics within the OGS and its overall benefits to Ontario.

The OGS 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, maps, and physical media (CD or DVD) of digital data are also available for a nominal fee through the Publication Sales:

Tel:	705-670-5691 (local)
Toll-free:	1-888-415-9845 ext. 5691 (Canada and United States)
Fax:	705-670-5770
E-mail:	pubsales.ndm@ontario.ca

REFERENCES

Biswas, S., Evangelatos, J and Burt, A.K. 2023. New ground gravity data from Guelph, Ontario; presentation, Ontario Geological Survey Virtual Showcase 2023, November 28–30, 2023.

Burt, A.K., Biswas, S. and Evangelatos, J. 2024. Getting gung ho for gravity in Guelph; abstract *in* Ontario Groundwater Geoscience 2024 Open House; Ontario Geological Survey, Open File Report 6406, p.6; recording available on the GSC Groundwater Geoscience Program YouTube channel under Playlists, www.youtube.com/channel/UCHIc7ff3vEdII708VhgsLsg/playlists, *see* "Ontario Groundwater Geoscience 2024 Open House Day 1 – February 27, 2024". [accessed October 3, 2024]

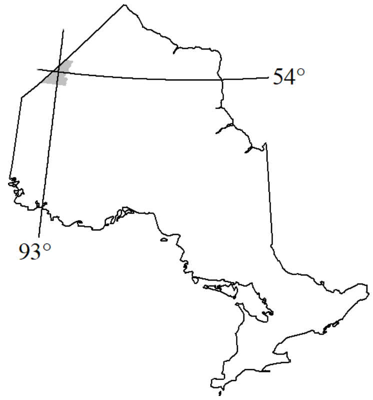
Marich, A.S., Priebe, E.H., Bajc, A.F., Rainsford, D.R.B. and Zwiers, W.G. 2011. A geological and hydrogeological investigation of the Dundas buried bedrock valley, southern Ontario; Ontario Geological Survey, Groundwater Resources Study 12, 248p.

Ontario Geological Survey 2013. Ontario geophysical surveys, ground gravity data, grid and point data (ASCII and Geosoft® formats) and vector data, Orangeville area; Ontario Geological Survey, Geophysical Data Set 1072.

——— 2014. Ontario geophysical surveys, ground gravity data, grid and point data (ASCII and Geosoft® formats) and vector data, Niagara area; Ontario Geological Survey, Geophysical Data Set 1073.

——— 2024. Ontario airborne geophysical surveys, magnetic gradiometer data, grid and profile data (ASCII and Geosoft® formats) and vector data, Winisk River area; Ontario Geological Survey, Geophysical Data Set 1069.

13. Project FN-24-002.
Far North Terrain Mapping, the Northern Opasquia Lake Area, Northern Ontario



C. Gao[1], N. Szumylo[1] and K.H. Yeung[1]

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

INTRODUCTION

Helicopter-supported field work in support of the Far North remote predictive terrain mapping project took place in the northern Opasquia Lake area, northwestern Ontario, from July 8 to 21, 2024 (Figure 13.1). This work is a continuation of the previous mapping in the contiguous Sandy Lake area to the south (Gao, Yeung and Szumylo 2017; Gao et al. 2018; Gao and Yeung 2024a-d). During the field season, the crew was based out of the Sandy Lake community. Information from this project is important for Far North land-use planning and the assessment of aggregate resources for infrastructure development, as well as for improved understanding of the glacial history in this region.

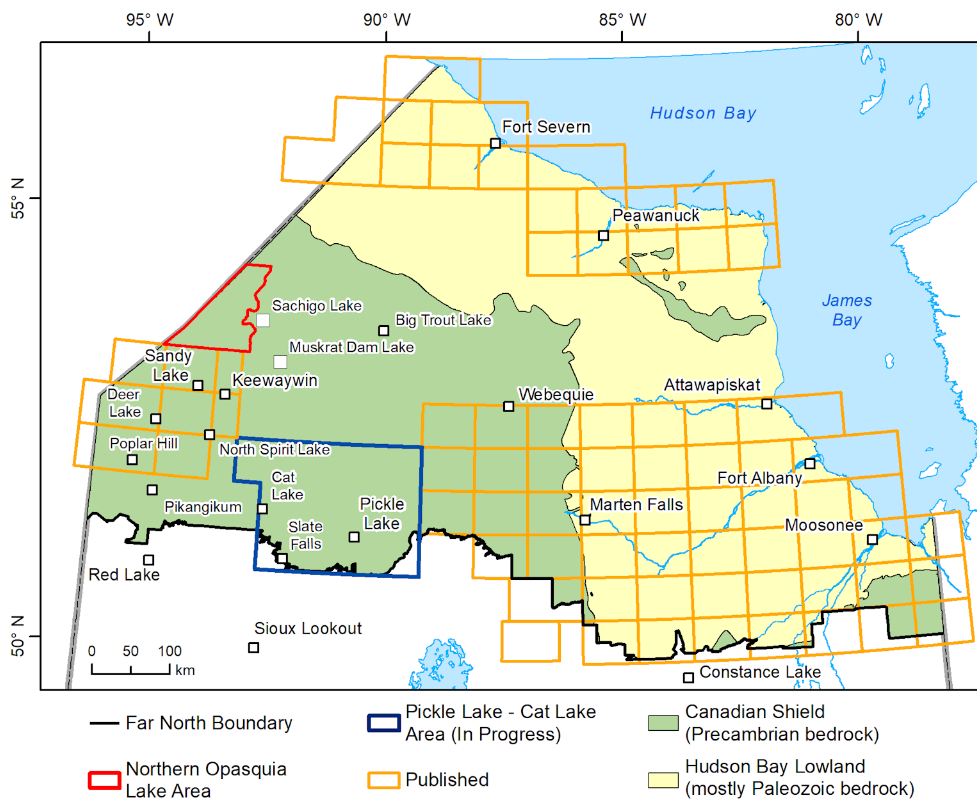


Figure 13.1. Location of the northern Opasquia Lake area (red line) and the status of the remote predictive terrain mapping project in the Far North of Ontario.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.13-1 to 13-10.

Remote predictive terrain mapping is based on satellite imagery analysis with limited field work because of the lack of road access in the region. Currently, it is done by analyzing Sentinel 2 satellite imagery, and the Ontario Radar Digital Surface Model (DSM) (Ministry of Natural Resources and Forestry 2015) and its derivatives. For details of the method, readers can refer to Barnett and Yeung (2010) and Gao, Yeung and Szumylo (2017). In this article, for consistency, all the elevations were estimated from Google Earth™ mapping service. In the study area, the Shuttle Radar Topographic Mission (SRTM) digital surface model used by Google Earth™ has a resolution of 30 m per pixel and a root mean square accuracy of 3.64 m in elevation (Gesch, Oimoen and Evans 2014). All ages cited below are calendar thousand years (ka) before 1950.

Sentinel 2 satellite imagery and the imagery from the Google Earth™ mapping service were used to select about 190 potential landing sites for field work. After landing, surficial sediments were logged at natural exposures or through trenching and augering using a hand-held Dutch soil auger, small glacial erosion features (e.g., striae and crescentic fractures) on bedrock outcrops were measured for ice flow directions, and samples were collected for geochemistry, radiometric dating and palynology. Where helicopter landing was not possible, the sites were flown over and photographed to document their geomorphic attributes and dominant tree types to help inform the prediction of surficial material.

PHYSIOGRAPHY AND VEGETATION

The study area, which is located on Precambrian terrain, has a bedrock upland with thin surficial sediments in its southern part and, to the north, it shows subdued relief with relatively thick surficial deposits consisting mainly of glaciolacustrine silt and clay (Figure 13.2). The Sachigo interlobate moraine, located along the northern and eastern boundaries of the study area, is a prominent landmark with an elevation up to 360 m above sea level (asl) at the Sachigo Hills, where it rises more than 110 m above nearby Sachigo Lake (248 m asl). A dense boreal forest consisting of black and white spruces (*Picea mariana, P. glauca*), jack pine (*Pinus banksiana*), balsam fir (*Abies balsamea*), poplar (*Populus tremuloides, P. balsamifera*), tamarack (*Larix laricina*) and white birch (*Betula papyrifera*) covers the region. Fens are treed mostly by tamarack and bogs by black spruce. Mixed tree stands consisting of spruce, balsam fir and poplar grow along riverbanks and on raised ground with thick lithic soils. Jack pine usually grows on bedrock ridges with thin soil, or where a dry substrate of loose sand, such as on moraine, kame and esker ridges exists.

BEDROCK GEOLOGY

The study area is in the Sachigo Subprovince of the Superior Province and the bedrock consists of Archean felsic plutonic domains dominated by granodiorite, granite and gneissic tonalite, interspersed with greenstone belts comprising primarily of mafic to intermediate metavolcanic assemblages (Thurston, Osmani and Stone 1991; Stone 2005). Three greenstone belts occur within the study area, namely, the east-southeasterly aligned Stull–Swan lakes and Ponask Lake greenstone belts in the northern and middle parts of the study area, respectively, and the eastward-aligned Lingman Lake greenstone belt, around Seeber and Pullan lakes, in the south (Thurston, Osmani and Stone 1991; Stone 2005). There is an abandoned gold mine, known as the Lingman Lake Mine (*see* Figure 13.2), in the Lingman Lake greenstone belt. Currently, Signature Resources is conducting explorations for gold deposits near this mine (www.signatureresources.ca/projects/lingman-lake-gold-project [accessed October 13, 2024]).

QUATERNARY GEOLOGY

Satterly (1937) first described the Sachigo moraine and reported extensive glaciolacustrine varved clay deposits, as revealed along the shores of Ponask and Sachigo lakes. He also noticed the converging of 2 ice flows along this moraine: one coming from the northwest and the other one from the northeast, and suggested that, because of the presence of this convergence of ice flows at this specific location, the Sachigo moraine could be an interlobate moraine. However, the prominent abandoned shoreline features on the moraine were not mentioned in his study. Harvey (1979) briefly surveyed the Opasquia moraine and the southern part of the Sachigo moraine for the creation of the Opasquia Provincial Park, but the full technical report from his survey has never been published. Harvey reported the presence of former shoreline features, including beach ridges and wave-cut shore scarps or bluffs, on the moraines. During bedrock geology mapping in the northern part of the study area (north of Ponask Lake), Stone, Morris and Crabtree (1999) collected surficial samples (beach sand predominantly) for indicator minerals, but there is no information in their report on Quaternary stratigraphy, ice flow directions and landform features. Some bedrock geology maps in the study area contain information on ice flow directions from striations (Bennett and Riley 1967; Riley and Davie 1967; Wilson, Pelletier and Paktunc 1982; Stone, Hallé and Pufahl 2001a, 2001b). Additional information on ice flow directions from unpublished sources is also included in an OGS compilation map (P.3610) (Barnett, Webb and Hill 2009).

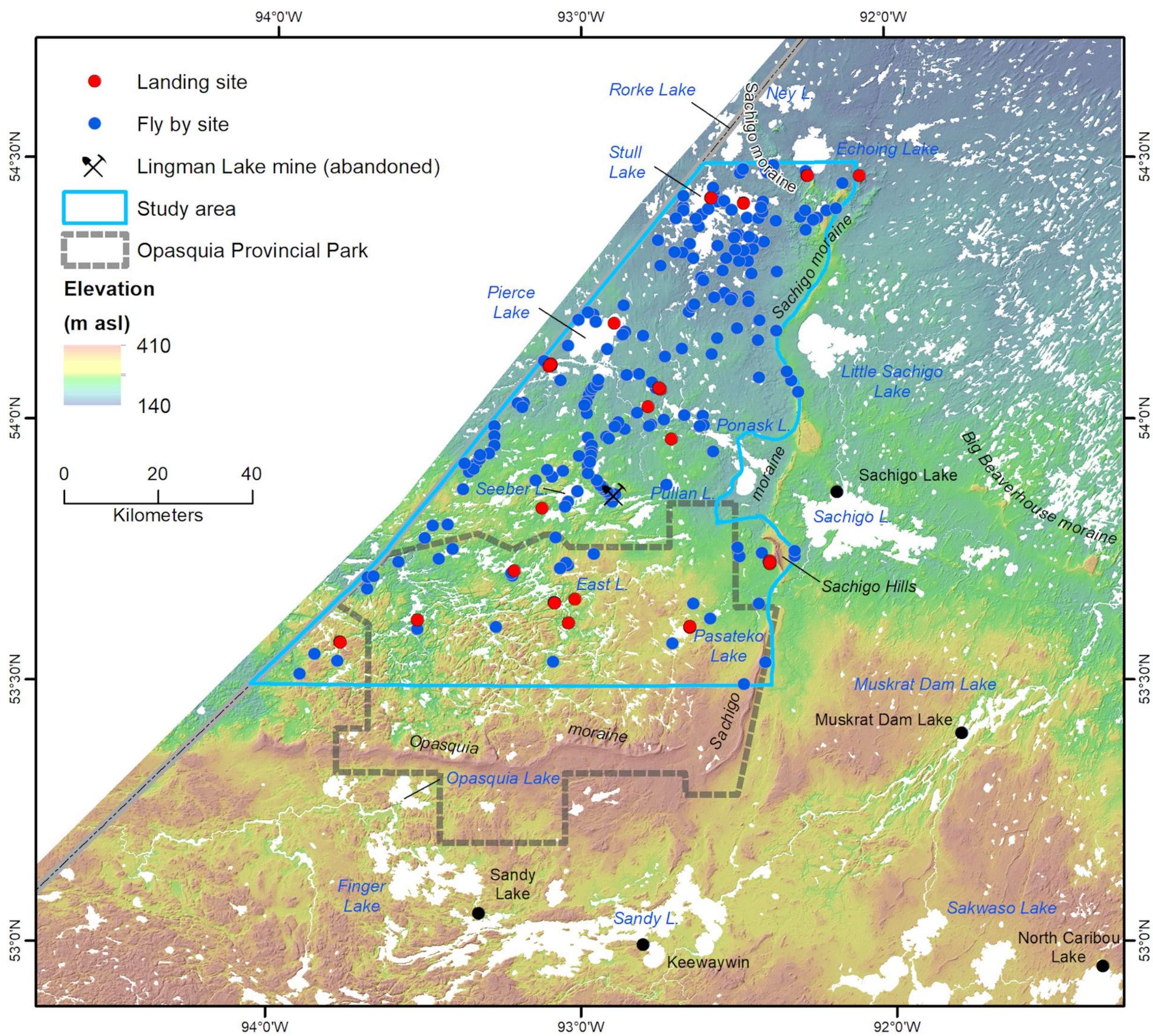


Figure 13.2. Study area (light blue line) and locations of field observation sites superimposed on the Ontario Radar Digital Surface Model (DSM) (Ministry of Natural Resources and Forestry 2015). Solid blue dots are predetermined sites and most of them were only flown by because of the difficulty for helicopter landing. Solid red dots are sites where the helicopter landed for field survey and sampling.

The Quaternary stratigraphy as described below consists of, from the oldest to the youngest, a Wisconsinan till, glaciofluvial sand and gravel, and glaciolacustrine deposits beneath the surface peat.

Till Deposits and Ice Flow Directions

Tills are poorly exposed within the study area because of a thick cover of glaciolacustrine deposits. Where observed, they have a sand to silty sand matrix that typically has no reaction to a 10% hydrochloric acid solution and have a moderate stone content consisting predominantly of a granitic lithology of local origin, as well as occasional far-travelled limestone and omar pebbles from Hudson Bay Lowland and the Belcher Islands in southern Hudson Bay, respectively. The tills may belong to different lithostratigraphic units, but this cannot be confirmed as most observations were from hand-augered holes which penetrated less than 20 cm into the top of the deposits. For this reason and until more detailed studies are completed, the tills at surface are tentatively considered as a single, undifferentiated deposit of Wisconsinan age.

Glacially streamlined large landforms observed from satellite imagery, e.g., drumlins, flutings, bedrock whalebacks and *roches moutonnées* (Photo 13.1A), indicate that the ice flowed to the south-southeast in the northern and eastern parts of the study area, shifting to the south and south-southwest in the southwest of the area, consistent with previous work (Prest, Grant and Rampton 1968; Pala, Barnett and Babuin 1991). Field measurements on small erosional features, including striae, crescentic fractures and, to a lesser extent, crescentic gouges, on bedrock outcrops confirmed these ice flow directions (Photo 13.1B). The shift in ice flow directions is believed to be associated with the late glacial Hayes ice lobe, which fanned out from the western part of the ice saddle over Hudson Bay along a southwest axis near the provincial border in Manitoba, with its eastern flank flowing across the study area in directions to the south-southeast, south and south-southwest (e.g., Dredge and Cowan 1989; Gauthier et al. 2019). The Hayes ice lobe converged with the Windigo sublobe of the Rainy lobe from the northeast and constructed the Sachigo interlobate moraine (Satterly 1937; Prest 1963; Dredge and Cowan 1989). This ice lobe was also responsible for the development of the Opasquia end moraine sometime between 11.4 and 10.1 ka (Gao 2024; Margold, Stokes and Clark 2018).

Ice flow directions predating the late glacial Hayes ice lobe were determined through measurement of striae and crescentic features including crescentic fractures and gouges. Crosscutting striae and crescentic features record at least 2 ice flows toward the west and then to the southwest before the Hayes ice lobe. A good record of such ice flow directions was found on a small isle made up of flat-lying granitic bedrock in East Lake in the northern part of Opasquia Provincial Park (*see* Figure 13.1 for location), where striae and crescentic fractures exhibit 3 ice flow directions (Photo 13.1C). The first ice flow was westward, as indicated by many well-preserved crescentic fractures with an average orientation at 260°, followed by a southwestward ice flow at 240°, as indicated by both striations and crescentic fractures (Photo 13.1D), which was then crosscut by the most recent ice flow associated with the Hayes ice lobe to the south-southwest, with an average orientation at 202° (*see* Photo 13.1C). Satterly (1937) and Riley and Davie (1967) also reported southwestward ice flows but provided no information on their crosscutting relations and relative chronologies. Crosscutting westward and southwestward ice flows were also observed in the Pickle Lake–Cat Lake area, located southeast of the study area, where crescentic fractures at 260° are crossed by striae at 238° (51°8′20.4″N, 90°0′7.2″W) (Gao et al. 2019, Photo 16.2D). Collectively, these ice flow directions indicate that the ice of the Wisconsinan main phases advanced into the study area and vicinity in northwestern Ontario from the east and then from the northeast, from the Quebec–Labrador sector of the Laurentide Ice Sheet. This succession of events is consistent with the ones documented in other’s work in northern Ontario, Quebec and northern Manitoba (Thorleifson, Wyatt and Warman 1993; Veillette et al. 2017; Gauthier et al. 2019). With the recession of the ice of the Quebec–Labrador sector, the Hayes lobe moved into the study area from the north-northwest.

Field observations also indicate the presence of a much older ice flow predating the aforesaid westward ice flow in the study area. On an island in Pasateko Lake in the southeastern part of the study area (*see* Figure 13.2 for location), deeply etched striae of the westward ice flow (280°) crosscut crescentic fractures that indicate an ice flow to the east-southeast at 120° (Photo 13.1E). Both ice flows were crossed by the most recent ice flow associated with the Hayes lobe to the south-southeast (160°). The crescentic fractures at this locality thus provide evidence of the earliest ice flow recorded in the study area, which

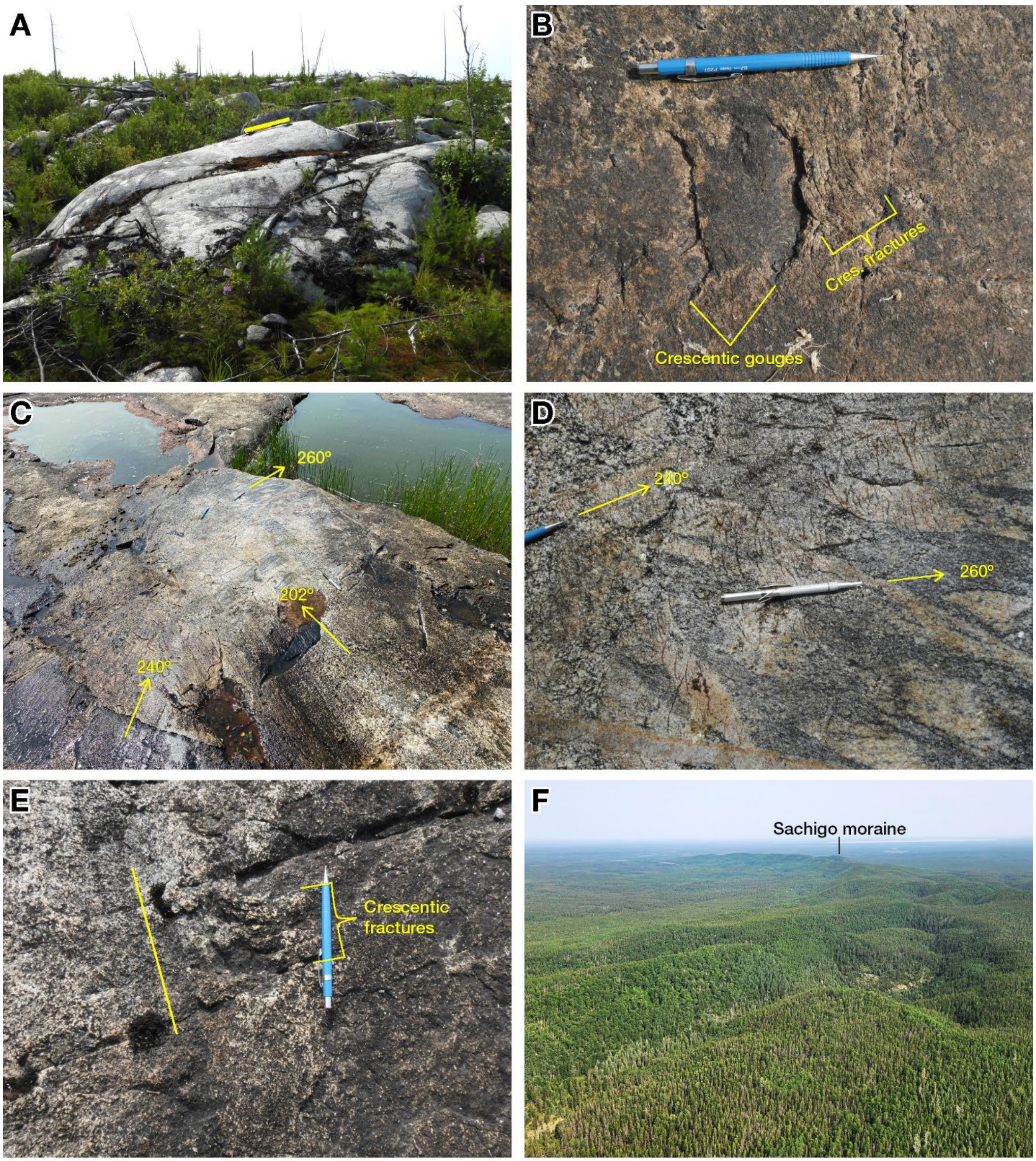


Photo 13.1. (caption on next page)

Photo 13.1. **Previous page. A**) A group of well-preserved *roches moutonnées* pointing at 200°, located near the provincial border in the southwestern part of the study area (53°34′55″N, 93°46′32″W). The striae on their stoss slopes (not shown) have the same direction. Shovel is 105 cm long (indicated by a parallel yellow line above it). **B**) Crescentic gouges as large scars cutting into crescentic fractures as curved fine joints, both created by the same ice flow that moved in the direction the pencil points (206°) (53°37′30″N, 93°31′37″W). Pencil is 14 cm long. **C**) At this locality on East Lake in northern Opasquia Provincial Park (53°43′14″N, 93°12′55″W), well-preserved striae and crescentic fractures indicate 3 crosscutting ice flow directions, with the earliest at 260° being crosscut by a later one at 240° which was in turn crosscut by the most recent flow in this area from the late glacial Hayes ice lobe at 202°. Pencil is 14 cm long. **D**) Close up of Photo 13.1C to show the crosscutting of the crescentic fractures of the westward ice flow (260°) by the striae of the southwestward ice flow (240°). Note that, in addition to the striae, the southwestward ice flow is also indicated by well-developed crescentic fractures (not shown in photo). Pencil is 14 cm long. **E**) On Pasateko Lake in the southeastern part of the study area (53°36′42″N, 92°38′55″W), partially preserved crescentic fractures on an island indicate ice flow at 120°, as the pencil points. They were crosscut by deeply etched striae (yellow line) created by an interpreted westward ice flow at 280°. At this site, the most recent ice flow associated with the late glacial Hayes ice lobe moved at 160° (not shown in the photo), crosscutting all the early ice flow directions. Pencil is 14 cm long. **F**) The Sachigo Hills, the highest segment of the Sachigo interlobate moraine near Sachigo Lake (to the right, not shown in the photo), with an elevation up to 360 m above sea level. Note in the foreground, the many depressions of kettle hole origin on the moraine. Trees are 15 to 20 m tall. The lake on the horizon is Ponask Lake. Aerial view to the northwest.

moved into this region from the west-northwest. This ice flow was probably related to the early phase of the Hayes lobe or some unknown ice lobes that require further work to delineate. The link between the till and the recorded ice flows in the study area remains unclear because of poor exposure and lack of till fabric analysis. However, its occurrence as a surface deposit suggests its likely emplacement by the most recent Hayes lobe.

Glaciofluvial Deposits and Moraines

Glaciofluvial sand and gravel deposits occur in predominantly southward-trending eskers and the Sachigo interlobate moraine (Photo 13.1F). Shoreline features and kettle holes in various sizes and shapes occur on the moraine (*see* Photo 13.1F). A northwestern branch moraine, or arm, from Ney Lake joins the main Sachigo moraine near Echoing Lake (*see* Figure 13.2). It strikes at west-northwest and, after extending into Manitoba, shifts to a northwest and north-northwest orientation. This branch moraine has a relatively low relief south of Echoing Lake but rises 90 m above the nearby lake near the provincial border south of Ney Lake (Photo 13.2A). In contrast to the main Sachigo moraine, it shows few prominent shoreline features, related probably to its younger age and submergence in Lake Agassiz until the very late phases of this lake.

Glaciolacustrine Deposits and Abandoned Shorelines

Glaciolacustrine deposits consist of basinal silt and clay and, to a lesser extent, nearshore sand and gravel. The latter occurs on bedrock and moraine ridges as sheet sand and lag boulders. The basinal silt and clay deposit is massive to varved in structure whereby the sediment with varve lamination is referred to informally here as varved clay. The basinal silt and clay is common in low-lying areas including laterally extensive lowlands and small bedrock depressions. It also occurs on the crest of the Sachigo moraine, as observed near the northern boundary of the study area. Thick varved clay is exposed along the shore of Ponask Lake (Photo 13.2B), with a total thickness estimated to be 12 m (Satterly 1937). The basinal silt and clay often reacts to a 10% hydrochloric acid solution, with varved clay always showing strong reaction in its light-toned silt and sand layer of a couplet (summer layer). The basinal silt and clay in the study area is the continuum of a regionally extensive deposit of glacial Lake Agassiz consisting mainly of varved clay, as observed at Sandy Lake to the south, Sachigo and Little Sachigo lakes to the east and Muskrat Dam Lake to the southeast (Gao 2024; Satterly 1937; Ayres 1967).

Photo 13.2. **A**) A southwest-aligning kame ridge associated with the northwestern arm of the Sachigo interlobate moraine south of Ney Lake near the provincial border (54°34′8″N, 92°20′37″W). It has an elevation of 285 m and rises more than 90 m above the nearby lake. Trees are 15 to 20 m tall. Aerial view to the southwest. **B**) Varved clay in a 5 m shore cliff with an estimated 220 varves, Ponask Lake (photo taken from helicopter). **C**) Abandoned shoreline features consisting of wave-cut scarps or bluffs on the Sachigo Hills of the Sachigo moraine (53°44′6″N, 92°23′22″W). Aerial view to the north-northwest. Small yellow triangles point to the locations of Photo 13.2D (triangle pointing down) and Photo 13.2E (triangle pointing up). **D**) Photo shows, to the right, a 2 m shore bluff above its base, a narrow belt of the former flat lake plain, which is in turn cut (near the shovel) by a younger shore bluff about 2 m deep to the left (only partly shown here). Boulders are covered with lichens dead and alive; location in Photo 13.2C. View is to the northwest. Shovel is 105 cm long. **E**) The large shore bluff at the base of the moraine which has a relief of more than 10 m above its base. The boulders in the foreground are approximately 1 m in size; location in Photo 13.2C. View is to north-northwest. The person in the middle of the picture is 195 cm tall. **F**) Photo shows ground ice in permafrost intercepted using a hand-held Dutch soil auger in glaciolacustrine silt and clay at 70 to 90 cm depth on an island in northern Stull Lake (54°26′0″N, 92°34′20″W). At this locality, the surface peat is 20 cm thick.

Well-preserved former shoreline features, mostly wave-cut scarps or bluffs, occur on the Sachigo moraine (Photos 13.2C to 13.2E) and the Opasquia end moraine (Gao and Yeung 2024a, 2024b, 2024c). These shoreline features developed during the stepwise lowering of Lake Agassiz (Gao 2024). The earliest strandline on the Opasquia moraine developed when the The Pas beach, inferred at 10.1 ka (Teller and Owen 2021), formed in the main basin in Manitoba (Gao 2024). The Sachigo moraine has a lower elevation and is located further to the northeast on the isobases (between isobase 10 and 11). As such, the earliest strandline on this moraine should be no older than the The Pas beach. The shorelines of the final drainage of Lake Agassiz into Hudson Bay are represented by the Ponton and Fiddler beaches in the main basin, and the projected water planes suggest that these 2 beaches likely occurred in the study area (Thorleifson 1996; McMartin 2000). The Ponton beach is radiocarbon dated at approximately 8.3 ka and the Fiddler is inferred at 8.16 ka (Gao 2024; Gao and Turton 2024; Brouard et al. 2021). Although confirmation is needed, the dates currently available would suggest the development of the shore strandlines on the Sachigo moraine between 10.1 ka and 8.16 ka.

Permafrost

On July 18, on an island in northern Stull Lake (*see* Figure 13.2 for location), permafrost was intercepted, using a hand-held auger, in a massive, brownish glaciolacustrine silt and clay at 70 to 90 cm depth (Photo 13.2F). Drilling was abandoned below 90 cm because of the auger becoming jammed in the permafrost. This site is in a dense forest consisting of spruce and balsam fir with low shrubs of Labrador tea (*Rhododendron groenlandicum*). The shade from the trees may have helped the permafrost form. The surface peat at this locality is thin (20 cm), and its role in permafrost development is likely insignificant. In the map area, active to inactive palsas and peat plateaus, indicating the likely presence of permafrost, were observed locally in low-lying areas where, below the surface peat, thick glaciolacustrine silt and clay tends to occur. These observations are consistent with previous work that placed the study area in the zone of sporadic discontinuous permafrost (Natural Resources Canada 1995).

AGGREGATE AND PEAT RESOURCES

The Sachigo moraine contains the largest sand and gravel deposit in the study area and vicinity. Significant sand and gravel resources may also come from the eskers. Gravel clasts in these deposits consist mostly of hard and durable granitic rocks, with low concentrations of deleterious rock types such as gneiss and schist. As such, they have good potential for construction of road base, secondary gravel roads and for other infrastructural applications. However, oversized boulders need to be removed or crushed. For high-quality applications in road building, such as hot-laid asphalt, laboratory testing is required. Currently, sand and gravel are extracted from the Sachigo moraine for roads and other infrastructure development by the Sachigo Lake community.

Surface peat is extensive and rarely exceeds 2 m in thickness although thicker peat may occur in some bogs and fens. The peat has a low degree of humification as indicated by its fibrous texture and the presence of abundant undecomposed moss and wood fragments. This suggests that the peat has limited use for the fuel industry, but it may have some potential for horticultural applications.

ACKNOWLEDGMENTS

The authors wish to thank Ontario Parks for granting permission to work in Opasquia Provincial Park. Mathieu Levesque of Ontario Geological Survey is thanked for his liaison work with the First Nation communities. Abigail Burt and Manuel Duguet reviewed the manuscript with helpful comments and edits.

REFERENCES

Ayres, L.D. 1967. Geology of the Muskrat Dam Lake area, District of Kenora (Patricia portion); Ontario Department of Mines, Geological Branch, Open File Report 5002, 102p.

Barnett, P.J., Webb, J.L. and Hill, J.L. 2009. Flow indicator map of the Far North of Ontario; Ontario Geological Survey, Preliminary Map P.3610, scale 1:100 000.

Barnett, P.J. and Yeung, K.H. 2010. Far North terrain mapping project—Fort Severn; *in* Summary of Field Work and Other Activities, 2010, Ontario Geological Survey, Open File Report 6260, p.25-1 to 25-6.

Bennett, G. and Riley, R.A. 1967. Operation Lingman Lake, Finger Lake sheet, District of Kenora (Patricia Portion); Ontario Geological Survey, Preliminary Map P.431, scale 1:126 720.

Brouard, E., Roy, M., Godbout, P.-M. and Veillette, J.J. 2021. A framework for the timing of the final meltwater outbursts from glacial Lake Agassiz-Ojibway; Quaternary Science Reviews, v.274. https://doi.org/10.1016/j.quascirev.2021.107269.

Dredge, L.A. and Cowan, W.R. 1989. Quaternary geology of the southwestern Canadian Shield; *in* Quaternary Geology of Canada and Greenland, Geological Survey of Canada, Geology of Canada, no.1 (also Geological Society of America, The Geology of North America, v.K-1), Ottawa, p.214-249.

Gao, C. 2024. Late history of glacial Lake Agassiz in northwestern Ontario, Canada: A case study in the Sandy Lake basin; Canadian Journal of Earth Sciences, v.61, no.3. https://doi.org/10.1139/cjes-2023-0014.

Gao, C. and Turton, C.L. 2024. Early Holocene marine incursion and a freshened Tyrrell Sea in Hudson Bay Lowlands, Canada; Quaternary Science Reviews, 109134 (accepted).

Gao, C. and Yeung, K.H. 2024a. Surficial geology of the Island Lake area southeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3676, scale 1:100 000.

——— 2024b. Surficial geology of the North Sprit Lake area northeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3691, scale 1:100 000.

——— 2024c. Surficial geology of the Opasquia Lake area southeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3678, scale 1:100 000.

——— 2024d. Surficial geology of the Opasquia Lake area southwest, northern Ontario; Ontario Geological Survey, Preliminary Map P.3677, scale 1:100 000.

Gao, C., Yeung, K.H., Dyer, J.A. and Dzuirban, K.R. 2018. Surficial geology of the Sandy Lake area, Far North of Ontario; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.18-1 to 18-10.

Gao, C., Yeung, K.H., Ho, K.K.-Y., Meagher, H.M. and Wolfe, T.N. 2019. Field studies in support of remote predictive mapping in the Pickle Lake–Cat Lake area, Far North of Ontario; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.16-1 to 16-11.

Gao, C., Yeung, K.H. and Szumylo, N. 2017. Field studies in support of remote predictive mapping in the Sandy Lake area, Far North of Ontario; *in* Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p.21-1 to 21-14.

Gauthier, M.S., Hodder, T.J., Ross, M., Kelley, S.E., Rochester, A. and McCausland, P. 2019. The subglacial mosaic of the Laurentide Ice Sheet; a study of the interior region of southwestern Hudson Bay; Quaternary Science Reviews, v.214, p.1-27.

Gesch, D.B., Oimoen, M.J. and Evans, G.A. 2014. Accuracy assessment of the US Geological Survey National Elevation Dataset, and comparison with other large-area elevation datasets: SRTM and ASTER; US Geological Survey, Open-File Report 2014–1008, 10p.

Harvey, T. 1979. A summary of Earth science elements in Opasquia candidate wilderness area (Patricia Portion, District of Kenora); internal technical report, Ontario Ministry of Natural Resources, 44p.

Margold, M., Stokes, C.R. and Clark, C.D. 2018. Reconciling records of ice streaming and ice margin retreat to produce a palaeogeographic reconstruction of the deglaciation of the Laurentide Ice Sheet; Quaternary Science Reviews, v.189, p.1-30.

McMartin, I. 2000. Paleogeography of Lake Agassiz and regional post-glacial uplift history of the Flin Flon region, central Manitoba and Saskatchewan; Journal of Paleolimnology, v.24, p.293-315.

Ministry of Natural Resources and Forestry 2015. Ontario radar digital surface model; Ministry of Natural Resources and Forestry, Land Information Ontario, Peterborough, Ontario.

Natural Resources Canada 1995. Canada permafrost; National Atlas of Canada, 5th edition, Natural Resources Canada, MCR 4177, scale 1:7 500 000.

Pala, S., Barnett, P.J. and Babuin, D. 1991. Quaternary geology of Ontario, northern sheet; Ontario Geological Survey, Map 2553, scale 1:1 000 000.

Prest, V.K. 1963. Surficial geology, Red Lake–Lansdowne House area, northwestern Ontario; Geological Survey of Canada, Paper 63-6, 27p.

Prest, V.K., Grant, D.R. and Rampton, V.N. 1968. Glacial map of Canada; Geological Survey of Canada, Map 1253A, scale 1:5 000 000.

Riley, R.A. and Davie, J.C. 1967. Operation Lingman Lake, Stull Lake sheet, District of Kenora (Patricia Portion); Ontario Geological Survey, Preliminary Map P.426, scale 1:126 720

Satterly, J. 1937. Glacial lakes Ponask and Sachigo, District of Kenora (Patricia portion), Ontario; Journal of Geology, v.45, p.790-796.

Stone, D. 2005. Geology of the northern Superior area, Ontario; Ontario Geological Survey, Open File Report 6140, 94p.

Stone, D., Hallé, J. and Pufahl, P. 2001a. Precambrian Geology, Rapson Bay area; Ontario Geological Survey, Preliminary Map P.3451, scale 1:50 000.

——— 2001b. Precambrian geology, Stull Lake area; Ontario Geological Survey, Preliminary Map P.3540, scale 1:50 000.

Stone, D., Morris, T.F. and Crabtree, D.C. 1999. Heavy mineral indicator database derived from overburden for kimberlite, metamorphosed magmatic massive sulphides and gold, Stull Lake area, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 45.

Teller, J.T. and Owen, L.A. 2021. Age of Gimli beach of Lake Agassiz based on new OSL dating; Journal of Quaternary Science, v.36, p.56-65.

Thorleifson, L.H. 1996. Review of Lake Agassiz history; *in* Sedimentology, geomorphology and history of the central Lake Agassiz basin, Field Trip Guidebook B2; Geological Association of Canada and Mineralogical Association of Canada Annual Meeting, May 27–29, Winnipeg, Manitoba, p.55-84.

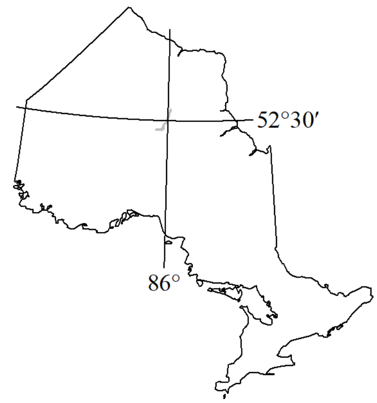
Thorleifson, L.H., Wyatt, P.H. and Warman, T.A. 1993. Quaternary stratigraphy of the Severn and Winisk drainage basins, northern Ontario; Geological Survey of Canada Bulletin 442, 59p.

Thurston, P.C., Osmani, L.A. and Stone. D. 1991. Northwestern Superior Province: Review and terrane analysis; Chapter 5 *in* Geology of Ontario; Ontario Geological Survey, Special Volume 4, Part 1, p.81-142.

Veillette, J.J., Roy, M., Paulen, R.C., Ménard, M. and St-Jacques, G. 2017. Uncovering the hidden part of a large ice stream of the Laurentide Ice Sheet, northern Ontario, Canada; Quaternary Science Reviews, v.155, p.136-158.

Wilson, B.C., Pelletier, C.C. and Paktunc, D. 1982. Geological series, Precambrian geology of Lingman Lake area, Kenora District, Patricia Portion; Ontario Geological Survey, Preliminary Map P.2485, scale 1:31 680.

14. Project FN-24-001. Riverbank Mapping for Quaternary Stratigraphy Along the Attawapiskat River, James Bay Lowland, Far North of Ontario



C. Gao[1], N. Szumylo[1] and K.H. Yeung[1]

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

INTRODUCTION

This helicopter-supported project is to study the Quaternary stratigraphy in the valley of the Attawapiskat River where Quaternary deposits are extensively exposed (Figure 14.1A). The study area is a 130 km long river segment that flows through the eastern margin of Ontario's McFaulds Lake ("Ring of Fire") area known for its rich nickel-copper-PGE and world-class chromite deposits (e.g., Metsaranta et al. 2015). The objective is to better understand the tills and intervening deposits with respect to their textures, compositions and sedimentary conditions. Such information is important for drift prospecting for mineral deposits; hydrogeological studies for aquitards and aquifers; delineation of groundwater recharge areas and buried sand and gravel resources; and for improved understanding of glacial history. Currently, there is little such information available for this area. Field work was conducted from August 4 to 18, 2024, and the crew was based out of the Esker Camp.

PHYSIOGRAPHY AND VEGETATION

The Attawapiskat River flows to the north-northeast along the western margin of the James Bay Lowland where it has a valley depth ranging from a few metres to more than 10 m in the study area. The James Bay Lowland has a low relief, with extensive open to treed bogs and fens where black spruce (*Picea mariana*) and tamarack (*Larix laricina*) grow, respectively. Where the water table is low, along riverbanks and on raised areas, e.g., drumlins and eskers, a mixed tall stand of spruce (*Picea glauca, P. mariana)*, balsam fir (*Abies balsamea*), poplar (*Populus tremuloides, P. balsamifera*) and white birch (*Betula papyrifera*) grows. Jack pine (*Pinus banksiana*) typically grows on eskers where a well-drained sandy soil usually exists.

FIELD OBSERVATIONS

Quaternary Lithostratigraphy

Twelve riverbank sections were logged and sampled during the two-week period. The following Quaternary lithostratigraphic units were observed and are described below: 1) a subtill nonglacial sequence, 2) a succession of up to 5 tills, 3) fine-grained glaciolacustrine and glaciomarine deposits, and 4) postglacial alluvium below the surface peat.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.14-1 to 14-10.

1) SUBTILL NONGLACIAL SEQUENCE

The subtill nonglacial sequence was examined and sampled at several localities at the river level as shown in the insets of Figure 14.1 (Figures 14.1B to 14.1D). Some of these sites were previously visited by Gao, Lee and Yeung (2015). Prest (1963) and McDonald (1969) also mentioned the deposit at a site somewhere near 24-CG-55 across the river. However, aside from the general descriptions, the previous works provided no details on this deposit as to its sedimentary structures and conditions, its upper contact with the overlying glacial deposits, and the pollen assemblages it contains. Gao and Crabtree (2016) named the deposit the Pym beds after Pym Island on the river. This stratigraphical term is adopted in the discussion below.

The nonglacial Pym beds, as observed, consist of a deposit that contains calcareous, massive to laminated silt and sand (Photos 14.1A to 14.1E), with thin, discontinuous organic lenses where peat and concentrated plant debris occur (*see* Photo 14.1D). Sand layers with ripple cross-lamination often contain peat lenses and

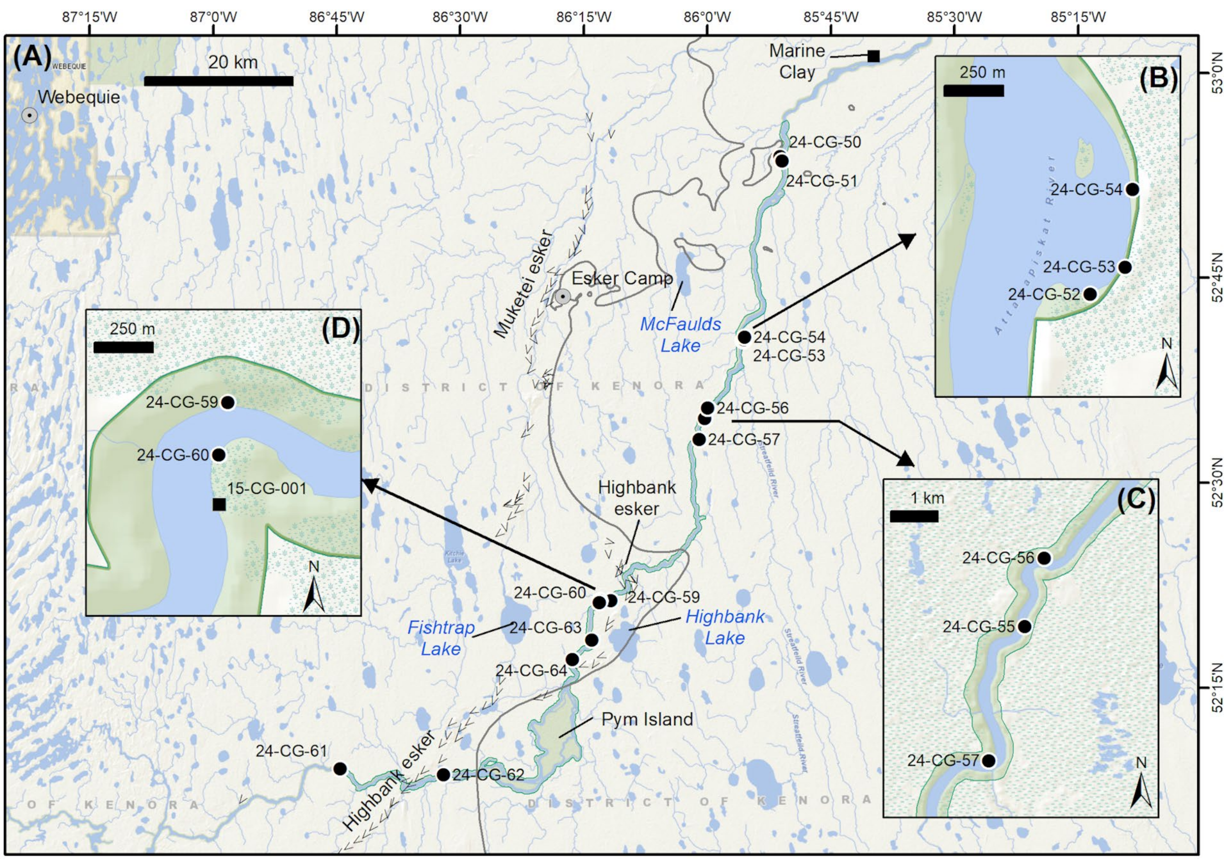


Figure 14.1. A) Study area (green line) along the Attawapiskat River in Otoskwin-Attawapiskat River Provincial Park**.** Small black dots with codes are the helicopter landing sites where geological observations were made and samples collected. The small black square in the northern part of the study area is the previous site where glaciomarine clays of the Tyrrell Sea were observed (Prest 1963). Trails of chevron symbols are eskers (Barnett, Yeung and McCallum 2013a, 2013b). Grey line is the boundary between the Precambrian crystalline (west) and Paleozoic carbonate sedimentary (east) bedrock; small polygons with grey lines within the Paleozoic bedrock area are inliers of Precambrian bedrock (Armstrong 2015). **B**) to **D**) Enlarged maps to show the sites where the subtill nonglacial sequence named the Pym beds was examined except for 24-CG-56 and 24-CG-60. Site 24-CG-56 consists of Paleozoic carbonate bedrock (>6 m thick) covered with 1.4 m of till and postglacial alluvium and surface peat and 24-CG-60 contains recent floodplain deposits (*refer to* Photo 14.3B). The small black square in 14.1D is the previous site where the Pym beds were observed below multiple tills; at this site, many detrital chromite grains were recovered from the middle till by Gao and Crabtree (2016).

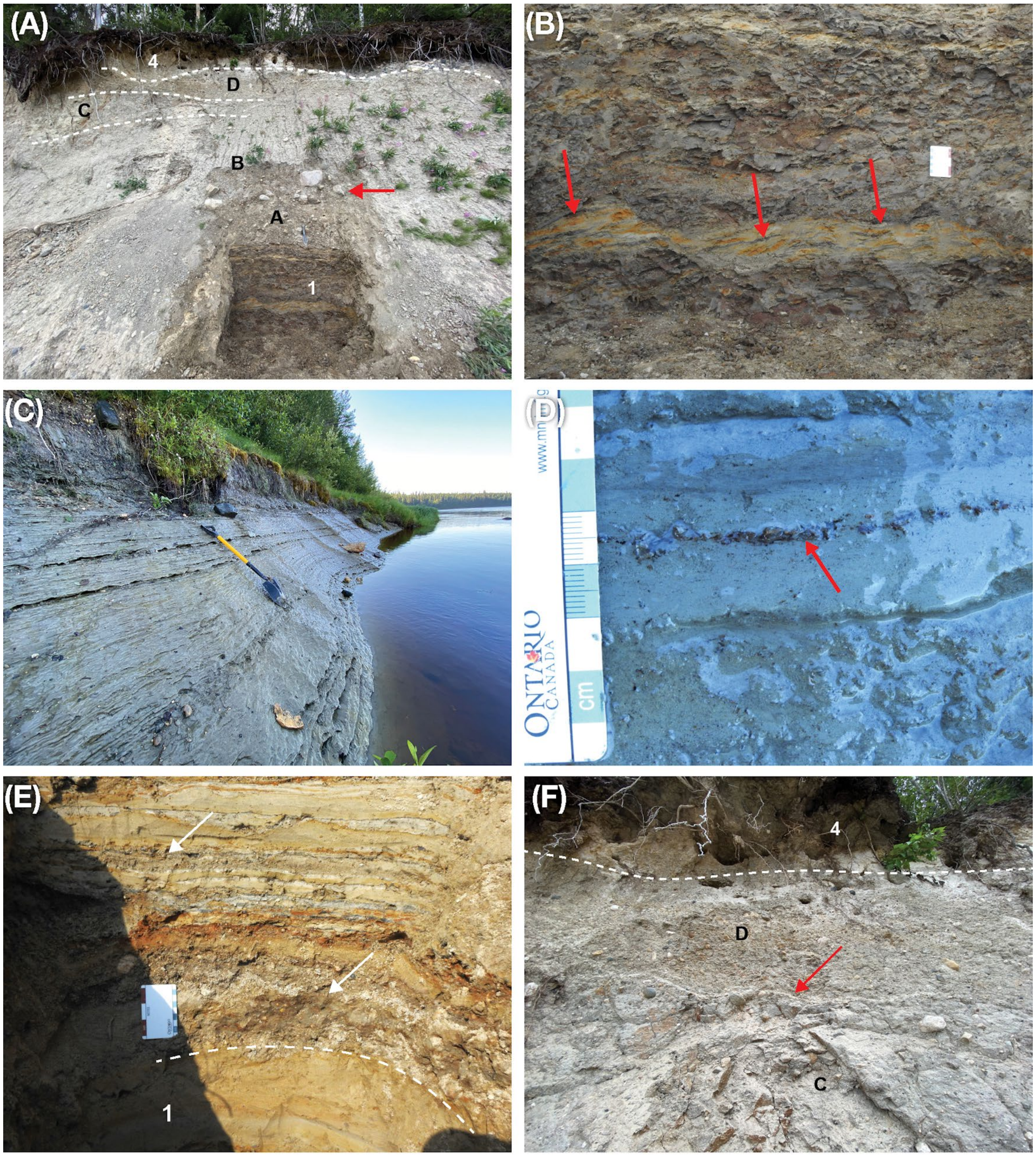


Photo 14.1. **A**) Riverbank section about 9 m deep at 24-CG-54 (52°41′21.48″N, 85°55′59.88″W) (*see* Figure 14.1B) where subtill nonglacial organic silt and clay of the Pym beds (location labelled with the number 1) is overlain by Till A to D below the postglacial alluvium and surface peat (labelled 4). Trowel at the upper contact of the Pym beds is 30 cm long. Arrow indicates the boulder pavement that separates Till A from Till B. **B**) Close up of the middle part of the Pym beds shown in Photo 14.1A (location 1), showing the dark-toned silt and clay and a light-toned layer of cross-laminated sand that contains lenses of peat (arrows). Orange colour is from iron rust staining. **C**) Horizontally bedded subtill nonglacial silt and clay of the Pym beds below glaciofluvial sand and gravel (not shown in the photo) at 24-CG-55 (52°35′26.52″N, 86°0′57.6″W) (*see* Figure 14.1C). The overlying material above the shovel handle is slumped material. Shovel is 105 cm long. **D**) Close up of Photo 14.1C showing the Pym beds in their upper part at this site where a lens of plant debris occurs (indicated by the red arrow). **E**) Horizontally bedded sand and silt of the Pym beds (labelled 1) below a glaciolacustrine sequence that contains layers of silt till at its base and in the middle (indicated by white arrows) at 24-CG-59 (52°22′12.0″N, 86°13′48.0″W) (*see* Figure 14.1D; *see also* Photo 14.2A for its location in the section). **F**) Close up of the upper part of the section at 24-CG-54 (Photo 14.1A), showing that Till C and D are separated by an irregular erosion surface accentuated by a thin layer of light-toned sand (indicated by the red arrow). Note that Till D differs from Till C in that it lacks vertical joints and has slightly increased stone content. Till D is overlain by postglacial alluvial sand and gravel under surface peat (labelled 4).

plant debris (*see* Photo 14.1B). The Pym beds are exposed 1.5 m above the river water level and extend 0.5 m and deeper below the river, with a total observed thickness of at least 2 m. The deposit has a sharp and erosional upper contact with the overlying till at all localities (*see* Photos 14.1A and 14.1E) except at site 24-CG-55 (*see* Figure 14.1C), where the upper contact was not observed because of thick slumped material. At this site, the overlying deposit is a glaciofluvial sand and gravel up to 6 m in thickness. At 24-CG-52 (*see* Figure 14.1B), this normally flat-lying deposit of the Pym beds is steeply tilted whereby its internal, original horizontal beds are tilted at a dipping angle of 40° (dipping direction at 102°). Based on the sedimentary facies, the Pym beds likely accumulated in lakes, into which peat and plant debris were washed from the surrounding land, in a sedimentary setting like the subtill lacustrine deposits examined on the Winisk and Mattagami rivers in the James Bay Lowland (Gao et al. 2020; Gao and Turton 2021).

The Pym beds are the only nonglacial sediments predating the Holocene, as observed in the study area. Based on this stratigraphical succession, they can be correlated with the Missinaibi Formation, as defined in the Moose River drainage basin to the southeast (Terasmae and Hughes 1960; Skinner 1973). A wood sample collected from the deposit was radiocarbon dated at older than 35 ka (GSC-83, Prest 1963), establishing the minimum age for the Pym beds.

2) TILLS

Complete lithostratigraphic successions, consisting of 4 to 5 tills above the nonglacial Pym beds, were observed at sites 24-CG-54 and 24-CG-59, after removal of slumped material (*see* Figure 14.1). The tills were differentiated based on the presence of unconformities in conjunction with colour, structure and texture. With few exceptions, the tills observed are silt-textured, calcareous and of low stone content, with clasts consisting predominantly of Paleozoic carbonate and Proterozoic greywacke rock types. The Proterozoic greywacke is derived from the Sutton Inlier and Belcher Islands along the northwestern coast of James Bay and in southern Hudson Bay, respectively. Among the greywacke clasts, there are pebbles with light-toned, small calcareous concretions and holes after their erosion; they are called omars and are derived from the Proterozoic Omarolluk Formation on the Belcher Islands (Prest, Donaldson and Mooers 2000).

At site 24-CG-54, 4 tills were observed (*see* Photo 14.1A), referred to here, from stratigraphically lowest to the highest, as Till A, B, C and D. Till A rests on the Pym beds and has moderate stone content and a dark brown to dark grey colour. Its relatively sandier matrix, when compared with the overlying tills, can be ascribed to incorporation of material from the underlying Pym beds. This till is separated from the overlying Till B, which is relatively siltier, by an unconformity marked by a boulder pavement (*see* Photo 14.1A). Till C is differentiated from Till B by its contrasting light grey colour and an erosional surface. Similar to the tills below, it shows well-developed vertical joints. A prominent erosion surface separates this till from the overlying Till D (Photo 14.1F). In contrast with the other tills, Till D lacks vertical joints and, instead, has a well-developed horizontal fissile structure. It contains at its base a persistent, centimetre-thick, light-toned, fine-grained sand (*see* Photo 14.1F). The upper surface of Till D is truncated by postglacial alluvial sand and gravel (*see* Photo 14.1F).

At site 24-CG-59, 5 tills were differentiated (Photo 14.2A to 14.2E) and they are numbered from Till I, the lowest till in the section, to Till V, the highest. When compared with the overlying tills (i.e., Till II to Till V), Till I is relatively sandier and contains many small sand lenses (*see* Photo 14.2B), interpreted as derived from the underlying sand and silt of the Pym beds. Its basal 0.65 m consists of a sequence of horizontally interbedded till, gravel, sand and clay *(see* Photo 14.2A). In this sequence, the beds or layers fine upwards and contain in their lower parts till and gravel and, in the upper, fine sand to clay (*refer to* Photo 14.1E). Judging from its stratigraphical position at the base of the till, this suite of sediments can probably be ascribed to deposition in a proximal glacial lake where coarse-grained debris material (i.e., till or till-like diamicton,

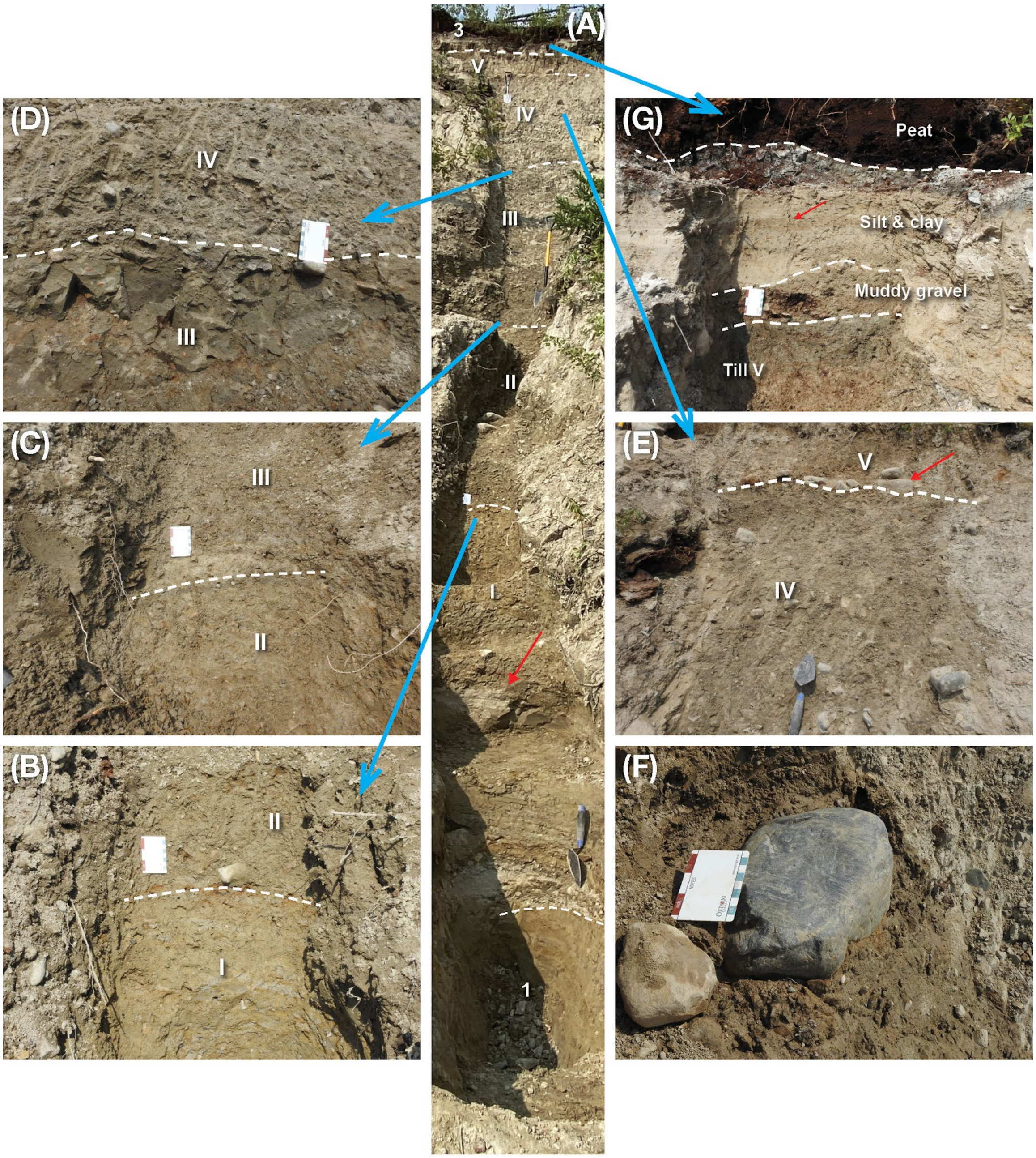


Photo 14.2. **A**) At locality 24-CG-59 (52°22′12.0″N, 86°13′48.0″W) (*see* Figure 14.1D), above the nonglacial sand and silt of the Pym beds (labelled 1 in the photo), 5 tills labelled as Till I to V occur in this 12.5 m thick section. Note that immediately above the Pym beds (1), Till I contains at its base a glaciolacustrine sequence approximately 0.65 m thick (arrow marks its upper contact), consisting of horizontally bedded till, gravel, sand and clay (*see* Photo 14.1E for enlarged view of the lower part of this sequence). Trowel is 30 cm long, yellow shovel, 105 cm, and small shovel near the top of the section is 50 cm long. **B**) to **E**) Close up views of Till I to V. Note that Till I has a silty sand texture and contains many light grey silt lenses and Till V has a red to reddish brown colour and is separated from Till IV by a boulder pavement. Also note the presence of a light-toned sand lens at the base of Till III in Photo 14.2C. Red arrow in Photo 14.2E indicates the boulder shown in the succeeding Photo 14.2F. Scale card is 8.5 cm long. **F**) A greywacke boulder, as indicated by the red arrow in the preceding Photo 14.2E, has striae aligning at 182° on its polished upper surface. **G**) The uppermost part of the section that shows, above Till V, a glaciolacustrine sequence of silt and clay of Lake Ojibway below surface peat. The glaciolacustrine sequence contains diamicton-like muddy gravel at its base and has a layer of reddish clay in the middle (red arrow). The grey colour in its uppermost 10 cm results from geochemical reduction by groundwater. Note that the grey colour from the same geochemical process is also visible in the uppermost part of the underlying Till V, which has an original red to reddish brown colour.

gravel and sand) accumulated on the lake floor by either turbidity currents, under flows of meltwater, as rain-out material from icebergs, or any combination of these (e.g., Teller 2005). The glacier later advanced and deposited the upper part of Till I. Another notable aspect about this section is the uppermost Till V, which, in contrast to other tills, has a red to reddish brown colour (*see* Photo 14.2E). Two large greywacke boulders in the boulder pavement at the base of this till show well-developed striae aligning consistently at 182° (Photo 14.2F). Till V is overlain by glaciolacustrine sediments (Photo 14.2G). It is noteworthy that the division of the tills at this site is tentative because of the limited exposure of the fresh sediments in a narrow channel 0.5 to 1.5 m wide cut through thick slumped material (*see* Photo 14.2A) and the lack of observations of the lateral extent of these tills. That said, the lowest Till I and the upper Till IV and V are well defined because of their contrasting texture and colour, in addition to the prominent unconformities that separate them (*see* Photos 14.2B and 14.2E). Previous work at a nearby site (15-CG-001), across the river (*see* Figure 14.1D), documented 3 tills above the Pym beds where a large number of detrital chromite grains were recovered from the middle till (Gao, Lee and Yeung 2015; Gao and Crabtree 2016).

The limited data currently available does not allow for correlations between the tills observed at the 2 sites (i.e., 24-CG-054 and 24-CG-059) and those from the previous work. As it becomes available, till composition and fabric data may provide clues in this exercise. Conversely, the lowest tills (Till A and Till I) at the 2 sites may be correlative, so may the uppermost tills (Till D and Till V) because of their stratigraphical positions. Till A and Till I have matrix textures related closely to the underlying Pym beds, which were laid down by the ice that advanced into the study area after the deposition of the nonglacial beds. As the uppermost or surface tills, Till D and Till V were likely deposited by the late glacial Winisk ice stream (e.g., Thorleifson, Wyatt and Warman 1993; Margold, Stokes and Clark 2018; Gao et al. 2020). As indicated by the striated boulders at its basal contact (*see* Photo 14.2F), Till V had an ice flow direction at 182°, consistent with the Winisk ice stream that moved southwards. Although the uppermost till is not always red in the study area, the reddish shade in Till V at 24-CG-59 was seen in likely equivalent surface tills as far south as 24-CG-61, about 30 km upstream on the river to the southwest, and at the Esker Camp, approximately 40 km to the north-northwest, where it is covered by 10 to 30 cm of glaciolacustrine red to reddish brown clay (*see* Figure 14.1). A similar till to Till V was also observed at the Webequie airport, more than 100 km to the northwest, where it consists of 0.5 m of reddish, calcareous silty clay diamicton with low stone content dominated by Paleozoic limestone and Proterozoic greywacke rock types, and rests on a pale, noncalcareous, stone-rich sandy till containing predominantly gravel clasts of Archean crystalline rock types of local origin. The red material is believed to have derived from the Silurian Kenogami River Formation, which contains reddish carbonate in its middle member and occurs extensively along the southern shore of Hudson Bay to the north (Johnson et al. 1992; Armstrong et al. 2018; Gao et al. 2020).

3) GLACIOLACUSTRINE AND GLACIOMARINE DEPOSITS

A calcareous silt and clay sequence, massive to laminated, of deep-water origin occurs above the uppermost till, i.e., Till V (*see* Photo 14.2G). Dropstone pebbles are common in the sediments, probably recording the deposition of ice-rafted debris. Locally, a diamicton-like muddy gravel occurs at the base of the sequence (*see* Photo 14.2G). In the study area, this silt and clay sequence has a thickness that does not typically exceed 1 m. In areas where reddish hue exists in the underling Till V, the sediments of this sequence tend to be red or contain red bands (*see* Photo 14.2G).

The silt and clay sequence likely developed in glacial Lake Ojibway (i.e., coalesced Lake Ojibway–Agassiz). The diamicton-like muddy gravel remains undetermined as to its origin. It can probably be attributed to debris flow deposition on the lake floor, rain-out diamicton material from icebergs in the lake, or a debris dump from an iceberg keel dragging on the lake floor. There is a possibility that the silt and clay may record, in its upper part, marine deposition in the Tyrrell Sea that incurred in the James Bay Lowland during the final drainage of Lake Ojibway into Hudson Bay between 8.3 and 8.1 ka (Teller and

Leverington 2004; Dyke 2004; Gao 2024; Gao and Turton 2024). Where in-situ marine macrofossils are absent, a marine silt and clay can be difficult to distinguish from glaciolacustrine argillaceous sediments (Prest 1963; Gao et al. 2020). Marine beach and basinal deposits mapped previously in the northern part of the study area are inferred from indirect evidence, e.g., from the upper elevation limit of marine incursion in the adjacent areas (Prest 1963; Barnett, Yeung and McCallum 2013a; Gao and Yeung 2018). The nearest, definite glaciomarine clays reported are beyond the study area, located at a site on the Attawapiskat River about 13 km further downstream to the northeast (53°02′N, 85°42′W) (*see* Figure 14.1 for location) (Prest 1963). Moreover, prior to the final drainage of Lake Ojibway and marine incursion, the lake and marine waters were probably already in exchange subglacially, resulting in a sediment sequence that contains abundant foraminifera in its upper part (Roy et al. 2011; Gao et al. 2020; Gao and Turton 2024). In this case, the upper part of the sequence is considered being of marine or, at least, brackish water origin (Gao et al. 2020). The samples collected are yet to be washed and examined. If marine, a fresh argillaceous sample should contain many foraminifera visible under microscope in its greater than 0.125 mm residue material. The red colour in the sediments resulted from the access by meltwater to reddish carbonate material in the ice sheet, which was, as already discussed, derived from the Paleozoic red carbonate to the north.

4) POSTGLACIAL DEPOSITS

The postglacial deposits consist of alluvium and surface peat (Photo 14.3A). The surface peat can reach 3 m and thicker in this region (e.g., Riley 2011), but it rarely exceeds 1 m thickness in the study area, as observed from the riverbank sections. The alluvium consists of channel and floodplain sediments. The former consists predominantly of massive to cross-bedded sand and gravel, usually not exceeding 1 m thick, and occurs as flat-lying beds, or in channels cutting into the underlying deposits. The channel sand and gravel deposit is overlain by massive to horizontally bedded floodplain sand and silt. A well-developed floodplain sequence was observed on a point bar where, on a channel deposit of sand and gravel, occurs 1.2 m of stratified floodplain sand and silt with peat layers that increase in frequency and thickness upwards (Photo 14.3B).

The alluvium developed after the drainage of Lake Ojibway, or where marine sediments exist (to be determined), after the withdrawal of the Tyrrell Sea from the study area. Some of the early streams later incised deep into the ground forming the major rivers as we see them today, including the Attawapiskat River. Currently, where deeply cut riverbanks exist, alluvial deposits are insignificant within the valley. The Attawapiskat River has a straight to meandering plan view morphology and the apices of river bends on the inner side of the valley are presumably point bars, where accretion of fluvial sediments would be expected. However, the presumed point bars examined are erosional at 24-CG-54, 24-CG-56, near 24-CG-55 across the river, and at 24-CG-57 (*see* Figure 14.1). They contain predominantly lag gravel clasts and reworked material by the river from collapsed sediments, mostly of tills, from the riverbank (Photos 14.3C and 14.3D) whereby only thin, discontinuous alluvium, usually not exceeding 1 m thickness, was observed on the downstream sides of some of the bars. The exception is the point bar examined at 24-CG-60 in the south of study area (*see* Figure 14.1D) where thick floodplain and channel deposits occur on the upstream side near the apex of the bar (*see* Photo 14.3B). Based on these observations, it appears that the accommodation space for alluvial deposition is limited within the valley for most of the river in the northern part of the study area, whereas thick alluvium mainly occurs upstream, in the southern part of the river.

Sand and Gravel and Peat Resources

A large, southwest-aligning esker system, hereby referred to as the Highbank esker, which the Attawapiskat River cuts through near Highbank Lake and southwest of Pym Island, contains the largest sand and gravel deposit in the study area (Barnett, Yeung and McCallum 2013b). The gravel clasts, rounded to subrounded, consist mainly of Paleozoic carbonate (limestone and dolostone) and Proterozoic argillite and greywacke rock types, which are relatively sound and durable. In the deposit, deleterious rock types, such as shale and chalky limestone, are of low concentrations.

Buried gravelly glaciofluvial deposits were found at sites 24-CG-53 and 24-CG-55 (*see* Figure 14.1), where up to 4 to 6 m of sand and gravel occur below a surface till and postglacial alluvium and surface peat (*see* Photo 14.3A). At the latter site, this sand and gravel deposit was also seen across the river in a similar stratigraphical setting (Prest 1963). Apart from these observations, the lateral extent of these deposits remains unknown. Like the Highbank esker, the deposits consist of rounded to subrounded gravel clasts of Paleozoic carbonate and Proterozoic argillite and greywacke and has the potential for use in construction of road base, secondary gravel roads and other infrastructural applications. That said,

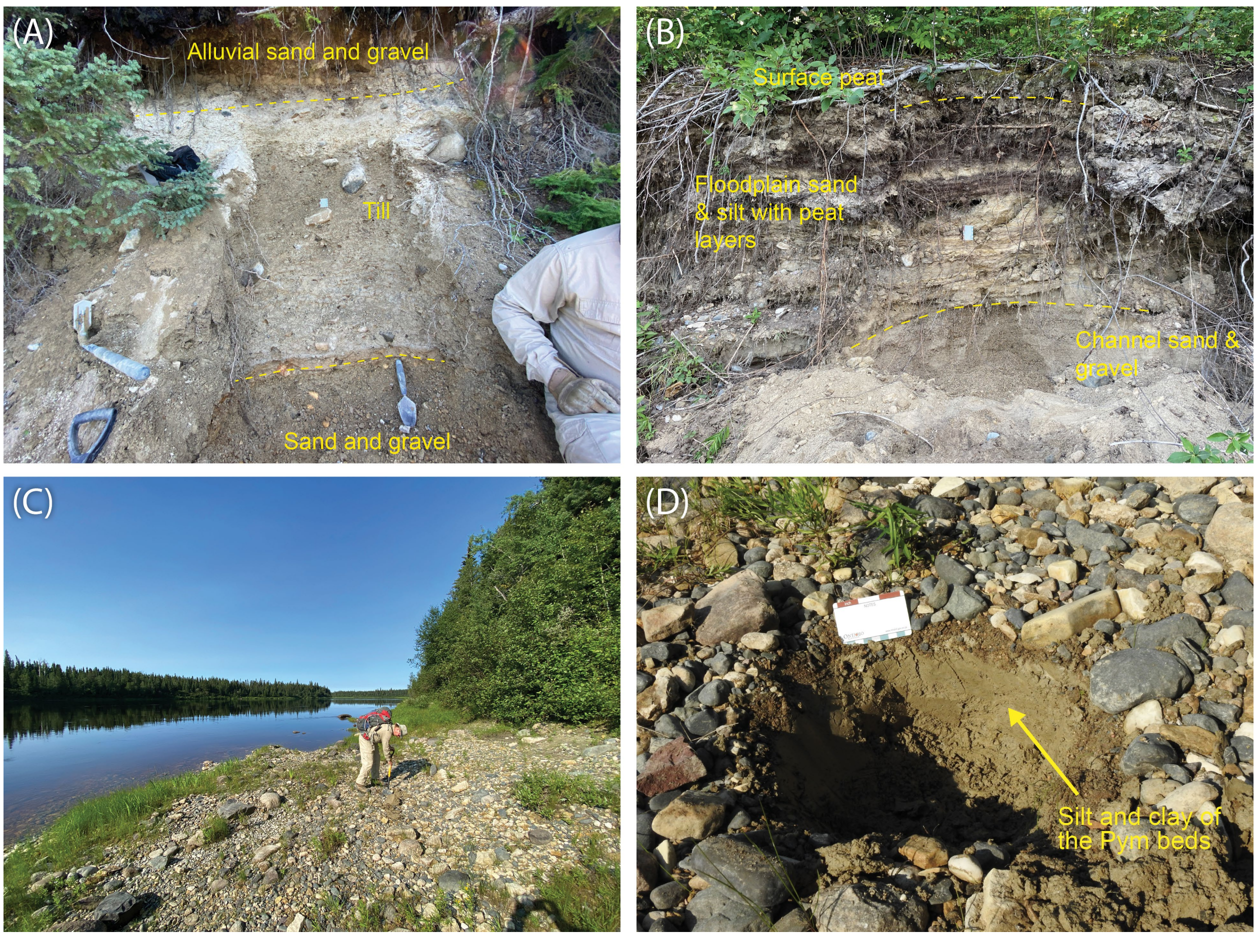


Photo 14.3. **A**) Photo shows the upper 0.5 m of glaciofluvial sand and gravel (6 m thick) below a till and postglacial alluvial sand and gravel in a riverbank section about 10 m deep at site 24-CG-55 (52°35′26.52″N, 86°0′57.6″W) (*see* Figure 14.1C). This sand and gravel deposit is underlain by the nonglacial Pym beds (not shown in the photo). Trowel is 30 cm long. **B**) Recent alluvium on a point bar, consisting of channel sand and gravel and overlying floodplain sand and silt with peat layers at locality 24-CG-60 (52°22′4.8″N, 86°13′50.16″W) (*see* Figure 14.1D). Scale card is 8.5 cm long. **C**) A modern point bar on the nonglacial Pym beds, consisting only of lag gravels on its surface at 24-CG-57 (52°33′55.08″N, 86°1′39.72″W) (*see* Figure 14.1C). The Pym beds are exposed as massive to laminated silt and clay in a nearby 1 m deep bank section to the right (not shown in the photo). **D**) Close up of the lag gravels and the underlying silt and clay of the Pym beds (arrow) in the preceding Photo 14.3C. The lag gravel clasts consist predominantly of dark-toned greywacke and light-toned limestone. Scale card has centimeter division.

these buried deposits locally contain silt and clay with some gravel clasts having mud coatings. For infrastructural applications, the muddy parts of the deposits, if encountered, need to be washed. For high-quality applications, such as hot-laid asphalt, laboratory testing is necessary. Glaciofluvial sand, up to 5 m thick, was also seen at 24-CG-50 under 3 to 4 m of till, glaciolacustrine and postglacial alluvium below 20 cm of surface peat. This sand is predominantly fine to medium grained and, as such, has limited usages as aggregate material.

Postglacial alluvium, as discussed above, contains channel sand and gravel locally (*see* Photo 14.3B). The gravel clasts are dominated by relatively hard and durable rock types similar to those in the glaciofluvial sediments. However, the deposit, usually thin and discontinuous, is unlikely to form a significant aggregate resource for the study area.

Surface peat is extensive. Although rarely exceeding 1 m thickness along the river banks, it has been reported to reach 3 m and thicker in this region (e.g., Riley 2011). The peat, as observed, has a low degree of humification as indicated by its fibrous texture and the presence of abundant undecomposed moss and wood fragments. This suggests that the peat has limited use for the fuel industry, but it may have some potential for horticultural applications.

ACKNOWLEDGMENTS

The authors wish to thank Marten Falls First Nation, especially Bob Baxter and Kathy Brady for allowing mapping on their traditional land-use area. Thanks are also extended to Webequie First Nation, Eabametoong First Nation, Neskantaga First Nation and Attawapiskat First Nation for allowing mapping on their traditional land-use area. Ontario Parks is thanked for granting the permission for working in the Otoskwin–Attawapiskat River Provincial Park. Paul McInnis of the Mines and Minerals Branch, Ministry of Mines, and Mathieu Levesque of the Ontario Geological Survey, Ministry of Mines, conducted liaison work with the local communities. Mike Styles, Camp Manager, and his staff provided logistic assistance and support at the Esker Camp. Riley Mulligan and Manual Duguet reviewed the manuscript with helpful comments and edits.

REFERENCES

Armstrong, D.K. 2015. Hudson Platform Project: Paleozoic geology of the McFaulds Lake, South Moosonee, Ekwan River and Attawapiskat River areas, James Bay Lowland; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.31-1 to 31-20.

Armstrong, D.K., Nicolas, M.P.B., Hahn, K.E. and Lavoie, D. 2018. Stratigraphic synthesis of the Hudson Platform in Manitoba, Ontario, and Nunavut: Ordovician–Silurian; Geological Survey of Canada, Open File 8378, 48p.

Barnett, P.J., Yeung, K.H. and McCallum, J.D. 2013a. Surficial geology of the Lansdowne House area northeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3697, scale 1:100 000.

——— 2013b. Surficial geology of the Lansdowne House area southeast, northern Ontario; Ontario Geological Survey, Preliminary Map P.3710, scale 1:100 000.

Dyke, A.S. 2004. An outline of North American deglaciation with emphasis on central and northern Canada; *in* Developments in Quaternary Sciences: Quaternary Glaciations – Extent and Chronology, Part 2: North America, v.2, pt. B, Elsevier, p.373-424.

Gao, C. 2024. Late history of glacial Lake Agassiz in northwestern Ontario, Canada: A case study in the Sandy Lake basin; Canadian Journal of Earth Sciences v.61, no.3, p.377-400. doi.org/10.1139/cjes-2023-0014

Gao, C. and Crabtree, D.C. 2016. Results of regional till and modern alluvium sampling in the McFaulds Lake ("Ring of Fire") area, northern Ontario; Ontario Geological Survey, Open File Report 6309, 164p.

Gao, C., Huot, S., McDonald, A.M., Crabtree, D.C. and Turton, C.L. 2020. Subtill nonglacial deposits and their climatic implications for the Last Interglacial (MIS 5e), Hudson Bay Lowlands, Canada; Quaternary Science Reviews, v.248, article 106590. doi.org/10.1016/j.quascirev.2020.106590

Gao, C., Lee, V.L. and Yeung, K.H. 2015. Field studies in support of remote predictive mapping in the Missisa Lake area, Far North of Ontario; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.27-1 to 27-12.

Gao, C. and Turton, C.L. 2021. Updates on drill-core logging in southern James Bay Lowland, Far North of Ontario; *in* Summary of Field Work and Other Activities, 2021, Ontario Geological Survey, Open File Report 6380, p.15-1 to 15-9.

——— 2024. Early Holocene marine incursion and a freshened Tyrrell Sea in Hudson Bay Lowlands, Canada; Quaternary Science Reviews, 109134 (accepted).

Gao, C. and Yeung, K.H. 2018. Surficial geology of the Missisa Lake area northwest, northern Ontario; Ontario Geological Survey, Preliminary Map P.3698, scale 1:100 000.

Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; Chapter 20 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.907-1008.

Margold, M., Stokes, C.R. and Clark, C.D. 2018. Reconciling records of ice streaming and ice margin retreat to produce a palaeogeographic reconstruction of the deglaciation of the Laurentide Ice Sheet; Quaternary Science Reviews, v.189, p.1-30.

McDonald, B.C. 1969. Glacial and interglacial stratigraphy, Hudson Bay Lowland; *in* Geological Survey of Canada, Paper 68-53, p.78-99.

Metsaranta, R.T., Houlé, M.G., McNicoll, V.J. and Kamo, S.L. 2015. Revised geological framework for the McFaulds Lake greenstone belt, Ontario; *in* Targeted Geoscience Initiative 4: Canadian Nickel-Copper-Platinum Group Elements-Chromium Ore Systems—Fertility, Pathfinders, New and Revised Models; Geological Survey of Canada, Open File 7856, p.61-73.

Prest, V.K. 1963. Surficial geology, Red Lake–Lansdowne House area, northwestern Ontario; Geological Survey of Canada, Paper 63-6, 27p.

Prest, V.K., Donaldson, J.A. and Mooers, H.D. 2000. The omar story: the role of omars in assessing glacial history of west-central North America; Géographie physique et Quaternaire, v.54, p.257–270.

Riley, J.L. 2011. Wetlands of the Hudson Bay Lowland: An Ontario overview; Nature Conservancy of Canada, Toronto, Ontario, 158p.

Roy, M., Dell'Oste, F., Veillette, J.J., de Vernal, A., Hélie, J.-F. and Parent, M. 2011. Insights on the events surrounding the final drainage of Lake Ojibway based on James Bay stratigraphic sequences; Quaternary Science Reviews, v.30, p.682-692.

Skinner, R.G. 1973. Quaternary stratigraphy of the Moose River Basin, Ontario; Geological Survey of Canada, Bulletin 225, 77p.

Teller, J.T. 2005. Subaquatic landsystems: Large proglacial lakes; *in* Glacial Landsystems, Hodder Arnold, p.348-371.

Teller, J.T. and Leverington, D.W. 2004. Glacial Lake Agassiz: A 5000 yr history of change and its relationship to the $\delta^{18}O$ record of Greenland; Geological Society of America Bulletin, v.116, p.729-742.

Terasmae, J. and Hughes, O.L. 1960. A palynological and geological study of Pleistocene deposits in the James Bay Lowlands, Ontario; Geological Survey of Canada, Bulletin 62, 15p.

Thorleifson, L.H., Wyatt, P.H. and Warman, T.A. 1993. Quaternary stratigraphy of the Severn and Winisk drainage basins, northern Ontario; Geological Survey of Canada, Bulletin 442, 59p.

15. Project ON-23-004. Determination of Indicator Minerals in Archived Fine-Fraction Nonmagnetic Heavy Mineral Concentrate Samples Using Scanning Electron Microscope Energy Dispersive Spectrometry: An Update

C. Gao[1], G.W. Hagedorn[1], D.C. Crabtree[2], S.A. Clarke[2], E.C.G Hastie[1], G. Launay[1], C.E. Beckett-Brown[1] and T.E. Gore[2]

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

INTRODUCTION

Over the past 40 years, Ontario Geological Survey (OGS) surficial sampling projects (Figure 15.1) have resulted in the collection of more than 10 000 samples (Gao, Hagedorn and Crabtree 2023). In the past, coarse-fraction (0.25–2 mm) nonmagnetic heavy mineral concentrate (HMC) samples from these projects were studied through visual identification, whereas the fine-fraction (<0.25 mm) nonmagnetic HMC samples were archived because the small grain size made visual identification difficult. Analyzing these legacy samples will provide complementary and value-added products, and, importantly, there is large potential for documenting indicator minerals from critical mineral deposits. These indicator minerals have likely been missed because of their rare occurrence in coarse-fraction nonmagnetic HMC and their preferential preservation in smaller grain sizes in surficial sediments from weathering and erosion (e.g., Gao et al. 2023).

A pilot study was carried out on selected fine-fraction nonmagnetic HMC samples from Ontario's McFaulds Lake ("Ring of Fire") area and was successful in identifying minerals of interest using scanning electron microscope energy dispersive X-ray spectroscopy (SEM–EDS) (Gao et al. 2021). This provided the impetus for analyzing all fine-fraction nonmagnetic HMC samples in the OGS archives and, in 2023, a multi-year project was initiated (Gao et al. 2023). The goal of the project is to employ an automated SEM–EDS method to assess the distribution of minerals characteristic of ore deposits and critical minerals in legacy surficial media samples. The automated SEM-EDS method has 2 distinct advantages over visual identification: 1) removal of sampling bias and possible human error, and 2) the substantial reduction of time in mineral analysis. Analysis of the samples and release of the results will be incremental, with sample submission prioritized for areas of active OGS projects, current pan-provincial thematic OGS projects (e.g., gold fingerprinting; Hastie et al. 2020; Melo-Gómez et al. 2022), or those planned for the near future. This article provides an update on the status of sample submissions, laboratory protocol and analysis.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.15-1 to 15-4.

SAMPLE PREPARATION AND ANALYSIS

Each archived fine-fraction HMC sample is dry sieved to separate 0.125 to 0.25 mm and less than 0.125 mm fractions. Approximately 0.1 g of each fraction is mounted in epoxy, such that the grains cover the surface of the sample mount without making contact at grain boundaries. The mounts are then ground to expose the grains, polished and carbon coated prior to analysis. Duplicate samples are analyzed for every 10 samples.

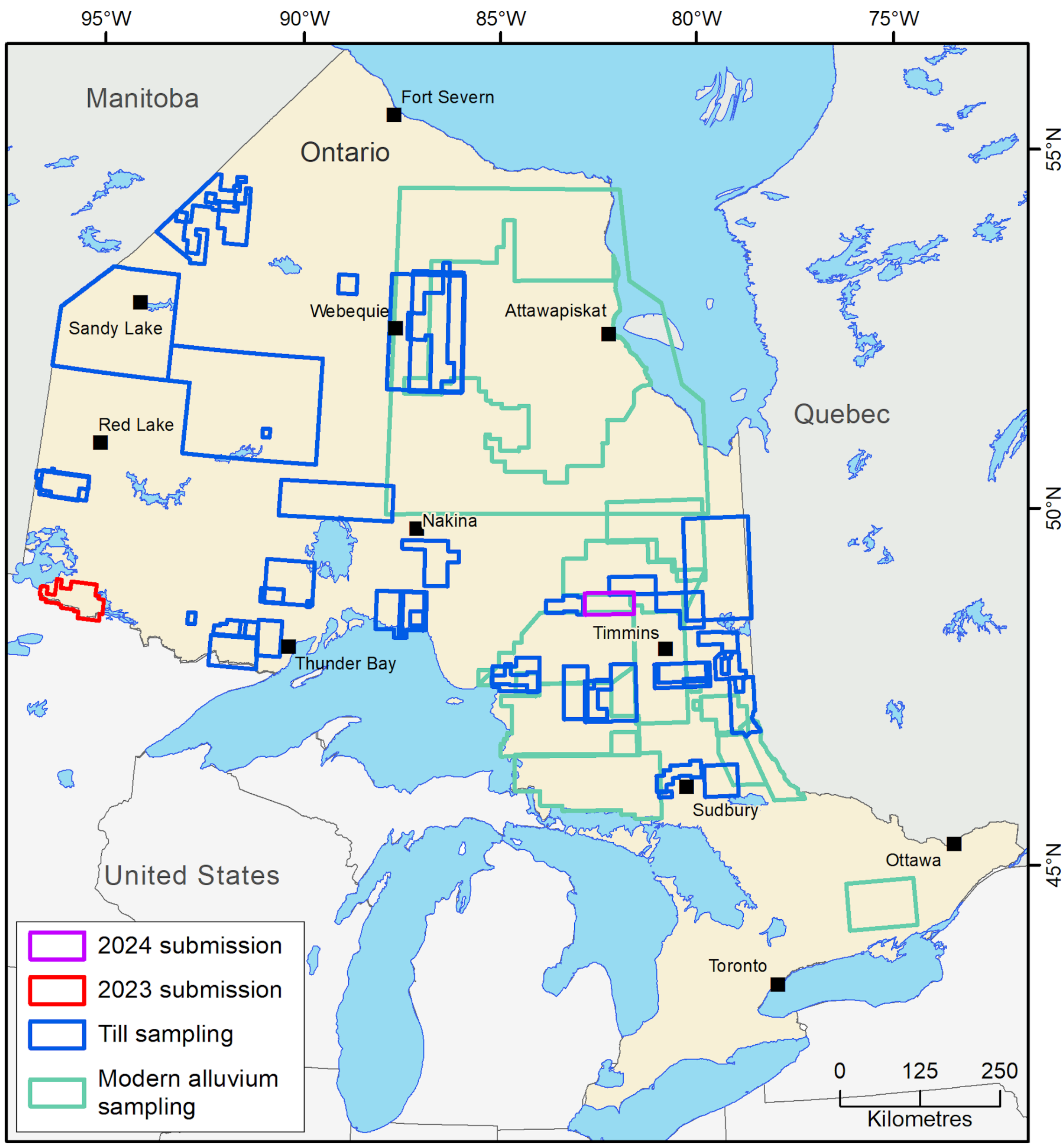


Figure 15.1. Map of the province of Ontario showing the current coverage of till (blue polygons) and modern alluvium (stream sediment) (green polygons) sampling projects completed by the OGS. The red and purple polygons represent areas where fine-fraction HMC from till samples have been recently submitted to the OGS Geoscience Laboratories for analysis.

The analytical routine is set to examine the entire surface area of the polished mount. The method involves identifying individual grains using imaging techniques, followed by SEM–EDS analysis from the center of the longest axis of each grain. The analyses are then processed to account for matrix effects and the resulting data are classified offline using a Microsoft® Excel® for Office 365 macro that identifies mineral types based on stoichiometric parameters. In addition to the routine analysis, which is set to analyze for a duration of 1 second or less for each mineral grain depending on the type of ED detectors used, an ED spectrometry filter is added to detect and analyze grains of arsenian pyrite for a longer time to better characterize the compositions of these minerals. Geochemistry of arsenian pyrite is used as tracers in gold fingerprinting studies.

PROJECT STATUS

In 2023, 184 archived fine-fraction HMC samples from till deposits from the Rainy River area (*see* Figure 15.1, red polygon) (Bajc 1991a, 1991b) were submitted to the OGS Geoscience Laboratories for analysis. This area was selected because the results can assist the Survey's ongoing gold fingerprinting and critical mineral studies (e.g., Hastie et al. 2020, 2023). The sample preparation has been completed. At the time of writing, 70 samples of the 0.25 to 0.125 mm fraction have been analyzed and the data are being processed for mineral classifications.

In 2024, 313 archived fine-fraction HMC samples from till sampling in the Kapuskasing area (*see* Figure 15.1, purple polygon) (Morris 1998; Morris, Crabtree and Averill 1998) were submitted to the OGS Geoscience Laboratories for analysis. This surficial sampling project is within the Kapuskasing Structure Zone (KSZ), which extends from Wawa in the southwest, through the Kapuskasing area, and into the James Bay Lowland to the northeast (Thurston 1991; Williams 1991). Previously published results from the coarse-fraction HMC samples show a significant number of detrital gahnite grains indicating potential volcanogenic massive sulphide (VMS) deposits often associated with mineralization of zinc and copper (Morris, Crabtree and Averill 1998). The fine-fraction HMC samples will provide additional information to better assess the mineral potential associated with the KSZ. The other notable aspect about this submission is that the data generated can help the proposed surficial mapping and sampling along the Highway 11 corridor west of Kapuskasing.

ACKNOWLEDGMENTS

Johanne Roux, José Pallot and Andy Bajc are thanked for help in retrieving the archived samples. Abigail Burt and Manuel Duguet reviewed the manuscript with helpful comments and edits.

REFERENCES

Bajc, A.F. 1991a. Till sampling survey, Fort Frances area: Results and interpretation; Ontario Geological Survey, Study 56, 263p.

——— 1991b. Till sampling survey, Fort Frances area: Results and interpretation; Data to accompany Study 56, Ontario Geological Survey, Miscellaneous Release—Data 8.

Gao, C., Crabtree, D.C., Dyer, R.D. and Clarke, S.A. 2021. Indicator mineral and geochemistry data for a till and alluvium sampling survey in the McFaulds Lake ("Ring of Fire") area, northern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 322 – Revised.

Gao, C., Hagedorn, G. and Crabtree, D.C. 2023. Surficial sampling in Ontario: Past, present, and future; abstract *in* Geological Association of Canada–Mineralogical Association of Canada–Society for Geology Applied to Mineral Deposits, Annual Meeting, Sudbury, Ontario, May 25–27, Abstracts, v.46, Geoscience Canada, v.50, p.143.

Gao, C., Hagedorn, G.W., Crabtree, D.C., Clarke, S.A., Hastie, E.C.G., Launay, G. and Beckett-Brown, C.E. 2023. Determination of indicator minerals in archived fine-fraction non-magnetic heavy mineral concentrate samples using scanning electron microscope energy dispersive spectrometry; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.21-1 to 21-8.

Hastie, E.C.G., Malegus, P.M., Campbell, D.A., Burnham, O.M. and MacDonald, P.J. 2023. An overview of the Critical Minerals in Gold Deposits Project; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.19-1 to 19-5.

Hastie, E.C.G., Petrus, J.A., Gibson, H.L. and Tait, K.T. 2020. Gold Fingerprinting: Using major and trace elements associated with native gold to work toward a global gold database; *in* Summary of Field Work, 2020, Ontario Geological Survey, Open File Report 6370, p.10-1 to 10-10.

Melo-Gómez, J.D., Hastie, E.C.G., Gibson, H.L., Tait, K.T. and Petrus, J.A. 2022. Trace element content of gold across Ontario: An update on the Gold Fingerprinting Project; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.15-1 to 15-11.

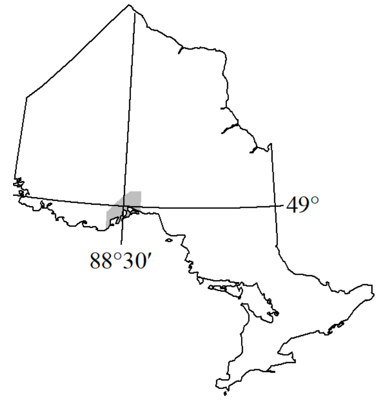
Morris, T.F. 1998. Heavy mineral indicator database derived from overburden, for kimberlite, massive magmatic sulfides and gold, Kapuskasing area, northeastern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 34.

Morris, T.F., Crabtree, D.C. and Averill, S.A. 1998. Kimberlite, base metal and gold exploration targets based upon heavy mineral data derived from surface materials, Kapuskasing, northeastern Ontario; Ontario Geological Survey, Open File Report 5967, 41p.

Thurston, P.C. 1991. Archean geology of Ontario: Introduction; Chapter 4 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.73-80.

Williams, H.R. 1991. Quetico Subprovince; Chapter 10 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.383-404.

16. Project NW-23-002. Till Sampling and Surficial Mapping South of the Georgia Lake Area, Northwestern Ontario



G.W. Hagedorn[1]

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

INTRODUCTION

During the last glaciation the Laurentide Ice Sheet (LIS) covered all of Ontario and significantly impacted the province's landscape. The LIS eroded underlying rocks and sediments, transported that material, and deposited it in a variety of environments. Examining the erosional record of the ice sheet (striations and landforms) can allow for a better understanding of the sequence of ice flow events during the last glaciation. Sampling and analysing material transported by the LIS (primarily till) is a proven technique for identifying buried mineral deposits (McClenaghan and Paulen 2018). In addition, maps of surficial deposits are useful for land use planning and infrastructure development needs (e.g., aggregates, agriculture, and groundwater resources).

This article outlines work completed during the second of 3 field seasons of a project in the Georgia Lake area, northwestern Ontario (Hagedorn and Beckett-Brown 2023). This area is of interest for many reasons. Because of the recent focus of government agencies on critical minerals (Ontario 2022; Canada 2022), the Georgia Lake rare-element pegmatite field presents a prime target area to test and possibly discover critical mineral deposits, in this case lithium. This project area also represents a gap in our provincial till sampling coverage 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 Lake Superior. Portions of the study area have also never had detailed surficial geology mapping. The aim of this project, therefore, is to fill the gap in regional till sampling and to map 2 areas, at 1:50 000 scale, surrounding the Georgia Lake rare-element pegmatite field (Figure 16.1).

BACKGROUND

Bedrock Geology

There are 4 main bedrock types across the study area (Figure 16.1). The oldest type is metamorphosed and deformed Archean turbidite sequences of the Quetico Subprovince. These metasedimentary rocks are comparatively incompetent to other local rock types and are often found at surface in lowlands. Several Archean plutonic suites intruded these metasedimentary rocks. The youngest and, by far, the most abundant plutonic suite in the area is composed of 2 mica granites, and these plutons are interpreted as the source for the Georgia Lake rare element-bearing pegmatites (Breaks, Selway and Tindle 2008). These granites are more competent and form bedrock highs when found at surface. The

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.16-1 to 16-7.

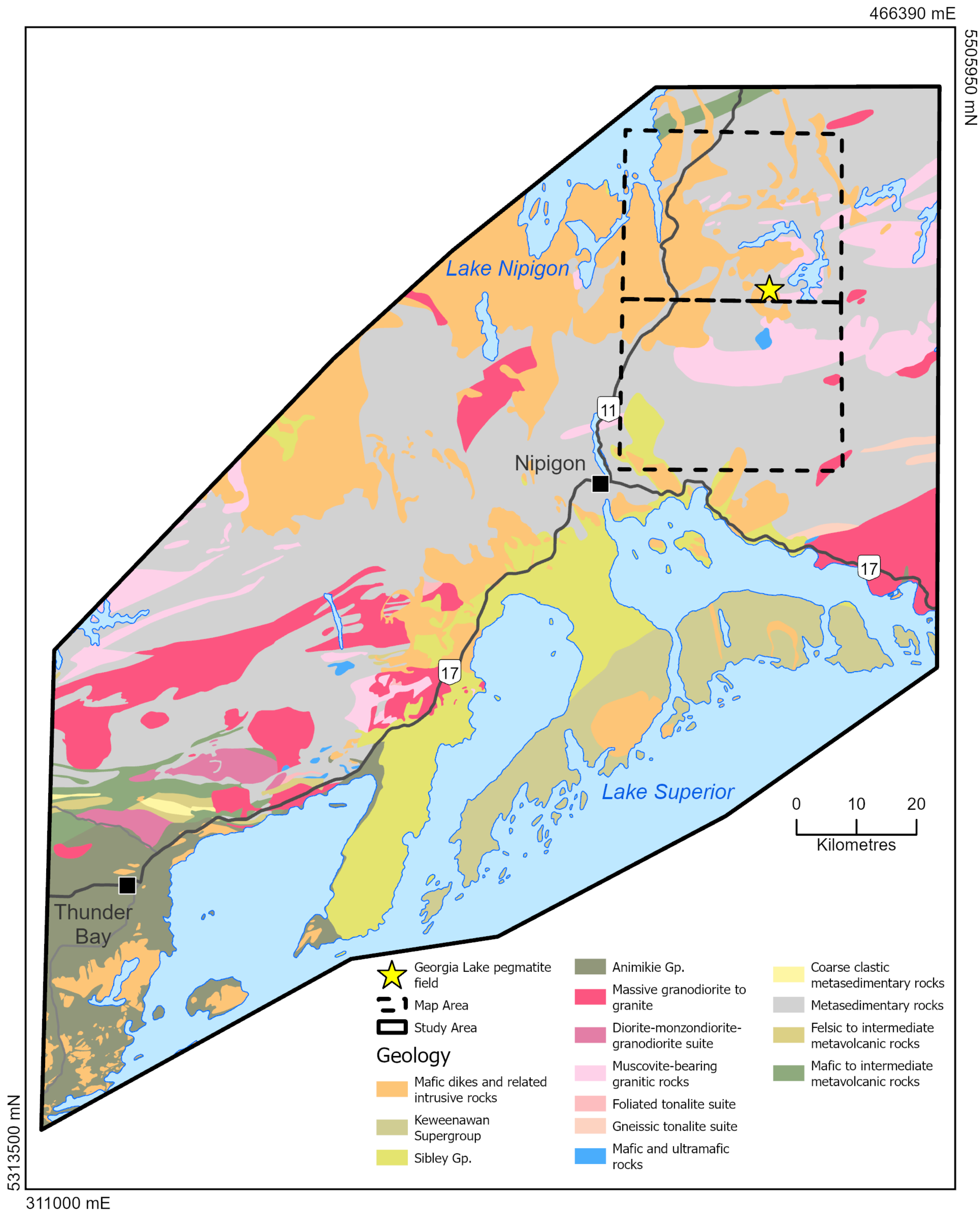


Figure 16.1. Bedrock geology of the whole study area *from* Ontario Geological Survey (2011). Major bedrock rock types include metasedimentary rocks (grey), granites (pink), sedimentary rocks (greens), and mafic sills (orange). All Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 16N.

third main bedrock type belongs to the Mesoproterozoic Sibley Group. These siliclastic and chemical sedimentary rocks are relatively flat lying and the most incompetent of all the local rock types (Rogala et al. 2007). The youngest of the 4 bedrock types are Mesoproterozoic mafic sills related to the Midcontinent Rift and are the most resistant to erosion, creating large uplands with steep flanks. The competency of each of these rock types influence not only the topography of the landscape, but also the ability to preserve striations as the ice sheet overrode them. For a detailed description of the bedrock geology, refer to Duguet (2019, 2020 and 2023).

Quaternary Geology

The study area was completely covered by the LIS until approximately 10 ka BP (Dalton et al. 2020). During this glaciation, a regionally pervasive ice flow to the southwest is interpreted based on streamlined landforms and eskers. The pattern of retreat, interpreted by moraines, indicate ice marginal positions broadly north-south oriented retreating west to east. During deglaciation, Glacial Lake Agassiz was impounded along the ice margin and went through stages of filling and draining as the ice margin fluctuated, periodically blocking the glacial lake's outlet (Lowell et al. 2021; Fisher and Breckenridge 2022). Previous regional mapping covering the study area (Barnett, Cowan and Henry 1991) is shown on Figure 16.2 along with observation and sample points of the current study. A more detailed description of the Quaternary history can be found in Hagedorn and Beckett-Brown (2023).

FIELD ACTIVITES

Summer 2024 field work focussed on the southern part of the map area with some follow up in the north and reconnaissance work in the west of the study area. Observations were made almost exclusively along roads. Altogether 454 sites were visited, including 131 striations sites (9 of which had 2 or more flow directions preserved), 33 till sample sites and 290 locations for ground truthing of surficial geology mapping (*see* Figure 16.2).

Till Sampling

Till was sampled following the standardized procedures used by the Ontario Geological Survey (OGS) (*see* Bajc 1999). There are at least 2 till units observed in the study area. There is a local till which has a brown-grey silty sand matrix and a higher clast content (~20%). The clast lithologies in this till indicate a local provenance, with higher proportions of Archean metasedimentary and granitic clasts. This till did not effervescence with 10% hydrochloric acid, indicating it has a low carbonate content; therefore, there has likely been little if any influence of far-travelled Paleozoic bedrock. The local till is most suitable for mineral exploration purposes because it is derived from more local bedrock sources. The second till unit has a grey sandy silt matrix with a lower clast content (10–15%). The high percentage of carbonate clasts in this till suggest a more distal source: from the Hudson Bay–James Bay Lowlands, over 200 km to the northeast. This till was identified in the field by its effervescence to 10% hydrochloric acid. A stratigraphic relationship between these 2 tills has yet to be observed in the study area likely because of thin till thicknesses, but to the north, 2 compositionally similar tills have been observed, with the 'local' till overlain by the far-traveled till (Thorleifson and Kristjansson 1993).

During till sampling, 2 bags were collected. A large 10 kg bag of till will be sent to Overburden Drilling Management to undergo indicator mineral processing and picking. A smaller, 3 kg bag of till will be sent to OGS Geoscience Laboratories for matrix geochemistry analysis, with both a partial and total digestion. Additionally, Chittick method analysis to determine carbonate content, pebble counts to determine the composition of the coarse size fraction, and particle size analysis to determine the percentages of sand silt and clay will all be completed to help with till unit differentiation.

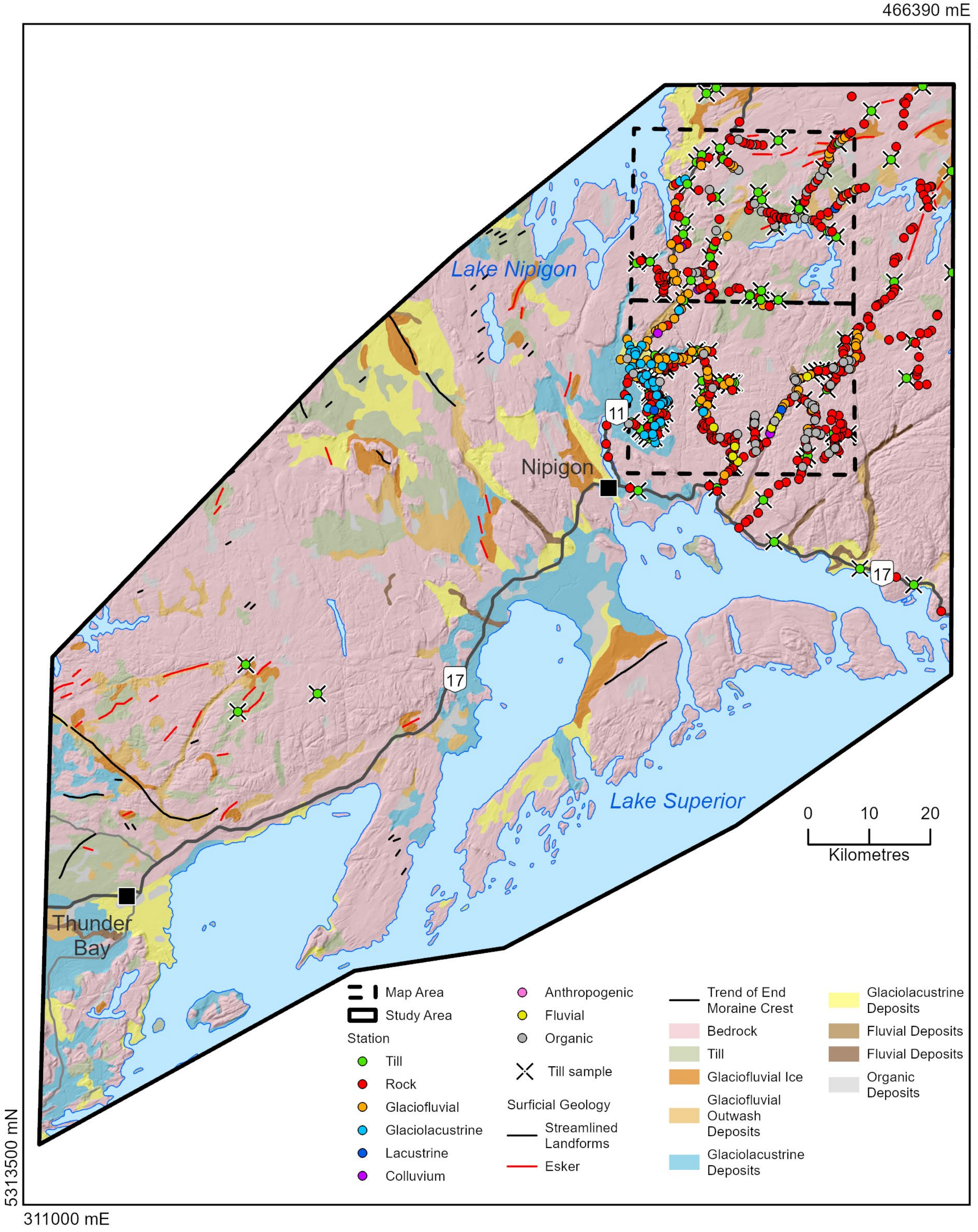


Figure 16.2. Regional (1:1 000 000 scale) surficial geology of the study area *from* Barnet, Cowan and Henry (1991) with the regional LiDAR as a hillshade underneath (Ministry of Northern Development, Mines, Natural Resources and Forestry 2022). Also shown are all surficial ground-truthed points from the 2023 and 2024 field seasons (Hagedorn and Beckett-Brown 2023). Till sample locations are highlighted with an X. All UTM co-ordinates provided using NAD83 in Zone 16N.

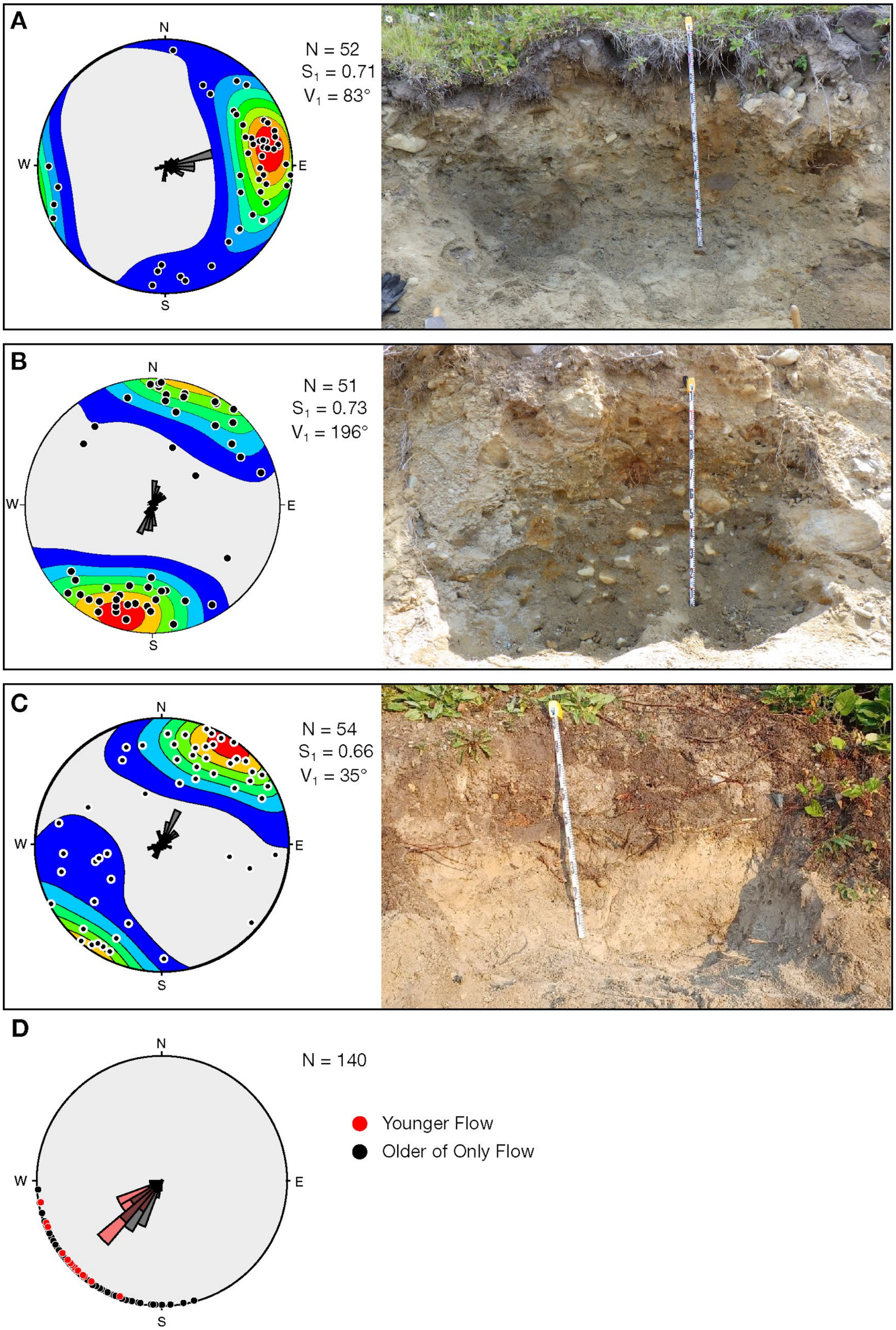


Figure 16.3. (caption on next page.)

Figure 16.3. Previous page. Three clast fabric stereonets showing a strong direction of shear that can be used to interpret the ice flow direction responsible for till deposition. N is the number of clasts measured, S_1 is the strength of the first eigenvalue, and V_1 is the corresponding eigenvector. Fabric A and B show ice flow direction to the west and southwest, respectively. Both fabrics were completed on the local till, identified based on texture and effervescence. Fabric C shows an ice flow direction to the southwest as well but was completed in the more distal sourced till. The rose plot D shows all the striation measurements collected over the course of this project. The older and only flow spans the whole south to west quadrant with the most common being southwest (black). The younger flows are more skewed to the southwest (red). These striation measurements mirror the directions observed in the clast fabrics and indicate that the sequence of ice flow is a rotation from south to southwest. Scale bar in A is 1.1 m, B is 1.1 m and C is 0.9 m long.

Ice Flow Indicators

Overall, less striations were observed in the southern portions of the study area because of the weak competency of the Sibley sediments. A similar trend to last year was observed with the more westward flow being younger, at the 9 sites with 2 or more ice flow indicators. A combined rose diagram of striation measurements over the past 2 years is shown in Figure 16.3D. Overall, younger flows (red) have a higher frequency to the west, while the older or only flow (black) ranges from 180° to 260° characterizing a broad shift in ice flow from south to south-southwest to west.

Three clast fabrics give direction of shear responsible for the deposition of the till (*see* Figure 16.3). Comparisons of the striae and clast fabric data show that the 2 data sets are similar, with broad south, southwest, and west directions. Interestingly, the 2 fabrics completed on the local till have varying ice flow directions. This could be because of the bedrock topography at the fabric sites, which could influence the trend and plunge of clasts measured, or that there are multiple ice flow directions recorded in the shear of the clasts due to inheritance from multiple flows. Overall, ice flow ranged from south to west, with more westward flows being younger. This indicates a broad shift from southward flow during thicker ice to more westward flows during deglaciation.

Surficial Mapping

Two 1:50 000 scale maps will be completed for this mapping project, centred on the Georgia Lake Pegmatite Field. Field data collected through sampling and observations will provide the basis for updating surficial geology maps. Overall, preliminary observations show more Quaternary sediment cover than is suggested by the 1:1 000 000 scale mapping of Barnett, Cowan and Henry (1991).

FUTURE ACTIVITIES

Surficial mapping is ongoing, and interpretation of data from the till analyses will be completed as the laboratory results become available. All data sets will be released as a Miscellaneous Release—Data (MRD) in association with the new maps. The final field season is planned for 2025 and will focus on regional-scale till sampling for the remainder of the study area.

ACKNOWLEDGMENTS

Andrea Marich and Manuel Duguet (OGS) are thanked for their reviews of this article. Summer field assistants Benjamin Gallagher (University of Toronto) and Vanda Osuchowski (McMaster University) are thanked for their amazing help in the field. Fort William First Nation, Red Rock Indian Band, Métis Nation of Ontario Region, 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 land-use areas. Carolyn Danco provided the wonderful house in Nipigon—a fantastic home base for the summer.

REFERENCES

Bajc, A.F. 1999. Results of regional humus and till sampling in the eastern part of the Shebandowan greenstone belt, northwestern Ontario; Ontario Geological Survey, Open File Report 5993, 85p.

Barnett, P.J., Cowan, W.R. and Henry, A.P. 1991. Quaternary geology of Ontario, west-central sheet; Ontario Geological Survey, Map 2554, scale 1:1 000 000.

Breaks, F.W., Selway, J.B. and Tindle, A.G. 2008. The Georgia Lake rare-element pegmatite field and related S-type, peraluminous granites, Quetico Subprovince, north-central Ontario; Ontario Geological Survey, Open File Report 6199, 176p.

Canada 2022. The Canadian Critical Minerals Strategy. From exploration to recycling: Powering the green and digital economy for Canada and the world; Natural Resources Canada, 52p., www.canada.ca/en/campaign/critical-minerals-in-canada/canadian-critical-minerals-strategy.html, also available to download: select “Download English PDF”. [accessed October 4, 2023]

Dalton, A.S., Margold, M., Stokes, C.R., Tarasov, L., Dyke, A.S., Adams, R.S., Allard, S., Arends, H.E., Atkinson, N., Attig, J.W., Barnett, P.J., Barnett, R.L., Batterson, M., Bernatchez, P., Borns, H.W., Breckenridge, A., Briner, J.P., Brouard, E., Campbell, J.E., Carlson, A.E., Clague, J.J., Curry, B.B., Daigneault, R-A., Dube-Loubert, H., Easterbrook, D.J., Franzi, D.A., Friedrich, H.G., Funder, S., Gauthier, M.S., Gowan, A.S., Harris, K.L., Hétu, B., Hooyer, T.S., Jennings, C.E., Johnson, M.D., Kehew, A.E., Kelley, S.E., Kerr, D., King, E.L., Kjeldsen, K.K., Knaeble, A.R., Lajeunesse, P., Lakeman, T.R., Lamothe, M., Larson, P., Lavoie, M., Loope, H.M., Lowell, T.V., Lusardi, B.A., Manz, L., McMartin, I., Nixon, C., Occhietti, S., Parkhill, M.A., Piper, D.J.W., Pronk, A.G., Richard, P.J.H., Ridge, J.C., Ross, M., Roy, M., Seaman, A., Shaw, J., Stea, R.R., Teller, J.T., Thompson, W.B., Thorleifson, L.H., Utting, D.J., Veillette, J.J., Ward, B.C., Weddle, T.K. and Wright, H.E. 2020. An updated radiocarbon-based ice margin chronology for the last deglaciation of the North American Ice Sheet Complex; Quaternary Science Reviews, v.234, paper 106223. doi.org/10.1016/j.quascirev.2020.106223

Duguet, M. 2019. Archean and Proterozoic geology of the Georgia Lake area, Quetico Subprovince, Ontario; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.12-1 to 12-9.

——— 2020. Geochemistry of Archean volcaniclastic and mafic intrusive rocks, Georgia Lake area, Quetico Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2020, Ontario Geological Survey, Open File Report 6370, p.8-1 to 8-10.

——— 2023. Archean geology of the Georgia Lake area, Quetico Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.12-1 to 12-11.

Dyer, R.D. and Barnett, P.J. 2005. Surficial geochemistry case studies project digital data set, Lake Nipigon region, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 154.

Fisher, T.G. and Breckenridge, A. 2022. Relative lake level reconstructions for glacial Lake Agassiz spanning the Herman to Campbell levels; Quaternary Science Reviews, v.294, article 107760. doi.org/10.1016/j.quascirev.2022.107760

Hagedorn, G.W. and Beckett-Brown, C.E. 2023. Till sampling and surficial mapping in the Georgia Lake area, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405.

Lowell, T.V., Kelly, M.A., Howley, J.A., Fisher, T.G., Barnett, P.J., Schwart, R., Zimmerman, S.R., Norris, N. and Malone, A.G. 2021. Near-constant retreat rate of a terrestrial margin of the Laurentide Ice Sheet during the last deglaciation; Geology, v.49, p.1511-1515.

McClenaghan, M.B. and Paulen, R.C. 2018. Chapter 20 – Applications of Till Mineralogy and Geochemistry to Mineral Exploration *in* Past Glacial Environments (2nd ed.), John Menzies, Jaap J.M. van der Meer, editors, Elsevier. p.689-751. doi.org/10.1016/B978-0-08-100524-8.00022-1

Ministry of Northern Development, Mines, Natural Resources and Forestry 2022. Ontario digital terrain model (lidar-derived) - Lake Nipissing 2020 DTM; Ministry of Northern Development, Mines, Natural Resources and Forestry, Provincial Mapping Unit, Peterborough, Ontario.

Morris, T.F. 2000. Kimberlite, base metal, gold and carbonatite exploration targets, derived from overburden heavy mineral data, Killala Lake area, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 52.

——— 2001. Geochemical and till pebble lithology data related to the Schreiber–Killala Lake overburden mapping and sampling program, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 74.

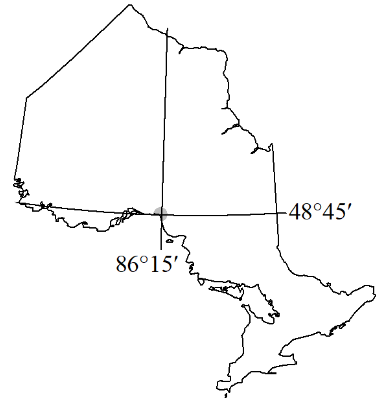
Ontario 2022. Ontario's Critical Mineral Strategy: Unlocking the potential to drive economic recovery and prosperity; Ministry of Northern Development, Mines, Natural Resources and Forestry, 53p., www.ontario.ca/page/ontarios-critical-minerals-strategy-2022-2027-unlocking-potential-drive-economic-recovery-prosperity, also available to download: select "Download English PDF". [accessed October 4, 2023]

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Rogala, B. Fralick, P.W. Heaman, L.M. and Metsaranta, R. 2007. Lithostratigraphy and chemostratigraphy of the Mesoproterozoic Sibley Group, northwestern Ontario, Canada; Canadian Journal of Earth Science, v.44, p1131-1149.

Thorleifson, L.H. and Kristjansson, F.J. 1993. Quaternary geology and drift prospecting, Beardmore–Geraldton area, Ontario; Geological Survey of Canada, Memoir 435, 146p.

17. Project NW-24-003. Surficial Geochemistry of the Marathon Deposit, Northwestern Ontario



G.W. Hagedorn[1], C.E. Beckett-Brown[1] and J.R.B. Jonsson[2]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, Ontario P3E 6B5
[2]Resident Geologist Program, Ontario Geological Survey, Thunder Bay, Ontario P7E 6S7

INTRODUCTION

Many easily discoverable mineral deposits that crop out at surface have already been found. As such, sound methods of exploration for mineralization beneath surficial cover are needed. One such method is surficial geochemistry. Surficial geochemistry can give an indication of the regional mineral potential in an area (i.e., watershed of a stream) or help trace directly back to the source of the mineralization (i.e., following mineralized till samples up ice to source). Characterizing the surficial response from different types of mineral deposits has been a priority for researchers over the past several decades (cf. McClenaghan and Paulen 2018 and references therein), and because of a new focus on critical mineral deposits, the surficial geochemical response from various critical minerals warrants further study (e.g., Brushett et al. 2024; McClenaghan et al. 2024). One such type of critical mineral deposit that has seen limited research is the platinum group elements (PGE)-dominated magmatic sulphide deposits, such as the Marathon deposit in northwestern Ontario (Figure 17.1).

The Marathon deposit is well suited for a case study of the surficial response of PGE deposits. First, it is extensively studied. After the first study in the 1980s, there has been a multitude of research into the deposition model and mineralogy of the deposit (e.g., Good and Crocket 1994; Ames et al. 2017 and references therein). Second, being only 4 km north of the TransCanada Highway and 10 km north of the town of Marathon, the deposit is easily accessible (*see* Figure 17.1). Finally, the local surficial geology makes it suitable for a variety of sample media to be collected and compared to one another. Currently, Generation Mining is conducting advanced exploration on this property and plans to bring it into production. Therefore, there is an urgency to study the surficial geochemical response of the Marathon deposit before it gets disturbed.

This project was initiated in collaboration with the Geological Survey of Canada as part of Targeted Geoscience Initiative–6 (TGI–6). The goal of the TGI–6 project is to characterize the surficial geochemical response from the Marathon PGE deposit in various media, including tree bark, surface water, stream sediments and till. The Ontario Geological Survey is responsible for the interpretation and release of the stream sediment (Chris Beckett-Brown) and till (Grant Hagedorn) data from the project. These will be the focus of this article.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.17-1 to 17-6.

BACKGROUND

Bedrock Geology

Bedrock along the north shore of Lake Superior forms part of the Superior Craton, containing 2 geological provinces: the Archean Superior Province and the Proterozoic Southern Province. Near the town of Marathon, the Superior Province rocks consist mostly of felsic intrusive, metasedimentary and metavolcanic rocks of the Wawa–Abitibi terrane (Stott et al. 2010) (*see* Figure 17.1). The Southern Province rocks in the immediate area of the Marathon deposit comprise felsic to mafic intrusive and minor mafic volcanic rocks that formed as part of the Midcontinent Rift system (*circa* 1.1 Ga; Sutcliffe 1991).

The Marathon deposit is a Mesoproterozoic magmatic sulphide deposit located 10 km north of Marathon on the eastern edge of the Coldwell Complex (*see* Figure 17.1). The Coldwell Complex is an approximately 580 km^2 alkalic complex that intruded the western end of the Archean Schreiber–Hemlo greenstone belt. The deposit is the largest known Midcontinent Rift-related mineral deposit in Canada, with Measured Reserves of 158.7 Mt at 0.60 g/t Pd, 0.19 g/t Pt, 0.20% Cu, 0.07 g/t Au, and 1.75 g/t Ag (Michaud et al. 2024).

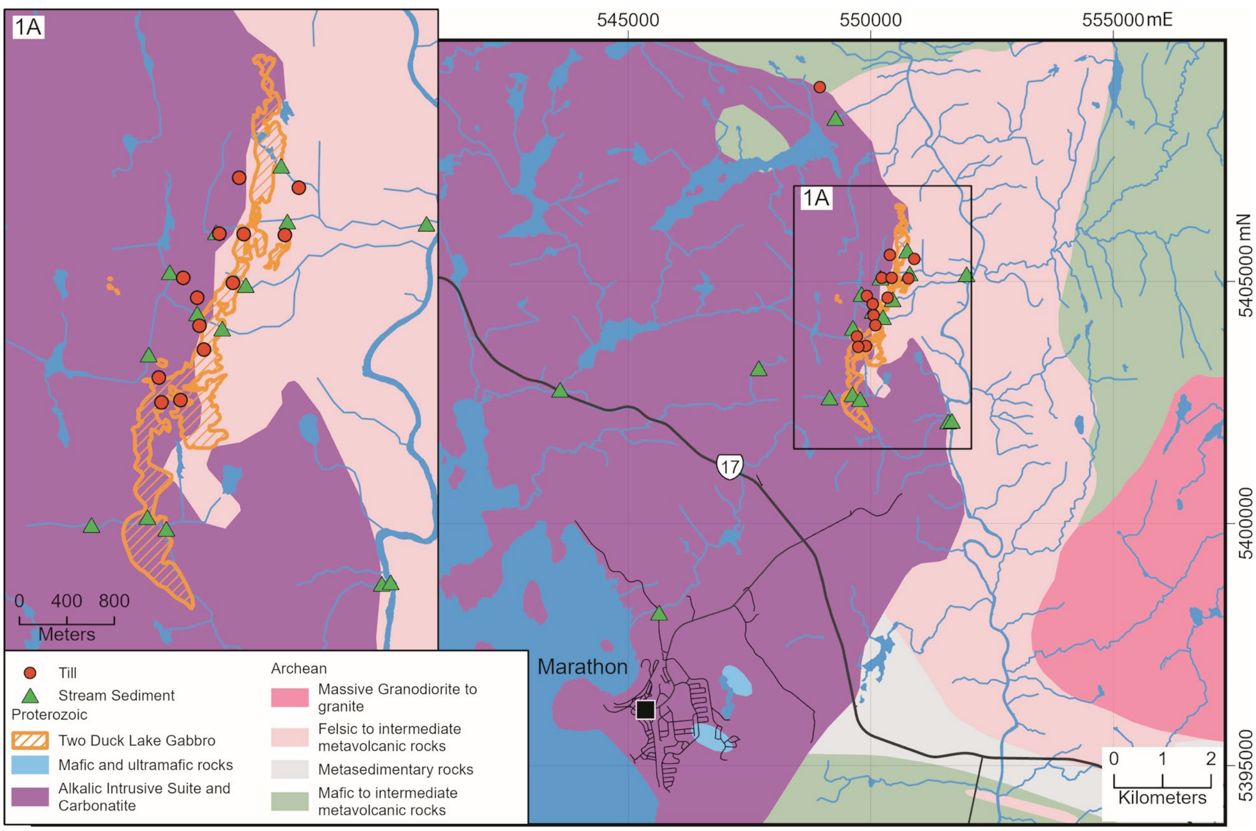


Figure 17.1: Location of till and stream sediment samples with underlying bedrock geology. The mineralized Two Duck Lake Gabbro is outlined in orange. Inset on the left shows a more detailed view of the sampling done in the vicinity of the Marathon property. Geology *modified from* Ontario Geological Survey 2011. Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 16.

The Coldwell Complex (emplaced between 1108 and 1105 Ma, Good et al. 2021) is compositionally diverse and consists of syenites, mafic to ultramafic intrusive rocks, and mafic volcanic rocks. Nepheline- and augite-syenites represent the largest components of the complex, and postdate most of the mafic-ultramafic rocks (Walker et al. 1993; Good et al. 2021). The complex is generally interpreted to have a sheetlike shape. This morphology has been diversely interpreted as resulting either from a series of syenitic magmatic chambers or “centers” (Mitchell and Platt 1978, 1982), or from the intrusion of several syenitic sills into a volcanic pile of basalt and gabbro (Good et al. 2021).

Platinum group element-copper mineralization in the Coldwell Complex is hosted in several mafic to ultramafic intrusions and intrusive complexes. Most of the mafic-ultramafic rocks are located on the northern and eastern boundary of the Coldwell Complex, including the Two Duck Lake Gabbro which hosts the Marathon deposit. The conduit-type Marathon deposit is interpreted to have formed in a dynamic magmatic environment consisting of several discrete intrusive phases that are exemplified by variations in host rock lithology, bulk geochemistry and PGE tenor in different parts of the deposit (Shahabi Far et al. 2019).

Surficial Geology

The region around Marathon was completely covered by ice during the last glaciation. Although there was a series of ice flow directions that overrode the deposit, the most prevalent ice flow direction was to the southwest. As the ice sheet moved over the landscape it incorporated material (rock and sediment) through abrasion and plucking, transported it, and then deposited this material as till. Previous surficial mapping by Bajc and Kristjansson (2009) indicates there is relatively thin till cover around the study area. As the ice sheet retreated, the area was then inundated by glacial lakes, which not only accumulated glaciolacustrine sediments, but also winnowed sediments and trimmed the high grounds through wave action. After glaciation, previously deposited sediments were remobilized by a variety of processes, such as rivers and streams. These rivers and streams show a deranged drainage pattern controlled by surficial geology and bedrock topography.

FIELD WORK

Striations

Only a limited number of striations were found because of the competency of local bedrock lithologies. Striation sites are preserved primarily on surfaces protected by sediment cover. Fourteen striations sites were observed across the Marathon property ranging from 186° to 215° (Figure 17.2). No crosscutting relationships were found during this work but in the mapping completed by Bajc and Kristjansson (2009) around the town of Marathon, the southwest flow was crosscut by a younger southward flow. Because of the prevalence of southwest striations on the landscape, the southwestward flow is likely the most significant ice flow direction that is responsible for dispersal in the study area.

Till

Fifteen till samples were collected across the property (*see* Figures 17.1 and 17.2). Till was sampled following standardized methods outlined in Bajc (1999) and McClenaghan et al. (2023). A maximum spacing of approximately 500 m between samples was achieved with the average being approximately 250 m. One sample was collected 4 km to the north to get a till sample up-ice of the deposit where no known mineralization occurs. Results from this sample will provide a background value to compare with other samples. All work was completed by truck, with sample sites being selected in road cuts. At each site, a 2 to 3 kg bag of till was collected for till matrix geochemistry and a larger 10 kg sample was collected for indicator mineral processing at Overburden Drilling Management. Pebbles from the 10 kg samples will be used to identify rock type as an indication of till provenance. Additional analyses will include Chittick method, particle size analysis and Munsell colour determination.

Stream Sediments

Twenty-one stream sediment samples were collected across the property following procedures outlined in Beckett-Brown et al. (2024) (*see* Figures 17.1 and 17.2). Sampling targeted different order streams upstream of confluences in order to identify the geochemical signatures of the catchments. Stream silts were collected for matrix geochemistry (2 kg) and a larger sand sample (10 kg) was collected for indicator mineral analysis; the larger samples will be processed at Overburden Drilling Management. Many of these sediment samples were paired with water samples for geochemical comparison.

FUTURE WORK

The raw data and interpretation of the stream and till data sets will be released together in a future Ontario Geological Survey Open File Report detailing the pathfinder elements and indicator minerals from the Marathon deposit. It is hoped that results of this study can help determine prospectivity of the surficial media samples in other areas across the province and globally in other glaciated terrains for PGE mineralization. Furthermore, as the Marathon property moves toward mine development, many of the till matrix and stream sediment samples can provide the baseline geochemical information needed for future remediation.

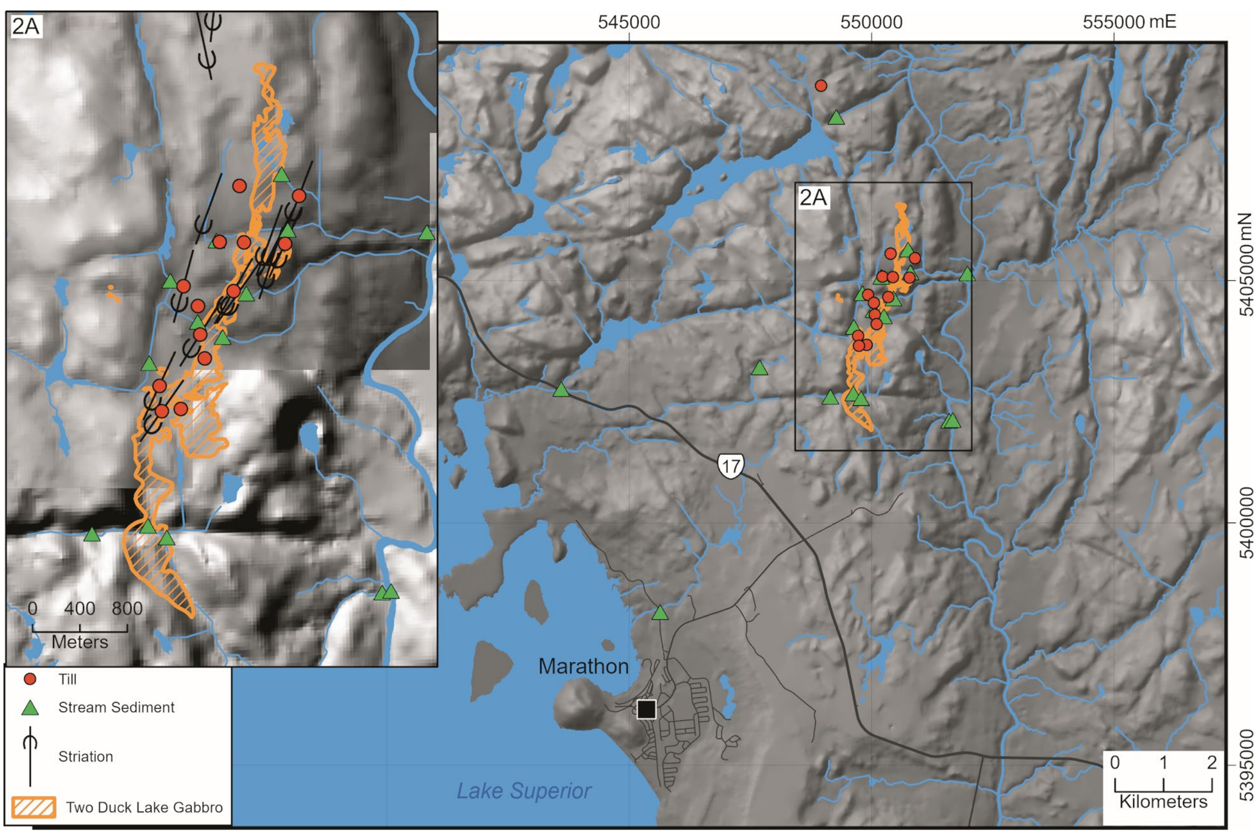


Figure 17.2: Location of till and stream sediment samples. The mineralized Two Duck Lake Gabbro is outlined in orange. Locations of striations measurements are shown and typically indicate a south-southwest ice direction (see text for discussion). Base data is the provincial digital elevation model (DEM). Location information provided as UTM co-ordinates using NAD83 in Zone 16.

ACKNOWLEDGMENTS

First, Generation Mining is thanked for allowing access to their property. The authors would like to thank James Kidder, Beth McClenaghan and Alex Voinot of the Geological Survey of Canada for their initiation of and collaboration on the project. Furthermore, Dan Layton-Matthews (Queen's University) is thanked for his help in the field. Pays Plat First Nation, Biigtigong Nishnaabeg, Pic Mobert First Nation, Michipicoten First Nation, Red Sky Métis Independent Nation, Superior North Shore Métis Council and Jackfish Métis are also thanked.

REFERENCES

Ames, D.E., Kjarsgaard, I.M., McDonald, A.M. and Good, D.J. 2017. Insights into the extreme PGE enrichment of the W Horizon, Marathon Cu-Pd deposit, Coldwell Alkaline Complex, Canada: Platinum-group mineralogy, compositions and genetic implications; Ore Geology Reviews, v.90, p.723-747.

Bajc, A.F. 1999. Results of regional humus and till sampling in the eastern part of the Shebandowan greenstone belt, northwestern Ontario; Ontario Geological Survey, Open File Report 5993, 85p.

Bajc, A.F. and Kristjansson, F.J. 2009. Quaternary geology of the Marathon area, northern Ontario; Ontario Geological Survey, Map 2680, scale 1:50 000.

Beckett-Brown, C.E., McDonald, A.M., McClenaghan, M.B. and McCurdy, M.W. 2024. Evaluating the application of texture and chemistry of detrital tourmaline as an indicator of porphyry Cu mineralization: A case study from the Casino porphyry Cu-Au-Mo deposit, Yukon, Canada; Journal of Geochemical Exploration, v.262, p.24.

Brushett, D.M., Beckett-Brown, C.E., McClenaghan, M.B., Paulen, R.C., Rice, J.M., Haji Egeh, A. and Pelchat, P. 2024. Till geochemical data for the Brazil Lake pegmatite area, southwest Nova Scotia, Canada (NTS 21-A/04, 20-O/16 and 20-P/13): Samples collected in 2020, 2021, and 2022; Geological Survey of Canada, Open File 9148, 35p. doi.org/10.4095/332384

Good, D.J. and Crocket, J.H. 1994. Genesis of the Marathon Cu-platinum-group element deposit, Port Coldwell alkalic complex, Ontario; a Midcontinent rift-related magmatic sulfide deposit; Economic Geology, v.89, no.1, p.131-149. doi.org/10.2113/gsecongeo.89.1.131

Good, D.J., Hollings, P., Dunning, G., Epstein, R., McBride, J., Jedemann, A., Magnus, S., Bohay, T. and Shore, G. 2021. A new model for the Coldwell Complex and associated dykes of the Midcontinent Rift, Canada; Journal of Petrology, v.62, no.7, p.1-37.

McClenaghan, M.B., Brushett, D.M., Beckett-Brown, C.E., Paulen, R.C., Rice, J.M. and White, C.E. 2024. Indicator-mineral signatures of the Brazil Lake lithium cesium-tantalum pegmatites, southwest Nova Scotia (parts of NTS 20-O/16, 20P/13, 21A/04, and 21B/01); Geological Survey of Canada, Open File, 9189, 57p. doi.org/10.4095/ph79gkgx0u

McClenaghan, M.B. and Paulen, R.C. 2018. Applications of Till Mineralogy and Geochemistry to Mineral Exploration; Chapter 20 *in* Past Glacial Environments (2nd ed.), Elsevier, Amsterdam, Netherlands, p.689-751. doi.org/10.1016/B978-0-08-100524-8.00022-1

McClenaghan, M.B., Paulen, R.C., Smith, I.R., Rice, J.M., Plouffe, A., McMartin, I., Campbell, J.E., Lehtonen, M., Parsasadr, M. and Beckett-Brown, C.E. 2023. Review of till geochemistry, indicator mineral, and boulder tracing methods for mineral exploration in glaciated terrain; Geochemistry: Exploration, Environment, Analysis, v.23, p.1-43. doi.org/10.1144/geochem2023-013

Michaud, C., Dorval, A., Maille, J-F., Hall, C.N., Puritch, E.J., Barry, J., Brown, F.H., Burga, D., Stone, W., Bissonnette, B., Paventi, J. and Nair, S. 2024. Feasibility study update, Marathon palladium and copper project, Ontario, Canada; G Mining Services, 500p., https://genmining.com/projects/feasibility-study. [accessed October 7, 2024]

Mitchell, R.H. and Platt, R.G. 1978. Mafic mineralogy of ferroaugite syenite from the Coldwell alkaline complex, Ontario, Canada; Journal of Petrology, v.19, p.627-651.

——— 1982. Mineralogy and petrology of nepheline syenites from the Coldwell alkaline complex, Ontario; Journal of Petrology, v.23, p.186-214.

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

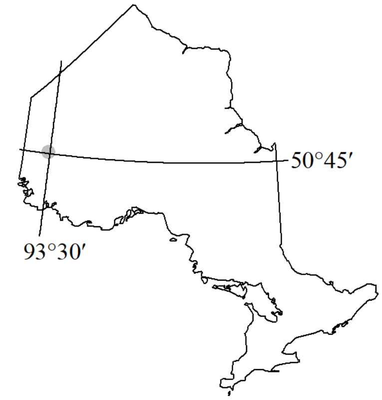
Shahabi Far, M. Samson, I.M., Gagnon, J.E. Good, D.J., Linnen, R.L. and Ames, D.E. 2019. Evolution of a conduit system at the Marathon PGE–Cu deposit: Insights from silicate mineral textures and chemistry; Journal of Petrology, v.60, no.7, p.1427-1460.

Stott, G.M., Corkery, M.T., Percival, J.A., Simard, M. and Goutier, J. 2010. A revised terrane subdivision of the Superior Province; *in* Summary of Field Work and Other Activities, 2010, Ontario Geological Survey, Open File Report 6260, p.20-1 to 20-10.

Sutcliffe, R.H. 1991. Proterozoic geology of the Lake Superior area; Chapter 16 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.627-658.

Walker, E.C., Sutcliffe, R.H., Shaw, C.S.J., Shore, G.T. and Penczak, R.S. 1993. Precambrian geology of the Coldwell Alkalic Complex; Ontario Geological Survey, Open File Report 5868, 31p.

18. Project NW-24-004. Top-To-Bottom Surficial Geochemical Characterization of the Great Bear Gold Project, Red Lake, Northwestern Ontario



C.E. Beckett-Brown[1], P.M. Malegus[2] and P.J. MacDonald[1]

[1]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, Ontario P3E 6B5
[2]Resident Geologist Program, Ontario Geological Survey, Red Lake, Ontario P0V 2M0

INTRODUCTION

Exploration in Ontario contends with challenges posed by the presence of unconsolidated sediments that cover approximately 65% of Ontario's surface (Barnett, Cowan and Henry 1991; Barnett, Henry and Babuin 1991a, 1991b; Pala, Barnett and Babuin 1991). The geochemical anatomy overtop of large mineral deposits is largely unknown, because of the lack or inability to conduct large surficial sampling studies before significant development begins, when much of the surficial sediment are removed or disturbed. To address this gap, a surficial geochemical study has been undertaken overtop of the Great Bear project (Kinross Gold Corporation), Red Lake, Ontario, before it goes into production so as to define the geochemical anatomy that overlies an Archean gold deposit.

This study will investigate and compare geochemical signatures collected on several media to identify the optimal material type and analyses methods for mineral exploration. During the summer of 2024, sampling was conducted on 1) the bedrock present at the top of drill-hole core (surface bedrock), 2) C-horizon till, glaciofluvial sands, or glaciolacustrine silts and clays, 3) B-horizon soil, 4) litter–fermented–humic (LFH)–horizon material, and 5) tree bark (black spruce). This sampling campaign will be followed by detailed geochemical analyses on the collected media. In addition to the sediment and biogeochemical investigation, detailed lithogeochemistry will be performed on bedrock sampled from drill hole near the bedrock surface in order to compare their geochemical signatures with those documented in the overlying sediment and tree bark.

Many of Ontario's prominent gold districts occur in regions of similar Quaternary sediment cover (e.g., Rainy River and Abitibi greenstone belts). With the data gathered during this study, an updated surficial geochemical guide for the exploration of gold deposits under the cover of a variety of Quaternary sediments will be produced.

REGIONAL BEDROCK GEOLOGY

The Great Bear project is located in the Red Lake greenstone belt, which occurs at the boundary of the dominantly Mesoarchean North Caribou terrane and the Neoarchean Uchi Subprovince of the Superior Province (Figure 18.1) (Stott et al. 2010). To the south of the Red Lake greenstone belt is the English River Subprovince, which is composed of metasedimentary and plutonic rocks (Breaks 1991). The Red Lake greenstone belt is composed of both Mesoarchean and Neoarchean supracrustal and

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.18-1 to 18-8.

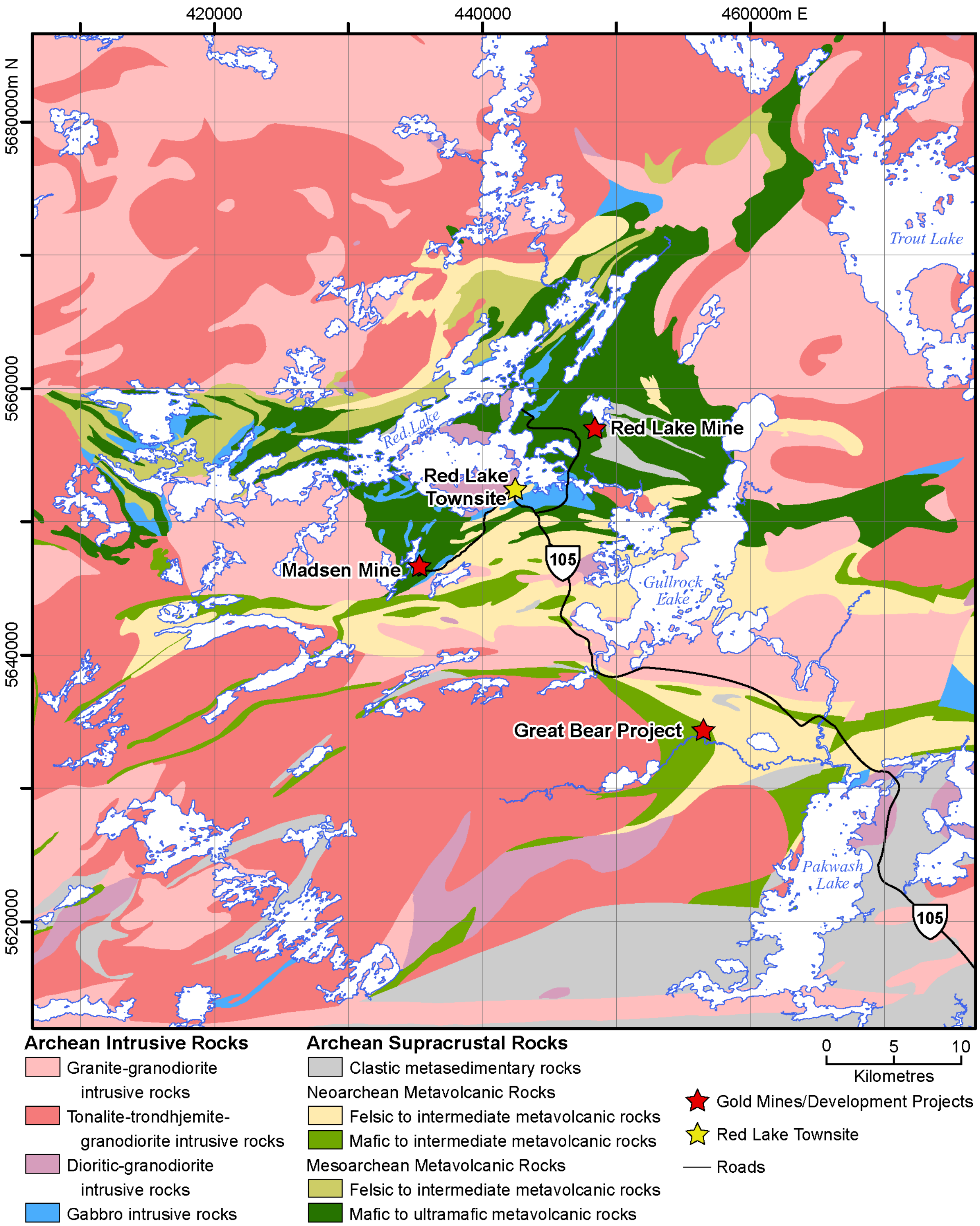


Figure 18.1. Simplified geological map of the Red Lake greenstone belt, with significant gold mines and exploration projects. Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 15 (*modified from* MacDonald and Malegus 2021).

intrusive rocks. Of the 7 supracrustal rock assemblages that comprise the Red Lake greenstone belt, 2 are of interest for the present study: the Mesoarchean (2989 to 2852 Ma) Balmer assemblage which is host to the majority of historical gold production in the area (i.e., Red Lake and Madsen mines; *see* Figure 18.1); and the Neoarchean (2750 to *circa* 2732 Ma) Confederation assemblage, which was thought, until recently, to host the Great Bear project (*see* Figure 18.1) (Sanborn-Barrie et al. 2004).

GREAT BEAR PROJECT GEOLOGY

The Great Bear project is located in the southern portion of the Red Lake greenstone belt, hosted within the metavolcanic rocks of the Confederation assemblage (*see* Figure 18.1); however, recent geochronology work by the Ontario Geological Survey on a felsic unit yielded an age at 2716±2 Ma (chemical abrasion isotope dilution thermal ionization mass spectrometry (CA-ID-TIMS) U/Pb on zircon: MacDonald, Kamo and Malegus 2023). This age suggests that at least some of the rocks at the Great Bear project area are younger. Nonetheless, the geological units at the Great Bear project have been classified into 2 domains: a mafic domain and a felsic domain (Pfeiffer et al. 2023).

The mafic domain is located in the southwestern half of the Great Bear project and is dominated by tholeiitic metabasalts, intercalated with thin metamudstone horizons (Pfeiffer et al. 2023). The mafic domain hosts 2 documented mineralized zones, named as the “Limb” and “Hinge” zones (Pfeiffer et al. 2023). Gold mineralization hosted in the mafic domain is similar in style to other producing and past-producing gold mines in the Red Lake area, with gold associated with quartz-carbonate veining, silicification and sulphide minerals (e.g., pyrite, pyrrhotite and arsenopyrite) (Pfeiffer et al. 2023).

The felsic domain is located in the northeastern half of the Great Bear project and is composed dominantly of metamorphosed porphyritic felsic flows and volcaniclastic rocks interlayered with metasedimentary rocks that experienced ductile deformation (Pfeiffer et al. 2023). Within the felsic domain, the most endowed gold mineralized area is the “LP zone”. Conversely to the “Limb” and “Hinge” zones in the mafic domain, gold mineralization in the “LP zone” differs from other gold mineralization within the Red Lake area because it is disseminated and associated with strongly deformed, altered (i.e., sericite and albite) and sulphide-bearing felsic rocks (Pfeiffer et al. 2023).

REGIONAL QUATERNARY GEOLOGY

During the Late Wisconsinan, the area of the Great Bear project was covered by south-southwest ice flow (Prest 1982). It was deglaciated around 10.5 and 10 ka BP (Dalton et al. 2020). The Quaternary geology in the study area has been mapped at a scale of 1:50 000 (Prest 1982). The area is dominated primarily by glaciolacustrine silts and clays with minor amounts of glaciofluvial sands, till and organic materials. These glaciolacustrine silts and clays were primarily deposited by glacial Lake Agassiz, which also modified previously deposited tills and glaciofluvial sands (Prest 1982). Drift thickness over the study area averages 5 m, but can reach up to 50 m in some sections (staff of Kinross Gold Corporation, personal communication, 2024).

METHODS

Sampling Procedures

Five different sample media were collected at each field station including black spruce (*Picea Mariana*) tree bark, LFH horizon, B-horizon soil, C horizon (including 52% glaciolacustrine, 36% glaciofluvial, and 12% till), and bedrock from top of the nearest drill hole. The sampling grid was predetermined based on diamond-drill hole locations (with sample availability), access, bedrock lithology, proximity to mineralized zones and ice-flow direction. Two “background” traverses extending 15 km down ice (8 stations), 5 km up ice (5 stations), and at least 5 km east and west (5 stations each) of the major mineralized "LP zone" were also collected extending parallel and perpendicular to ice flow to ensure anomalous geochemical signatures can be effectively distinguished from background values. In total, 166 stations (Figure 18.2) were visited, with the different sample media collected for all except 2 sites, where the organic material was either too thick above the required media or the media occurred below the water table, preventing collection.

Bark

Black spruce (*Picea Mariana*) bark was collected at all stations using a stainless-steel paint scraper and a plastic dust pan (Photo 18.1A). Care was used to avoid regions of irregular growth, significant tree sap and tree flesh (i.e., cambium, sapwood, or heartwood layers) that could influence the bark geochemical signal. A minimum of 100 g of bark was collected and sealed in cloth bags. Between each sample site, all tools were cleaned with distilled water. When tree sap began to buildup on the scraper, alcohol was used to clean off the sap, followed by a rinse with distilled water. Associated with each bark sample, various metadata were collected including tree diameter, tree trunk photo, bark photo, tree top photo, distance and azimuth from sediment sampling site, bark flake size, and removal difficulty.

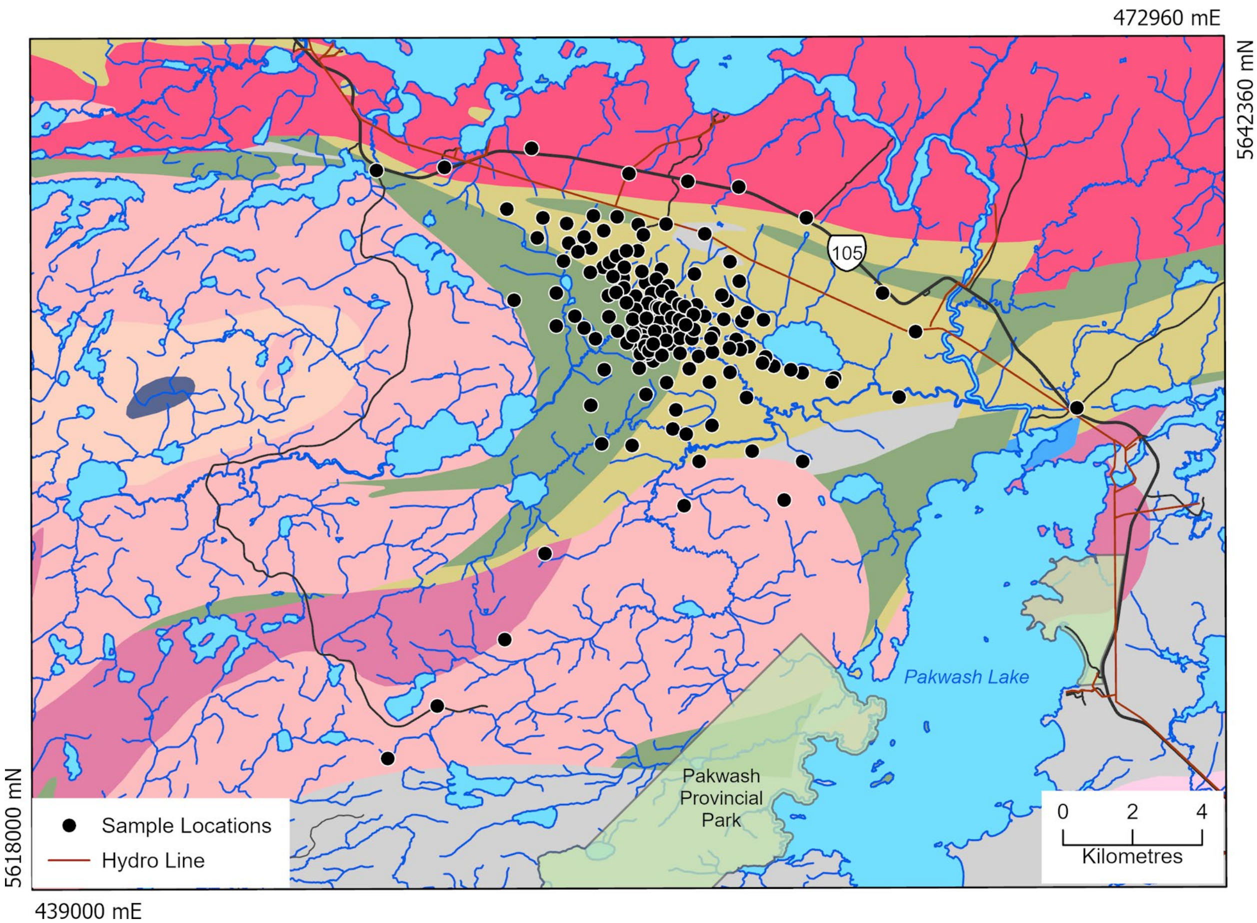


Figure 18.2. Map showing the locations of samples (black dots) collected during the 2024 summer field season. All UTM co-ordinates are provided using NAD83 in Zone 15N. Bedrock geology *from* Ontario Geological Survey (2011). Bedrock legend is provided in Figure 18.1.

Litter–Fermented–Humic Horizon[3]

The LFH–horizon samples were collected primarily by hand, or with a stainless-steel trowel and placed into 7 by 12.5 inch cloth bags until full. The average weight for each sample was 2 kg. All sampling equipment and hands were cleaned with distilled water between sampling sites. Most samples are a mixture of the LFH material, but the target for this sampling was the humic portion of this horizon, although it was not always well developed or abundant enough to sample in its entirety. At many stations, the LFH horizon was topped by a moss matt that was removed and sampled underneath (Photo 18.1B). This horizon consists primarily of moss, decomposing leaves, twigs, logs, needles and cones and is typically thin, brown to black and is generally less than 5 cm, but, in rare cases, reached up to 30 cm thick.

B Horizon

The B-horizon materials in the study area are predominantly brunisols (Photo 18.1C). This horizon is generally poorly developed, 5 to 7 cm thick, brown to black, and more rarely orange-red-brown near surface. These juvenile soils are formed through near-surface oxidation and hydrolysis of mineral grains in underlying Quaternary sediments as a result of climate, logging and forest fires. Notably, B horizons that form on glaciolacustrine sediments are poorly developed, difficult to identify and generally thin, less than 5 cm thick (Photo 18.1D). The B horizon samples were collected with a stainless-steel trowel and placed into cloth bags, cleaning sampling equipment between samples with distilled water.

C Horizon

Various types of C-horizon material are present in the study area, including glaciolacustrine (52%), glaciofluvial (36%) and till (12%). The C-horizon material was sampled at various depths depending on the development and thickness of the B horizon. The C horizon was sampled with either a stainless-steel trowel, or shovel, which was precleaned following digging and before sampling. The average depth to the upper surface of the C horizon was 14 cm and, in general, sampling depth began around 20 cm; an attempt was made to omit greater than 4 mm clasts in glaciofluvial and till samples. Till samples in the study area vary in terms of their sand, silt and clay contents.

Bedrock Samples

A total of 122 bedrock samples were collected from drill core located within less than 50 m of the surficial samples. The top of the drill hole (i.e., top of bedrock surface) was targeted for sampling with up to 1.0 m of core being sampled and placed in plastic bags. The surficial sampling grid was organized around drill-hole distribution so that as many surficial sample sites as possible could be directly tied to underlying bedrock surface samples. These bedrock samples were successfully collected at 78% of the sample stations. Photographs of all core samples were taken along with detailed hand-sample descriptions.

---

[3] *"Litter–fermented–humic (LFH)" horizons form in forested regions.*
L - An organic horizon characterized by an accumulation of organic matter in which the original structures are easily discernible (litter).
F - An organic horizon characterized by an accumulation of partly decomposed organic matter (folic). The material may be partly altered by soil fauna (moder), or it may be a partly decomposed mat permeated by fungal hyphae (mor).
H - An organic horizon characterized by an accumulation of decomposed organic matter in which the original structures are indiscernible. This horizon differs from F by having greater humification chiefly because of the action of organisms. It is frequently intermixed with mineral grains, especially near the junction with a mineral horizon.

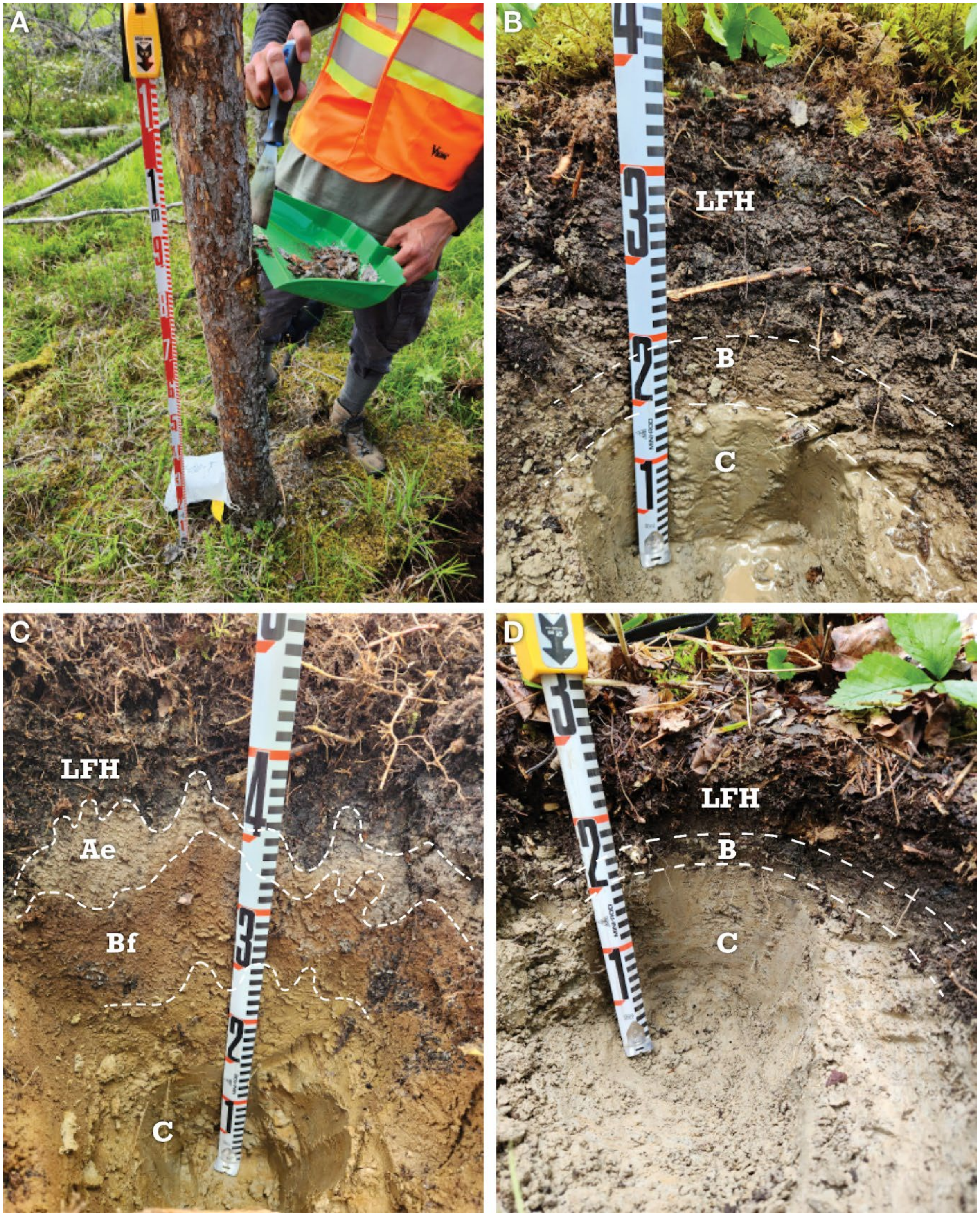


Photo 18.1. **A)** Black spruce (*Picea Mariana*) bark being collected with a stainless-steel paint scraper and a plastic dust pan (456825E 5634176N). On the measuring tape, 1 cm is represented by a red tick. **B**) Example of a thick litter–fermented–humic) (LFH)–horizon sample (457349E 5633866N). **C)** Example of a brunisols, which is common in the glacial fluvial sediments. This horizon is generally poorly developed, brown to black and, more rarely, orange-red-brown near the surface; B horizons are typically 5 to 7 cm thick (456175E 5636203N). **D)** Example of the typical poorly developed soil profile forming over glaciolacustrine material with almost no B-horizon development (457913E 5633140N). For scales seen on Photos 18.1B, 18.1C and 18.1D: 1 cm is represented by a black tick on the scale; 10 cm is represented by a full red tick. All UTM co-ordinates provided using NAD83 in Zone 15.

SAMPLE PREPARATION AND ANALYTICAL METHODS

All bark and sediment samples will be dried at less than 50°C before being submitted for analyses. Bark and sediment samples will be submitted for aqua regia digestion followed by inductively coupled atomic emission spectroscopy (ICP–AES) analysis for major elements and inductively coupled plasma mass spectrometry (ICP–MS) analysis for minor and trace elements at the OGS Geoscience Laboratories in Sudbury. The B- and C-horizons samples will be sent to an external laboratory for a partial extraction (e.g., MMI® or Ionic Leach®). Surface bedrock samples (sampled from the top of the drill hole) will be submitted for polished thin sections. Chemical analyses on bedrock samples will be done using a closed beaker (near total) digestion followed by ICP–MS analysis for minor and trace elements, as well as X-ray fluorescence (XRF) for major elements, ferrous iron by titration, loss on ignition, total carbon and total sulphur, chlorine, and fluorine, and an aqua regia digestion followed ICP–MS for leachable minor and trace elements. This work will also be conducted at the OGS Geoscience Laboratories in Sudbury.

ACKNOWLEDGMENTS

Grant Hagedorn, Manuel Duguet and Michael Easton (OGS) are thanked for their reviews of this article and Evan Hastie (OGS) for discussions on gold in Red Lake. Kinross Gold Corporation staff and, more particularly, Hanna Dallmeier, Dana Cipelletti, Rick Greenwood and Dylan Langille are thanked for support at the Great Bear property and in Red Lake. The senior author is grateful to Kiran Fisher and Alex Gott for field assistance, to Julien Bonin, OGS, for assisting with figures and OGS Publication Services Unit for editorial assistance.

REFERENCES

Barnett, P.J., Cowan, W.R. and Henry, A.P. 1991. Quaternary geology of Ontario, southern sheet; Ontario Geological Survey, Map 2556, scale 1:1 000 000.

Barnett, P.J., Henry, A.P. and Babuin, D. 1991a. Quaternary geology of Ontario, east-central sheet; Ontario Geological Survey, Map 2555, scale 1:1 000 000.

——— 1991b. Quaternary geology of Ontario, west-central sheet; Ontario Geological Survey, Map 2554, scale 1:1 000 000.

Breaks, F.W. 1991. English River Subprovince; Chapter 7 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.239-278.

Dalton, A.S., Margold, M., Stokes, C.R., Tarasov, L., Dyke, A.S., Adams, R.S., Allard, S., Arends, H.E., Atkinson, N., Attig, J.W., Barnett, P.J., Barnett, R.L., Batterson, M., Bernatchez, P., Borns, H.W., Breckenridge, A., Briner, J.P., Brouard, E., Campbell, J.E., Carlson, A.E., Clague, J.J., Curry, B.B., Daigneault, R-A., Dube-Loubert, H., Easterbrook, D.J., Franzi, D.A., Friedrich, H.G., Funder, S., Gauthier, M.S., Gowan, A.S., Harris, K.L., Hétu, B., Hooyer, T.S., Jennings, C.E., Johnson, M.D., Kehew, A.E., Kelley, S.E., Kerr, D., King, E.L., Kjeldsen, K.K., Knaeble, A.R., Lajeunesse, P., Lakeman, T.R., Lamothe, M., Larson, P., Lavoie, M., Loope, H.M., Lowell, T.V., Lusardi, B.A., Manz, L., McMartin, I., Nixon, C., Occhietti, S., Parkhill, M.A., Piper, D.J.W., Pronk, A.G., Richard, P.J.H., Ridge, J.C., Ross, M., Roy, M., Seaman, A., Shaw, J., Stea, R.R., Teller, J.T., Thompson, W.B., Thorleifson, L.H., Utting, D.J., Veillette, J.J., Ward, B.C., Weddle, T.K. and Wright, H.E. 2020. An updated radiocarbon-based ice margin chronology for the last deglaciation of the North American Ice Sheet Complex; Quaternary Science Reviews, v.234, paper 106223.

MacDonald, P.J., Kamo, S.L. and Malegus, P.M. 2023. Geochronology of the LP zone volcanic rocks, Red Lake area, Uchi Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.10.1 to 10-8.

MacDonald, P.J. and Malegus, P.M. 2021. Introduction to the Red Lake bedrock geology mapping compilation project, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2021, Ontario Geological Survey, Open File Report 6380, p.9-1 to 9-5.

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Pala, S., Barnett, P.J. and Babuin, D. 1991. Quaternary geology of Ontario, northern sheet; Ontario Geological Survey, Map 2553, scale 1:1 000 000.

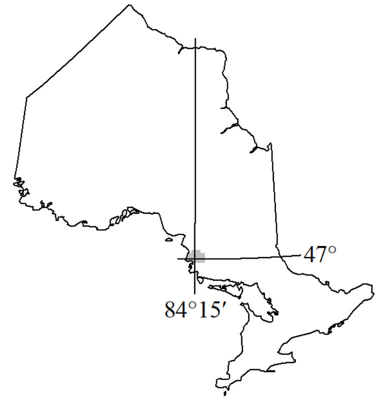
Pfeiffer, N., Sims, J., Breau, Y., Greenwood, R. and Prawasono, A. 2023. Great Bear gold project, Ontario, Canada, voluntary National Instrument 43-101 Technical Report, prepared for Kinross Gold Corporation; NI 431-101 Technical Report, filed February 13, 2023 with SEDAR+®, *see* www.sedarplus.ca, 243p. [accessed September 5, 2024]

Prest, V.K. 1982. Quaternary geology of the Madsen area, Kenora District (Patricia Portion); Ontario Geological Survey, Preliminary Map P.2484, scale 1:50 000.

Sanborn-Barrie, M., Rogers, N., Skulski, T., Parker, J., McNicoll, V. and Devaney, J. 2004. Geology and tectonostratigraphic assemblages, east Uchi Subprovince, Red Lake and Birch–Uchi belts; Ontario; Geological Survey of Canada, Open File 4256 (also Ontario Geological Survey, Preliminary Map P.3460), scale 1:250 000.

Stott, G.M., Corkery, M.T., Percival, J.A., Simard, M. and Goutier, J. 2010. A revised terrane subdivision of the Superior Province; *in* Summary of Field Work and Other Activities, 2010, Ontario Geological Survey, Open File Report 6260, p.20-1 to 20-10.

19. Project NE-24-006. Restarting the Lake Sediment and Water Geochemistry Program: Batchawana Greenstone Belt, Northeastern Ontario



C.E. Beckett-Brown[1] and L.A. Handley[1]

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

INTRODUCTION

The Ontario Geological Survey (OGS) lake sediment and water sampling surveys are back! After almost 10 years in hiatus, the program has been restarted. The OGS has been conducting lake sediment surveys since the 1980s to better understand the geology and geochemistry of Ontario, with the goal of covering the entire province with high-density lake sediment surveys. Field work for a lake sediment and water geochemical survey of the Batchawana Bay area, in northeastern Ontario, was carried out between September 10 and 30, 2024. This survey targeted the Batchawana greenstone belt and surrounding area to infill and update the low-density surveys previously completed by the OGS in this part of the province (Fortescue and Vida 1989, 1990, 1991; Hamilton and Fortescue 1995, 2007; Hamilton, Fortescue and Hardy 1995).

For this survey, a total of 969 lake sediment samples and 969 water samples were collected over an approximate area of 2700 km^2 (Figure 19.1). The sampling coverage corresponds to an average density of 1 sample site per 2.8 km^2. Improvements to the program were made, including a complete redesign of the water sampling system (Photos 19.1A and 19.1B), inclusion of sample storage boxes to prevent cross contamination between samples (Photo 19.1C) and elimination of shallow sediment collection (<15 cm, below the sediment–water interface) following discussion and outreach with clients.

BEDROCK GEOLOGY

The Batchawana Bay area lies within the Superior Province and is subdivided into distinct lithotectonic domains including the Chapleau gneiss domain, Ramsey gneiss domain, Algoma plutonic domain, and the Batchawana volcanic domain (Grunsky 1991; Card 1979). The volcanic domain has been subdivided into the Western Volcanic subdomain, which is underlain mainly by tholeiitic mafic metavolcanic flows and sills with minor intercalated metasedimentary rock and tuffs, and the Eastern Volcanic subdomain, which consists of a lower sequence of tholeiitic flows as well as calc-alkalic mafic to felsic metavolcanic rocks (Grunsky 1991). The Ramsey gneiss domain consists of tonalite (massive to foliated), granodiorite and granite with localized remnants of supracrustal rocks (Card 1979; Grunsky 1991). The Chapleau gneiss domain consists of migmatitic paragneiss, and tonalitic and granitic intrusive rocks. The Algoma plutonic domain consists of a western granodiorite terrain and an eastern granitic terrain. Supracrustal rocks of the volcanic subdomains were subjected to greenschist- to amphibolite-facies metamorphism, whereas the gneiss domains consistently are at amphibolite facies. Proterozoic volcanic, intrusive and sedimentary rocks of the Mamainse Point Formation occur along the coast of Lake Superior, unconformably overlying the Batchawana volcanic domain. Most of the hydrothermal copper systems in the area are Proterozoic (Grunsky 1991; Sutcliffe 1991).

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.19-1 to 19-6.

QUATERNARY GEOLOGY

The Quaternary geology of the study area has been investigated by McQuay (1979, 1980) and Roed and Hallett (1979, 1980). The last glacial advance was south-southwest. The study area is dominated by bedrock, with minimal Quaternary deposits. The bulk of Quaternary cover occurs along the shoreline of Lake Superior, which is predominantly glaciolacustrine deposits in the study area. The remaining Quaternary cover is predominantly glaciofluvial outwash and fluvial deposits occurring along former meltwater channels that now form many of the large river systems in the study area.

SAMPLING METHODS

Organic-rich lake sediment samples were collected from a helicopter equipped with floats, using the OGS-designed gravity corer (Photo 19.1D). Deep sediment (>15 cm) samples were obtained at each sampling site. Deep sediment samples were targeted because they represent true 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. The deep sediment, therefore, reflects sedimentation older than 100 years showing natural effects of geochemical inputs related to local geological features. Sediment

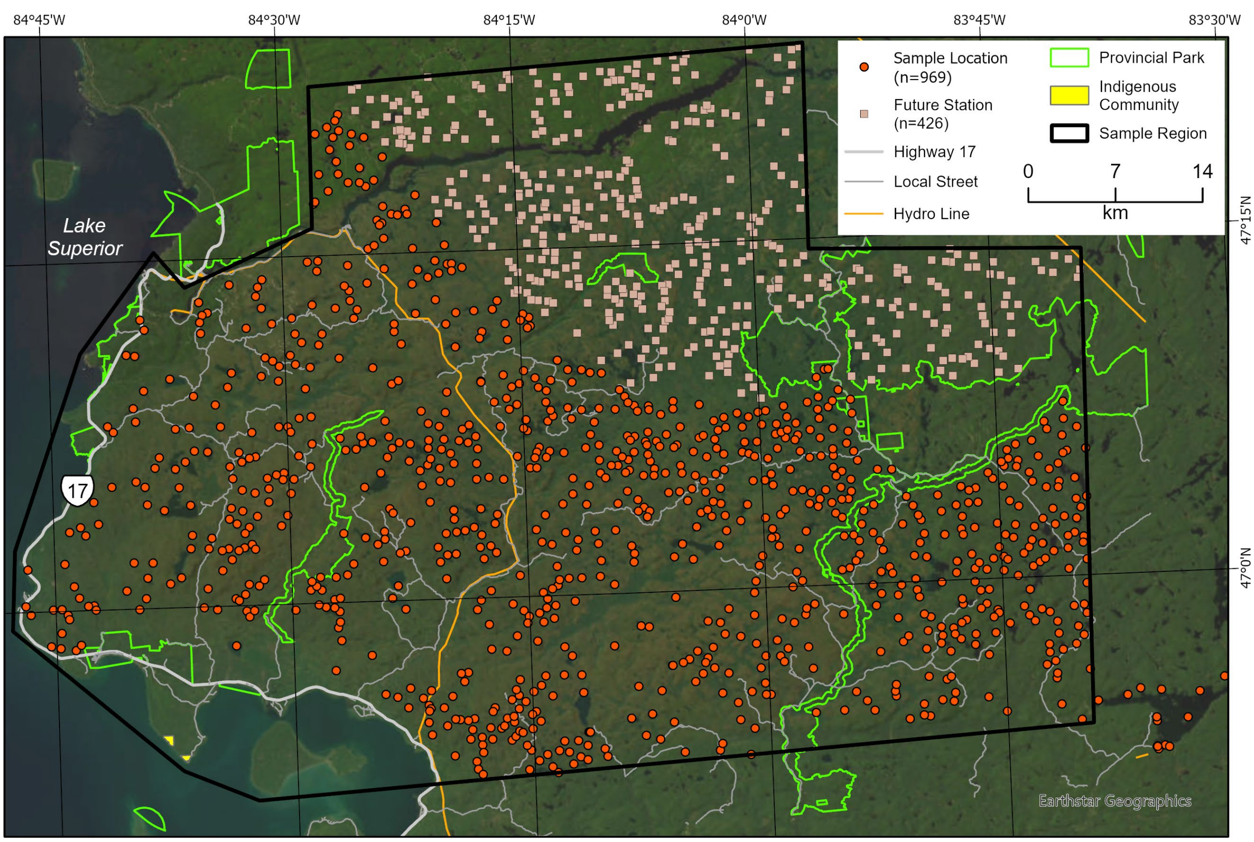


Figure 19.1. Map showing the location of samples collected during the 2024 field season (red circles) and the remaining samples to be collected to complete the study (brown squares). Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 16N and 17N. Base map image *from* European Space Agency (2021).

sample metadata were collected using a Mesa® tablet on a field form created in QField® (Photo 19.1E). Global positioning system (GPS) data were collected at each site using the tablet with an average vertical, and horizontal accuracy of less than 3 m. A separate tablet was mounted for the pilot to show the navigation between lakes for each run using Fore Flight® and the preplanned flight path, taking into account wind direction, lake size and weight of aircraft (i.e., fuel remaining) to create the most efficient sampling runs.

Lake water samples were collected at each site from a depth of approximately 0.5 m using a foot valve intake attached to hard plastic high-density polyethylene (HDPE) tubing, placed into the water upon landing (*see* Photo 19.1B). 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* Photo 19.1B). The sonde was connected via Bluetooth® to a cell phone mounted in the back of the helicopter beside the water sampling system for data collection (*see* Photo 19.1A). 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, 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 (*see* Photo 19.1A) 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

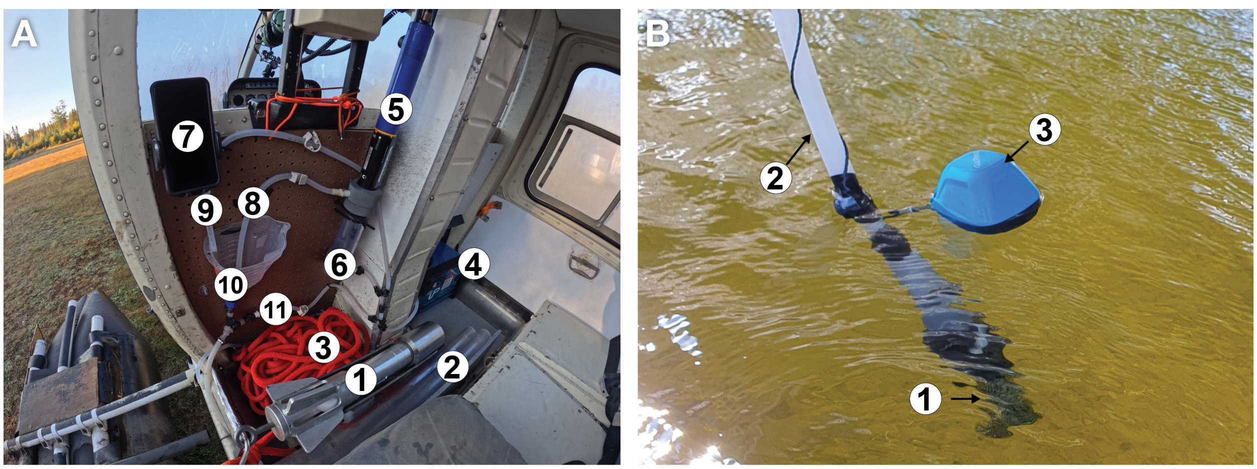


Photo 19.1. A) Image of the back seat of the helicopter. From this position, the scientist lowers and raises the torpedo and collects the water samples. Items used in the collection process are labelled 1 to 11 in the image and include 1) OGS-designed lake sediment torpedo; 2) polycarbonate sample tubes, which nest inside the sampler for sample collection; 3) sampler rope, which is attached to the torpedo for lowering and raising the sampler from the bottom of the lake; 4) Waterra® 1UP peristaltic pump; 5) YSI EXO1™ multiparameter sonde, which measures in real-time temperature, conductivity, pH, oxidation–reduction potential (ORP), and dissolved oxygen; 6) flow cell, where water is pumped in from the bottom, filling the cell, and outflows at the top; 7) cell phone connected via Bluetooth® to the sonde to collect the live data; 8) flow cell outflow with white flow-valve clip; 9) sampling hose, where the scientist connects a Waterra® 0.45 µm high volume filter, following tube flushing, before collecting the sample; 10) outflow drainage basin, all water flowing through the system can be discharged through this funnel. 11) system drainage valve, which allows the entire system to be purged of water between sampling sites and draining the flow cell to allow for faster stabilization of sonde readings. **B)** Water sample intake setup lowered into the lake after landing at each sample site. Items used in this setup are labelled 1 to 3 in the image: 1) coarse mesh stainless steel foot valve for water intake approximately 0.5 m below surface; 2) high-density polyethylene (HDPE) hard plastic tubing to keep the intake at the predetermined sample depth; 3) Garmin® Striker® depth finder, which was connected via Bluetooth® to a cell phone in the front of the helicopter for recording sample depth measurements.

sampling tubing before filling 2 sample bottles. The bottles included a 125 mL HDPE bottle filled to the bottom of the bottle neck (to allow for acidification later) for metals analyses, and a 60 mL HDPE bottle 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 prior to metals analysis.

SAMPLE PREPARATION AND ANALYTICAL METHODS

Lake sediment samples were collected into breathable fabric bags (Photo 19.1F) and allowed to air dry prior to transport to Sudbury. Final drying was completed in ovens at temperatures less than 40°C prior to pulverization (if required) in a ceramic ring mill and sieving to obtain the under 60 mesh (<250 µm) size fraction. 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

Photo 19.1, *continued*. C) Newly designed sample boxes, which help organize sample sets for each run and which allow samples to be stored in separate slots preventing cross contamination. The box is outfitted with a false bottom allowing excess water from the samples to drain to the bottom. **D)** OGS-designed lake sediment torpedo, with polycarbonate sampling tube fit into the sampler, ready to be lowered to the bottom of the lake. **E)** Sampler's view while sitting in the front of the helicopter. Labelled items are 1) MESA® tablet with QField® and an OGS-designed sampling form loaded for data collection and navigation; 2) cell phone linked via Bluetooth® to the depth finder; 3) prelabelled sample bags. **F)** Field assistant hanging samples at the end of the day to air and drip dry before transport to Sudbury.

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. Quality control will be monitored through the use of field and laboratory duplicates, blanks, and certified reference materials.

ACKNOWLEDGMENTS

Laura Colgrove, Michael Easton and Mathieu Levesque (OGS) are thanked for their reviews of this article. The authors are grateful to Vanda Osuchowski for field assistance and to OGS staff: Julien Bonin for assisting with figures; and OGS Publication Services Unit for editorial assistance. Thanks are extended to Expedition Helicopters, specifically pilots Kelvin Jones and François Audet for their excellent flying. The authors appreciated the outstanding accommodations at Ranger Lake Resort and for the hospitality of Kevin and Joel McCarthy and Ruger. The authors would like to thank Batchewana First Nation, Garden River First Nation, Michipicoten First Nation, Métis Nation of Ontario Region 4 and Bar River Métis for access to their traditional land-use areas.

REFERENCES

Card, K.D. 1979. Regional geological synthesis, central Superior Province; *in* Current Research, Geological Survey of Canada, Paper 79-1A, p.87-90.

Dickman, M. and Fortescue, J.A.C. 1991. The role of lake deacidification as inferred from sediment core diatom stratigraphies; AMBIO: A Journal of the Human Environment, v.20, no.3-4, p.129-135.

European Space Agency 2021. Copernicus Sentinel-2 Multispectral Image (MSI) Level-2A Bottom of atmosphere (BOA) Reflectance Product, Collection 1; Copernicus Sentinel-2 processed by European Space Agency. doi.org/10.5270/S2_-znk9xsj

Fortescue, J.A.C. and Vida, E.A. 1989. Geochemical survey of the Trout Lake area; Ontario Geological Survey, Map 80 803, scale 1:50 000.

——— 1990. Geochemical survey, Hanes Lake area; Ontario Geological Survey, Map 80 806, scale 1:50 000.

——— 1991. Geochemical survey, Pancake Lake area; Ontario Geological Survey, Map 80 807, scale 1:50 000.

Grunsky, E.C. 1991. Geology of the Batchawana area, District of Algoma; Ontario Geological Survey, Open File Report 5791, 214p.

Hamilton, S.M. and Fortescue, J.A.C. 1995. Lake sediment geochemical survey of the Cow River area, Batchawana greenstone belt; Ontario Geological Survey, Miscellaneous Release—Data 9.

——— 2007. Lake sediment geochemical survey of the Cow River area, Batchawana greenstone belt; Ontario Geological Survey, Miscellaneous Release—Data 9 – Revised.

Hamilton, S.M., Fortescue, J.A.C. and Hardy, A.S. 1995. A zinc-cadmium-copper anomaly: Preliminary results of the Cow River geochemical mapping project, Batchawana greenstone belt; Ontario Geological Survey, Open File Report 5917, 31p.

Hunt, C. 2003. Metal concentrations and algal microfossil diversity in pre-industrial (pre-1880) sediment of lakes located on the Sudbury Igneous Complex in Sudbury, Ontario; unpublished MSc thesis, Laurentian University, Sudbury, Ontario, 124p.

McQuay, D.F. 1979. Northern Ontario engineering geology terrain study, data base map, Batchawana, NTS 41N/SE; Ontario Geological Survey, Map 5011, scale 1:100 000.

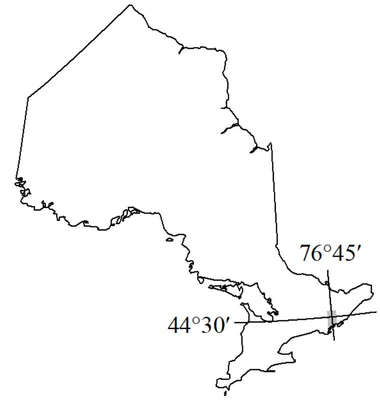
——— 1980. Batchawana area (NTS 41N/SE), District of Algoma; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 85, 13p.

Roed, M.A. and Hallett, D.R. 1979. Northern Ontario engineering geology terrain study, data base map, Wenebegon Lake, NTS 41O/SW; Ontario Geological Survey, Map 5016, scale 1:100 000.

——— 1980. Wenebegon Lake Area (NTS 41O/SW), Districts of Algoma and Sudbury; Ontario Geological Survey, Northern Ontario Engineering Geology Terrain Study 86, 16p.

Sutcliffe, R.H. 1991. Proterozoic geology of the Lake Superior area; Chapter 16 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.626-658.

20. Project SO-22-001. Paleozoic Geology of Eastern South-Central Ontario: Tichborne–Sydenham and Bath–Yorkshire Island Areas



K.E. Hahn[1]

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

INTRODUCTION

In 2022, the Ontario Geological Survey (OGS) initiated a multi-year mapping project focussed on the Paleozoic geology of eastern south-central Ontario (Figure 20.1). This work builds upon current OGS mapping projects in eastern Ontario, which, over the past few years, have helped inform several revisions to the Ordovician stratigraphic nomenclature in eastern Ontario (Béland Otis 2017, 2018, 2019, 2022, 2023; Hahn 2022, 2023). These mapping projects, led by the OGS, are contributing to a formalized revision to Paleozoic stratigraphic nomenclature for use in Ontario (Brunton et al. 2021).

The study area encompasses the region from Belleville to Gananoque, just east of Kingston, and is bounded by Lake Ontario to the south and the Precambrian–Paleozoic unconformity in the north (*see* Figure 20.1). The study area is represented by 10 National Topographic System (NTS) maps and was last updated by the OGS in the 1980s as a series of 5 Paleozoic bedrock maps (Carson 1981a, 1981b, 1981c, 1982a, 1982b). Prior to mapping by the OGS, the study area was mapped in the 1960s by Liberty (1963, 1971), and the stratigraphic nomenclature in use by the OGS for this part of Ontario is based on the work of Liberty (1963, 1969) (Figure 20.2).

The Paleozoic bedrock near Kingston has been the subject of many academic studies and thesis projects (e.g., McFarlane 1992; Salad Hersi and Dix 1999; Lowe et al. 2017; Oruche, Dix and Kamo 2018; James, Narbonne and Armstrong 2020). The bulk of these studies employ stratigraphic nomenclature that is not in use by the OGS, but rather includes nomenclature that predates the work of Liberty (1969) or is more commonly used in New York State (*see* Figure 20.2).

This project has 3 goals:

1. reconcile the nomenclature and stratigraphic framework of the Paleozoic bedrock in the study area with proposed revisions to OGS Paleozoic stratigraphic nomenclature (*see* Brunton et al. 2021; Béland Otis 2017, 2018, 2019, 2022, 2023; Hahn 2022, 2023);
2. establish a regional chemostratigraphic profile using stable carbon and oxygen isotopes to assist in regional correlation;
3. update the mapped formational-rank contacts between the various Paleozoic units as well as along the Precambrian–Paleozoic unconformity.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.20-1 to 20-11.

In addition, the Ordovician sedimentary rocks of eastern south-central Ontario are important sources for aggregate and groundwater resources and the updated mapping will contribute to better land-use planning in the region. Updates and improvements made to the maps will also help improve the regional understanding and predictability of karst landforms (Brunton 2019). Anticipated products of this project include geological maps, at a scale of 1:50 000, and an Open File Report. Maps produced during this project will be incorporated into the seamless Paleozoic bedrock map for southern Ontario (Armstrong and Dodge 2007).

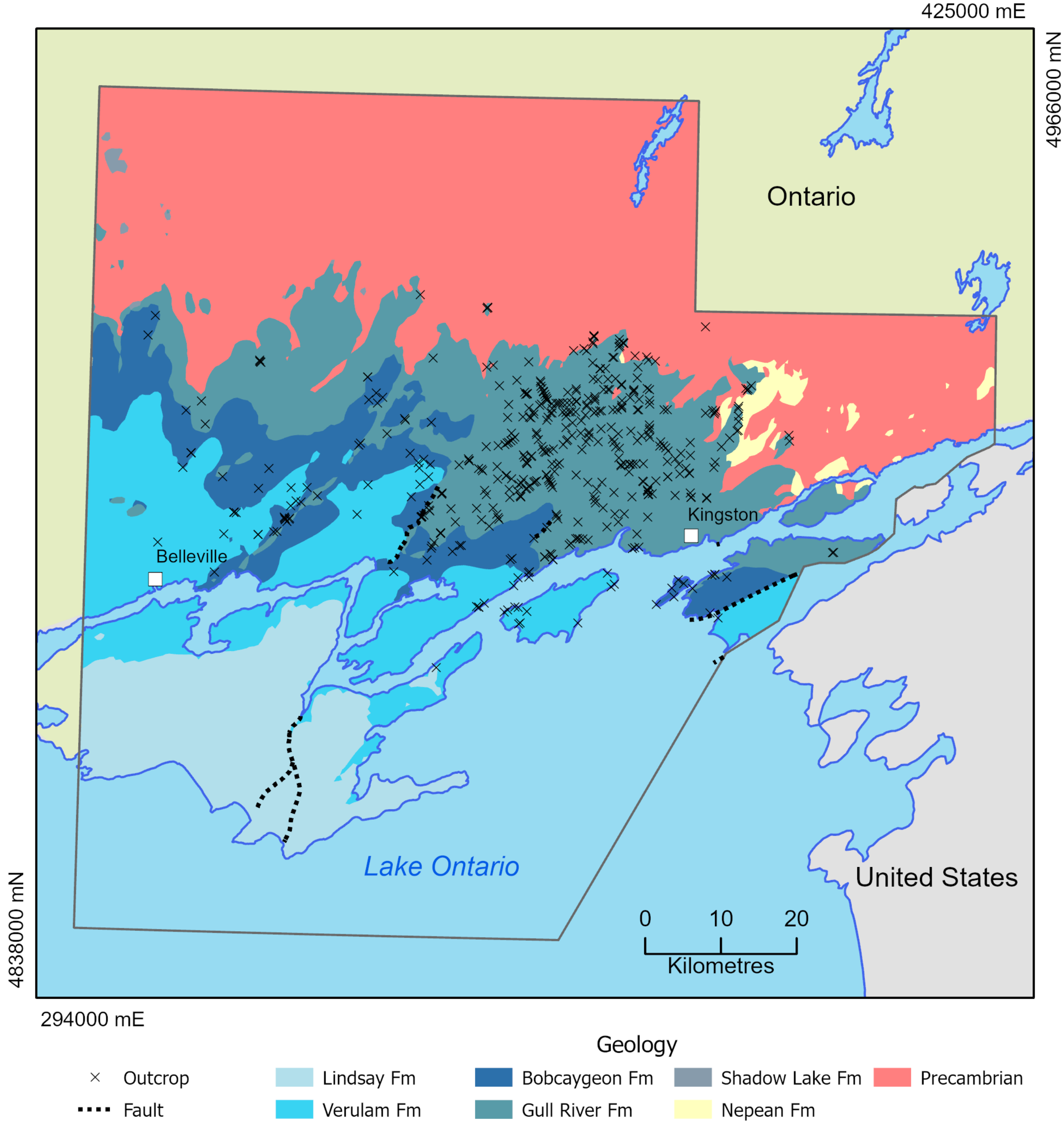


Figure 20.1. General bedrock geology (*from* Armstrong and Dodge 2007; *modified from* Carson 1981a, 1981b, 1981c, 1982a, 1982b) of the current study area showing the locations of stations visited in 2024. Universal Transverse Mercator (UTM) co-ordinates provided in North American Datum 1983 (NAD83) in Zone 18. Major cities in the areas shown with small white box outlined in black. Abbreviation: Fm, Formation.

2024 STUDY AREA AND FIELD WORK

The 2024 field season focussed on mapping in 4 of the 10 NTS map sheets that represent the study area, and included the Tichborne–Sydenham (NTS 31 C/10 and 31 C/7) and Bath–Yorkshire Island (NTS 31 C/2 and 30 N/15) map areas. These 4 map areas (of the 2024 field season) will herein be referred to as the "map area". Additionally, some outcrops and quarries were visited in the Tweed–Kaladar (NTS 31 C/11 and 31 C/6), Belleville–Wellington (NTS 31 C/3 and NTS 30 N/14) and Gananoque–Wolfe Island (NTS 31 C/8 and 31 C/1) areas as follow-up work from mapping in 2022 and 2023. The 2024 season included the documentation of 423 outcrops, 12 active quarries and 8 inactive quarries (*see* Figure 20.1). A total of 170 samples were taken for whole-rock geochemical analyses and thin sections.

Many of the outcrops that were mapped during the 1980s (Carson 1981a, 1981b, 1981c, 1982a, 1982b) are no longer present in the study area because of widening of roads and urban expansion. In some places, large-scale construction projects have temporarily exposed bedrock at surface and new outcrops were noted. Fresh building excavations on construction sites were visited whenever access was granted.

PALEOZOIC STRATIGRAPHY OF THE TICHBORNE–SYDENHAM AND BATH–YORKSHIRE ISLAND AREAS

The Potsdam Group forms the oldest sedimentary rocks in the map area and mainly crop out as outliers sitting unconformably on Precambrian basement in the Tichborne–Sydenham map area. Distribution of the Potsdam Group is patchy, and it was not observed, anywhere, to be in contact with the overlying Simcoe Group. The Potsdam Group is subdivided into 2 formations: the Covey Hill Formation (mainly conglomerate) and the overlying Nepean Formation (mainly sandstone). Only the Nepean Formation has been previously described by the OGS in the project area (Carson 1981b; Armstrong and Dodge 2007), but recent work by Lowe et al. (2017) has proposed that the formation names from New York State have historical precedence and that the Potsdam Group should follow a tripartite

		OGS Nomenclature			Other Nomenclature in Use		
		Group	**Formation**	***Member***	**Group**	**Formation**	***Member***
Ordovician	Upper	Simcoe	Lindsay		Trenton	Cobourg	
			Verulam			Sherman Falls	
			Bobcaygeon	*upper*		Kings Falls/Hull	
						Rockland	Napanee
				lower			Selby
			Gull River	*upper*	Black River	Chaumont/Watertown	
				middle		Lowville	
				lower		Pamelia	
			Shadow Lake				
Cambrian		Potsdam	Nepean		Potsdam	Keeseville	
			Covey Hill			Hannawa Falls	

Figure 20.2. Terminology of Paleozoic strata in the study area and a simplified overview of other nomenclature in use; a more extensive review of other nomenclature in use can be found in Béland Otis (2017) and Brunton et al. (2021). The OGS nomenclature is based on Liberty (1963, 1969). The Napanee and Selby are members (mb) of the Rockland Formation (e.g., Kay 1937; Cameron and Mangion 1977). Grey areas outlined by dashed lines represent disconformities. *See* Brunton et al. (2021) for additional information.

subdivision. A detailed overview of the proposed changes can be found in Béland Otis (2017, 2018, 2019). In the map area, the Potsdam Group was observed in only a few outcrops, where it was a fine- to medium-sand grade quartz arenite with variable amounts of red staining due to hematite cement. These outcrops most likely belong to the Nepean Formation.

The Simcoe Group, which includes the Shadow Lake, Gull River, Bobcaygeon, Verulam and Lindsay formations, is composed of a series of limestones, dolostones and shales that disconformably overly the Potsdam Group. In other jurisdictions, the Simcoe Group is equivalent to the Black River Group and overlying Trenton Group.

Throughout most of the map area, the Shadow Lake Formation crops out near the Precambrian–Paleozoic unconformity. It is present in only a few small outcrops in the Tichborne–Sydenham map area. Red and green sandstone, siltstone and shale are the most common rock types in the Shadow Lake Formation as well as minor amounts of lime mudstone or dolomudstone. Clasts of underlying basement rock or large quartz granules can be present in the various rock types. In eastern Ontario, the Shadow Lake Formation has been included as part of the Pamelia Formation (e.g., McFarlane 1992; Salad Hersi and Dix 1999). In the map area, the Shadow Lake Formation is generally 3 m thick, but can have significant variability depending on underlying basement topography. The upper contact with the overlying Gull River Formation is gradational and is generally marked at the first occurrence of a thick carbonate bed; however, there has been considerable debate as to how to define this contact because of its transitional nature (e.g., Liberty 1969, 1971; Carson 1981a, 1981b, 1981c, 1982a, 1982b; Melchin et al. 1994).

The Gull River Formation consists of thin- to thick-bedded tabular limestone, dolostone and dolomitic limestone. In the map area, it is subdivided into lower, middle and upper members (Carson 1981b, 1982b). Elsewhere in Ontario, the Gull River Formation is subdivided into a lower and upper member (central Ontario and Ottawa graben; Liberty 1963; Williams 1991; Armstrong 2000), and in neighbouring jurisdictions the lower member has been recognized as the Pamelia Formation of the Black River Group (e.g., Okulitch 1939; Wilson 1946; Clark 1972; Fisher 1977; Williams 1991; McFarlane 1992), and the upper member has been recognized as the Lowville Formation of the Black River Group (e.g., Clark 1972; Fisher 1977; McFarlane 1992).

The lower and middle members of the Gull River Formation in the map area are combined for descriptive purposes because of the variety of rock types and sedimentary features that are present in both members. Herein, the combined members will be referred to as the “lower Gull River Formation”. Outcrops of the lower Gull River Formation are most common near the Paleozoic–Precambrian boundary and extend approximately 10 km to the south of it. In low-lying areas, outcrops of it can be found even further south. Outcrops are found along lakeshores, roadcuts and as bedding planes in fields in the eastern two-thirds of the map area, while they are less common in the western part of the mapping area because of thicker Quaternary cover. Based on similarity in stratigraphic position, depositional setting and lithology, the lower Gull River Formation of the Kingston region is approximately equivalent to that in the Ottawa area and central Ontario, and the Pamelia Formation of New York State (e.g., Wilson 1946; Williams 1991; McFarlane 1992). In general, this unit is recognized in the field as a grey to dark grey-brown, finely crystalline limestone with interbeds of pale grey to pale green or yellow dolomitic limestone and dolostone. At least 3 greenish, argillaceous dolomitic limestone beds can be recognized as marker beds through the map area. Varying amounts of rounded, frosted, quartz sand and/or silt may be present throughout the entire lower Gull River Formation. Sedimentary features include intraclastic beds composed of rip-up clasts, ooids, mud cracks, microbial laminations, vertical and horizontal burrows, salt hoppers, dissolved gypsum laths and pink calcite-filled nodules. A restricted marine fauna of ostracods, molluscs and arthropods is most common; however, there are also occurrences of stromatolites and rare crinoids.

The upper Gull River Formation is exposed throughout the Sydenham and Bath map sheet areas. In the Sydenham area towards the north, this rock unit forms a bedrock plane on topographic highs, whereas to the south, it is exposed throughout the entire map area. In the Kingston area, thick stratigraphic sections are present along Taylor Kidd Boulevard, the off-ramp on Gardiners Road, and in many of the quarries in the area. The upper Gull River Formation is approximately 18 m thick in this region and displays the most variable vertical lithofacies of the stratigraphic units, making regional correlations difficult. There are several stratigraphic horizons where distinct stromatolitic mounds occur (Photo 20.1A), including towards the top of the Gull River Formation, where the mounds form bioherms with diverse faunal assemblages (Photo 20.1B). In general terms, the basal part of the upper Gull River Formation comprises medium to thick tabular beds of dark grey to brownish limestone. Lithofacies vary and include bivalve wackestone to floatstone, ooid grainstone, mudstone and intraclastic packstone to floatstone. Thin-bedded irregular to tabular bedded mudstone is more common in the upper part of the unit, but facies from lower in the unit can still be present. This part of the upper Gull River Formation is approximately equivalent to the

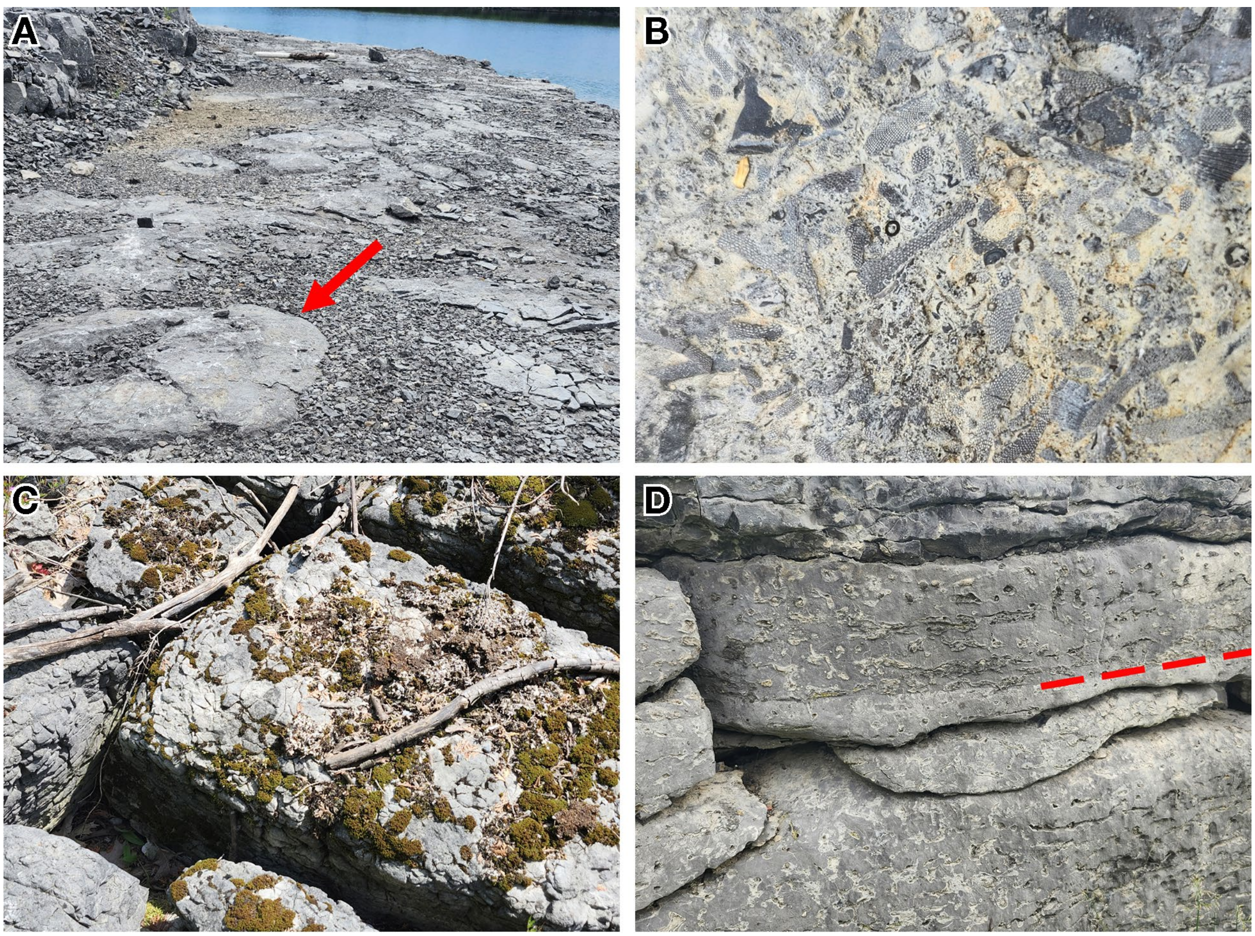


Photo 20.1. Selected photographs of the upper Gull River Formation in the Tichborne–Sydenham and Bath Yorkshire Island map areas. **A)** Stromatolite mounds (approximately 50 cm in diameter) surrounded by calcareous shale in the lower part of the upper Gull River Formation, located in an inactive quarry (now private residence) near Perth Road. **B)** Diverse fauna related to bioherms in the upper part of the upper Gull River Formation, located along several outcrops on Taylor Kidd Boulevard west of Kingston. Section of rock pictured is approximately 8 cm across. **C)** Distinctive clint and grike morphology observed on bedding planes in specific lithofacies throughout the map area. Cracks depicted in photograph are up to 10 cm wide and extend downwards between 50 and100 cm. In places, deeper cracks are present. **D)** Hardground surface (red dashed line) in upper Gull River Formation rocks interpreted to be equivalent to the Chaumont Formation. Located in several localities on Wolfe Island. Section of rock depicted is approximately 50 cm in width.

Lowville Formation of the Black River Group (e.g., Liberty 1963; McFarlane 1992). The uppermost part of the Gull River Formation in the map area is an additional approximately 8 m of thick-bedded, peloidal wackestone to packstone that is elsewhere variably recognized as the Chaumont Formation of the Black River Group (Liberty 1963, 1971; McFarlane 1992). In places, thick-bedded peloidal wackestone of the upper Gull River Formation displays a clint and grike crack morphology across bedding planes, but it is currently unresolved whether this feature is limited to only the uppermost part of the upper Gull River Formation, or the entire upper Gull River Formation (Photo 20.1C). A distinct feature of the Chaumont-like unit in the Kingston area are several hardgrounds within the more massive beds (McFarlane 1992; *see* Photo 20.1D). This unit is much more difficult to identify to the west, possibly because of a facies change. One of the key outcrops in the area that has been described as representing the Black River–Trenton (or Gull River Formation–Bobcaygeon Formation) contact interval is in the Bath map sheet area near the Camden East–Highway 401 intersection. Approximately 15 m of nearly continuous outcrop is exposed here, illustrating the transition from the most upper part of the Gull River Formation (Chaumont Formation) into the overlying Bobcaygeon Formation. The contact between the 2 units is sharp and is defined at the contact between thick-bedded wackestone and an overlying rust-stained crinoid grainstone. Large cephalopods, stromatoporoids and other megafauna are common along the upper bedding plane of the uppermost bed. Thick-bedded limestone containing cephalopods, corals and stromatoporoids that may be related to the Chaumont Formation, were observed in the Napanee area (Photos 20.2A and 20.2B). Overlying beds of the Bobcaygeon Formation are described below.

Limestone that is currently mapped as the Bobcaygeon Formation is distributed on the western side of both the Bath and Sydenham map sheet areas. In general, outcrops are limited and mainly exposed as bedding planes, or bedrock surfaces in roadside ditches, where individual sections are less than 1 m thick. The most continuous exposures through this interval are in quarries. In the map area, the Bobcaygeon Formation is subdivided into a lower and upper member (Carson 1981b, 1982b). Other authors (e.g., Kay 1937; Cameron and Mangion 1977) have termed these units the Selby and Napanee members of the Rockland Formation. Distinguishing features of the Bobcaygeon Formation include a change from the restricted marine fauna of the underlying Gull River Formation (or Black River Group) to an increase in crinoids, brachiopods and bryozoans, an overall increase in shale content and an increase in common hardground surfaces and storm beds. This suggests a general upward deepening trend and a transition to more open marine conditions for this succession. At the Camden East–Highway 401 outcrop, at least 2 informal members of the Bobcaygeon Formation are present. The unit directly overlying the thick-bedded Gull River Formation is a thin-bedded mudstone to wackestone with a rubbly-textured weathering pattern and a petroliferous odour when freshly broken. This unit is approximately 3 m thick and is consistent with published descriptions of the Selby member (Kay 1937; Cameron and Mangion 1977; Photo 20.2C). Due to the thinness of the unit and rubbly weathering, it was not observed in many outcrops and its regional continuity remains unclear. Interbedded packstone and shale, as well as beds of intraclastic rudstone, overlie the thin-bedded, rubbly weathering unit. This unit is consistent with descriptions of the "Napanee member" of Kay (1937).

The Verulam Formation conformably overlies the Bobcaygeon Formation. In the map area, the contact between these 2 units was not observed. The Verulam Formation is present in the southern part of the Bath map area, where it mainly crops out along the Lake Ontario shoreline, or in small roadside exposures. Many of the shoreline outcrops of the Verulam Formation that were shown on previous maps are now covered by different forms of erosion control. In general, the Verulam Formation is described as interbedded wackestone, packstone and grainstone beds between 5 and 25 cm thick, with shale seams (Liberty 1963, 1971; Carson 1982b; Photo 20.2D). In outcrop, shale-rich beds display recessive weathering and outcrops tend to be quite rubbly. The most common fauna in the Verulam Formation includes brachiopods, bryozoans, trilobites and crinoids (Liberty 1969). In the map area, it is very difficult to differentiate between the shale-rich part of the upper Bobcaygeon Formation and the overlying Verulam Formation because the lithofacies are so similar and outcrops are generally small. Furthermore, even in drill core, the contact between the upper Bobcaygeon Formation and the Verulam Formation is ambiguous. The lack of differentiation between the 2 units contrasts with the Ottawa area, where the shale content is markedly different between both units (Williams 1991).

The Lindsay Formation (also known as Cobourg Formation; Armstrong and Carter 2010) is not present in the map area but overlies the Verulam Formation in the adjacent Belleville–Yorkshire Island map sheet area. The Lindsay Formation is the uppermost unit of the Simcoe Group (Trenton Group). It is a fossiliferous, bioturbated limestone with shaly partings. In outcrop, depending on weathering style, the Lindsay Formation can form either thick, resistant-weathering ledges of thinner, irregularly bedded nodular limestone, or it can be recessively weathering and display a crumbly weathering with breaks along shale partings. The overall texture is nodular, and wackestone, packstone and grainstone beds can all be found (e.g., Liberty 1969; Carson 1981c; Hahn 2023).

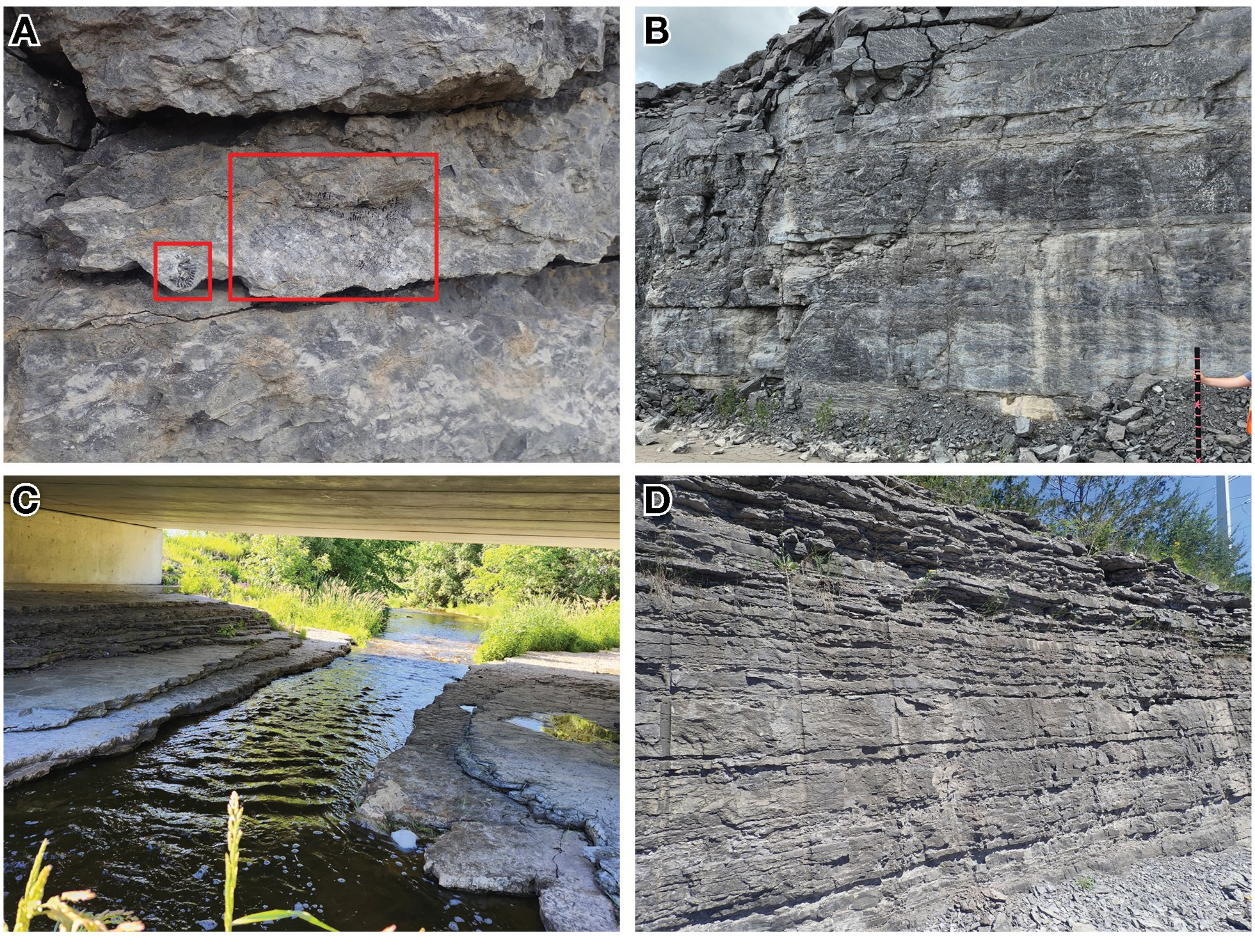


Photo 20.2. Photographs of selected sites visited during 2024 field work. **A)** Large fossil corals (red boxes; large box ~10 cm wide) observed in thick-bedded limestone at a quarry in Napanee. The thick-bedded limestone is mapped as upper Gull River Formation (Carson 1982b). **B)** Thick-bedded limestone at the base of Long's Quarry, near Tyendinaga (measuring staff is 1 m). It is currently unknown how these beds correlate with either the upper Gull River Formation or the lower Bobcaygeon Formation. **C)** Outcrop along Selby Creek, near the type section for the Selby member of Kay (1937). These rocks are currently mapped as Bobcaygeon Formation (Carson 1981b). **D)** Approximately 4 m tall rock face along the railway tracks at the Lennox and Addington Generating Station. These are currently mapped as Verulam Formation (Carson 1982b).

STRUCTURAL GEOLOGY

Paleozoic strata in the study area are generally flat lying or display shallow dips (<5° to the south). Locally, beds can be tilted up to 20° in the vicinity of Precambrian inliers. Strike orientation is varied near these inliers, where Paleozoic sedimentary rocks drape Precambrian bedrock highs, and the tilted bedding is interpreted to be a result of paleotopography and nontectonic deformation. Several normal faults are documented in the adjoining map sheet areas (Kaladar–Tweed and Belleville–Wellington), where rivers follow the topographic expression of normal faults (Carson 1981c). The Napanee River in the Tichborne–Sydenham map area follows the trend of normal faults through the region and vertical displacement along this fault is apparent in the city of Napanee, where the elevation of the Bobcaygeon Formation is lower on the west side of the river than the elevation of the Gull River Formation. Estimating the amount of displacement along these faults will be done using modern digital elevation data.

DISCUSSION AND FUTURE WORK

During the 2024 field season, sampling for stable carbon and oxygen isotopes was conducted at several stations where thick stratigraphic sections are preserved. Here, sampling was completed at a 50 cm vertical spacing. Samples collected during 2024 will be compared to a thick reference section that was collected during 2023 to establish local chemostratigraphic patterns. These data sets can then be used as a tool to correlate stratigraphic successions locally and perhaps in a regional and/or global context.

Despite the extensive scientific literature regarding the stratigraphic interval spanning the Gull River through Bobcaygeon formations, also termed the Black River–Trenton groups boundary, considerable confusion still exists related to delineating formational and group rank boundaries. The nomenclature of Upper Ordovician sedimentary rocks in eastern and south-central Ontario varies both geographically and between the outcrop belts and the subsurface and has been discussed in detail in several recent OGS publications (Brunton et al. 2021 and references therein). In the Sydenham map area, the upper and lower subdivisions of the Gull River Formation are relatively easy to identify because of the distinctive lithofacies present in those members. Although direct outcrop to outcrop correlation in the upper Gull River Formation is difficult as a result of rapid facies changes, sections can generally be placed in a relative stratigraphic position within the Gull River Formation. In the Bath map sheet area, however, it is more difficult to identify with confidence what units are present at surface. As described above, some of the facies from the uppermost upper Gull River Formation (Chaumont Formation?) may not be present to the west and identifying members within the Bobcaygeon Formation is difficult (*see* Discussion section in Hahn 2023).

Of note during the 2024 field season, was the lack of major lithofacies differences between the upper member of the Bobcaygeon Formation and the Verulam Formation. During the spring of 2024, several drill cores from across Ontario were examined in support of the updates to the Paleozoic legend project. During this work, it was observed that 2 reference cores in the map area (Prince Edward County and Tyendinaga) displayed no obvious facies change between the upper Bobcaygeon Formation and the Verulam Formation. Further detailed core logging will be undertaken during fall 2024 in order to better describe this stratigraphic interval.

Mapping for this project, over the last 3 years, has helped resolve some of the knowledge gaps related to regional correlation and nomenclature of Ordovician stratigraphy in eastern south-central Ontario. From a mapping perspective, the main subdivisions of the Gull River Formation (i.e., lower and middle, upper) in the study area are now correlated with higher confidence to the subdivisions of the Gull River and Bobcaygeon formations in the Ottawa graben and the Black River Group of New York State. A better understanding of the regional differences in the Bobcaygeon Formation has been gained and work to define the subdivisions is ongoing.

Based on the 2024 field season results, key questions to be addressed include the following:

- Is there a significant difference between the uppermost Bobcaygeon Formation and the Verulam Formation in the study area and do they warrant being described as separate map units?
- How do these units correlate to the stratigraphy in central Ontario and the Ottawa graben?

ACKNOWLEDGMENTS

The author wishes to acknowledge the assistance of Elizabeth Edwards during the field season, as well as Kei Yeung (GIS technical help, OGS) and Julien Bonin (drafting figures, OGS), who are gratefully acknowledged for providing help with preparing maps and figures. The Ministry of Transportation is gratefully acknowledged for allowing access to construction zones along the Highway 401 corridor, and for providing assistance in documenting outcrop exposure along select highway ramps. The author would like to thank the Algonquins of Pikwakanagan First Nation, Alderville First Nation, Curve Lake First Nation, Hiawatha First Nation, Mississaugas of Scugog Island First Nation, Mohawks of the Akwesasne and the Mohawks of the Bay of Quinte for allowing the Ontario Geological Survey to map their traditional land-use areas. Finally, Catherine Béland Otis and Frank Brunton (OGS) are thanked for many lively discussions, technical expertise and for reviewing this report.

REFERENCES

Armstrong, D.K. 2000. Paleozoic geology of the northern Lake Simcoe area, south-central Ontario; Ontario Geological Survey, Open File Report 6011, 43p.

Armstrong, D.K. and Carter, T.R. 2010. The subsurface Paleozoic stratigraphy of southern Ontario; Ontario Geological Survey, Special Volume 7, 301p.

Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 219.

Béland Otis, C. 2017. Paleozoic geology of eastern Ontario; *in* Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p.22-1 to 22-11.

——— 2018. Paleozoic geology of eastern Ontario: Ottawa area; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.22-1 to 22-10.

——— 2019. Paleozoic geology of eastern Ontario: Arnprior–Quyon area; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.20-1 to 24-10.

——— 2022. Paleozoic geology of eastern Ontario: Russell–Thurso area; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.23-1 to 23-8.

——— 2023. Paleozoic geology of eastern Ontario: Hawkesbury and Alexandria areas; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.24-1 to 24-9.

Brunton, F.R. 2019. Karst map of southern Ontario: An update; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.21-1 to 21-9.

Brunton, F.R., Béland Otis, C., Hahn, K.E. and Yeung K. 2021. Progress on the development of a new stratigraphic framework for the Paleozoic geology of southern Ontario; *in* Summary of Field Work and Other Activities, 2021, Ontario Geological Survey, Open File Report 6380, p.16-1 to 16-9.

Cameron, B. and Mangion, S. 1977. Depositional environments and revised stratigraphy along the Black River–Trenton boundary in New York and Ontario; American Journal of Science, v.277, p.486-502.

Carson, D.M. 1981a. Paleozoic geology of the Kaladar–Tweed area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2411, scale 1:50 000.

——— 1981b. Paleozoic geology of the Tichborne–Sydenham area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2413, scale 1:50 000.

——— 1981c. Paleozoic geology of the Belleville–Wellington area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2412, scale 1:50 000.

——— 1982a. Paleozoic geology of the Gananoque–Wolfe Island area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2496, scale 1:50 000.

——— 1982b. Paleozoic geology of the Bath–Yorkshire Island area, southern Ontario; Ontario Geological Survey, Preliminary Map P.2497, scale 1:50 000.

Clark, T.H. 1972. Montreal area; Ministère des Richesses Naturelles du Québec, Geological Report 152, 244p.

Fisher, D.W. 1977. Correlation of the Hadrynian, Cambrian and Ordovician rocks in New York State; New York State Museum and Science Service, Map and Chart Series 25, 75p.

Hahn, K.E. 2022. Paleozoic geology of the Kingston area, eastern Ontario; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.22-1 to 22-10.

——— 2023. Paleozoic geology of eastern south-central Ontario: Tweed–Kaladar and Belleville–Wellington areas; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.27-1 to 27-11.

James, N.P., Narbonne, G.M. and Armstrong, A.K.R. 2020. Aragonite depositional facies in a Late Ordovician calcite sea, Eastern Laurentia; Sedimentology, v.67, p.3513-3532.

Kay, G.M. 1937. Stratigraphy of the Trenton Group; Geological Society of America, Bulletin, v.48, p.233-302.

Liberty, B.A. 1963. Geology of Tweed, Kaladar, and Bannockburn map areas, Ontario, with special emphasis on Middle Ordovician stratigraphy; Geological Survey of Canada, Paper 63-14, 15p.

——— 1969. Paleozoic geology of the Lake Simcoe area, Ontario; Geological Survey of Canada, Memoir 355, 201p.

——— 1971. Paleozoic geology of the Wolfe Island, Bath, Sydenham, and Gananoque map-areas, Ontario; Geological Survey of Canada, Paper 70-35, 12p., 4 maps.

Lowe, D.G., Arnott, R.W.C., Nowlan, G.S. and McCracken, A.D. 2017. Lithostratigraphic and allostratigraphic framework of the Cambrian–Ordovician Potsdam Group and correlations across Early Paleozoic southern Laurentia; Canadian Journal of Earth Sciences, v.54, p.550-585.

McFarlane, R.B. 1992. Stratigraphy, paleoenvironmental interpretation, and sequences of the Middle Ordovician Black River Group, Kingston, Ontario, Canada; unpublished PhD thesis, Queen's University, Kingston, Ontario, 167p.

Melchin, M.J., Brookfield, M.E., Armstrong, D.K. and Coniglio, M. 1994. Stratigraphy, sedimentology and biostratigraphy of the Ordovician rocks of the Lake Simcoe area, south-central Ontario; Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, Waterloo, Ontario, Guidebook for Field Trip A4, 101p.

Okulitch, V.J. 1939. The Ordovician section at Coboconk, Ontario; Royal Canadian Institute, Transactions, v.33, p.319-339.

Oruche, N.E., Dix, G.R. and Kamo, S.L. 2018. Lithostratigraphy of the upper Turinian–lower Chatfieldian (Upper Ordovician) foreland succession, and a U–Pb ID–TIMS date for the Millbrig volcanic ash bed in the Ottawa Embayment; Canadian Journal of Earth Sciences, v.55, p.1079-1102.

Salad Hersi, O. and Dix, G.R. 1999. Blackriveran (lower Mohawkian, Upper Ordovician) litho-stratigraphy, rhythmicity, and paleogeography: Ottawa Embayment, eastern Ontario, Canada; Canadian Journal of Earth Sciences, v.36, p.2033-2050.

Williams, D.A. 1991. Paleozoic geology of the Ottawa–St. Lawrence Lowland, southern Ontario; Ontario Geological Survey, Open File Report 5770, 292p.

Wilson, A.E. 1946. Geology of the Ottawa–St. Lawrence Lowland, Ontario and Quebec; Geological Survey of Canada, Memoir 241, 66p.

21. Project ON-21-005. Proposed Nomenclature for New Water Well Records: Internal Test Results

J.M. Galvao[1] and A.K. Burt[2]

[1]School of Environmental Sciences, University of Guelph, 50 Stone Road East, Guelph, Ontario, Canada N1G 2W1
[2]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, Ontario P3E 6B5

INTRODUCTION

Geological information on water well records, typically accessed using the Ministry of the Environment, Conservation and Parks (MECP) Water Well Information System (WWIS), is an important source of subsurface data for many geological, geotechnical and hydrogeological projects across Ontario. However, the reliability of the data is an ongoing problem. The current WWIS restricts well technician descriptions to 1 colour field, with 1 of 9 possible terms, and 3 material fields, with 1 of 82 possible terms. Many of the terms in the current WWIS are redundant or have limited geological or hydrogeological meaning, whereas others describe minerals rather than rock types or simply do not reflect the typical geology of Ontario. A previous investigation of how individual terms are used and combined revealed a cumbersome database with 36 495 unique combinations of terms (Burt et al. 2021a, 2021b). Of them, 20 000 combinations occur only once or twice in the database, whereas just 100 combinations comprise approximately 60% of the records, suggesting there is considerable potential for simplification. In an online survey conducted during a recent Ontario Groundwater Geoscience Open House lightning talk (Burt et al. 2024), 29 out of 30 respondents indicated that improving the geological information on new water well records will create efficiencies in their workflow. This reflects the results of a much broader Well Record Data Enhancement stakeholder survey, administered by WSP Inc. on behalf of MECP in 2017, in which inaccuracies in overburden and/or bedrock material descriptions were identified as a major challenge when using water well records as a source of subsurface information.

The Ontario Geological Survey is collaborating with a team of water supply well technicians, geotechnical drillers, MECP staff and other stakeholders on a project to improve the quality and consistency of geological information on new water well records. A jurisdictional review, stakeholder interviews and feedback obtained from groundwater practitioners guided the initial development and subsequent refinements of a two-step system for entering geological materials on Ontario water well records (Burt et al. 2021a, 2021b, 2023a, 2023b, 2024). The unit depth and a mandatory primary material category, consisting of fill, previously constructed, sediment, weathered bedrock or bedrock, are entered in Step 1 (Figure 21.1). Optional pick-lists are then made available to the submitter in Step 2 to provide information on colour, sediment texture, bedrock lithology, qualifiers, hardness and moisture, collectively referred to as descriptors.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.21-1 to 21-6.

Step 1 Step 2

From	To	
		Fill
		Previously Constructed
		Sediment
		Weathered Bedrock
		Bedrock

Primary Material
clay (10)
sand (43)
gravel and cobbles (30)
broken rock (32)
clay and gravel (4)

From	To	
		Fill
		Previously Constructed
		Sediment
		Weathered Bedrock
		Bedrock

Colour	Primary Material	Secondary Material	Tertiary Material	Qualifier	Hardness	Moisture
black (370)	topsoil (782)	clay (488)	clay (103)	layered (233)	cemented (57)	dry (79)
blue (651)	clay (3786)	silt (452)	silt (91)	lost circulation	hard (1521)	wet (192)
brown (2879)	silt (311)	sand (858)	sand (99)	till (677)	loose (457)	
brown-grey (59)	sand (2173)	gravel (975)	gravel (165)	organics (30)	soft (645)	
green (11)	fine sand (347)	cobbles (746)	cobbles (183)	other (1)		
grey (2443)	medium sand (90)	boulders (388)	boulders (125)	- - -		
red (273)	coarse sand (146)			weathered (1)		
white (36)	gravel (1091)			wood (12)		
yellow (182)	fine gravel (59)					
other (31)	medium gravel (9)					
- - -	coarse gravel (91)					
blue-grey (13)	cobbles (131)					
orange (4)	boulders (164)					
pink (5)	peat (24)					
tan (5)						

From	To	
		Fill
		Previously Constructed
		Sediment
		Weathered Bedrock
		Bedrock

Colour	Primary Rock Type	***Sediment***	Qualifier	Hardness	Moisture
black (19)	dolostone (1)	***clay (18)***	fractured (109)	hard (8)	dry (0)
blue (3)	limestone (49)	***silt (5)***	layered (4)	soft (13)	wet (1)
brown (32)	sandstone (1)	***sand (17)***	lost circulation		
brown-grey (0)	shale (40)	***gravel (10)***	other (0)		
green (1)	shale and limestone (5)		- - -		
grey (50)	basalt (0)		weathered (17)		
pink, grey, black (0)	granite (27)				
red (11)	greenstone (0)				
white (3)	marble (0)				
other (1)	quartzite (0)				
- - -	slate (2)				
blue-grey (0)	other (0)				
orange (0)	- - -				
tan (0)	mudstone (1)				
yellow (1)					

From	To	
		Fill
		Previously Constructed
		Sediment
		Weathered Bedrock
		Bedrock

Colour	Primary Rock Type	Qualifier	Hardness	Moisture
black (496)	dolostone (18)	***chert (16)***	hard (670)	dry (6)
blue (84)	limestone (1175)	fractured (59)	soft (236)	wet (9)
brown (399)	sandstone (122)	layered (233)		
brown-grey (65)	shale (428)	lost circulation		
green (76)	shale and limestone (74)	other (0)		
grey (1559)	basalt (8)	- - -		
pink, grey, black (55)	granite (1450)	weathered (0)		
red (391)	greenstone (45)			
white (144)	marble (14)			
other (15)	quartzite (33)			
- - -	slate (23)			
blue-grey (7)	other (65)			
orange (2)	- - -			
tan (1)	mudstone (8)			
yellow (6)				

Figure 21.1. Recommended terms for describing the fill, sediment, weathered bedrock and bedrock material categories in Step 2. Pick-lists and terms in ***bold italics*** are new. Terms below the dashed lines will be dropped. The numbers within parentheses refer to the number of occurrences within the test database.

INTERNAL TESTING

A province-wide database of descriptions of geological materials, assembled from 3673 portable document format (*.pdf*) copies of original water well records, was prepared by previous OGS student assistants. This test database has been used to test the proposed system and lists of terms as part of a co-operative education work term project by the lead author. The database consists of descriptions of geological materials of wells drilled through Quaternary sediments representing all glacial and non-glacial depositional environments within Ontario, as well as igneous, metamorphic and sedimentary bedrock. The number of described units in each well record ranges from 1 to 21, with an average of 3.7. In total, the database includes descriptions for 13 732 units.

Method

The test database was created using Microsoft® Excel®, because the software has the functionality to create drop-down pick-lists to select material categories and descriptors, simulating how the proposed system will be implemented. The pick-lists used for testing reflect recent refinements to the proposed system, as described by Burt et al. (2023b), incorporating suggestions from well technicians and groundwater practitioners (Burt et al. 2024). During testing, each unit (geological material) was carefully assessed to determine its probable material category, colour and descriptors. Terminology outside of the proposed system was recorded in a “notes” field for later analysis. Microsoft® Access® was used to compile and interpret the test results using filters, queries and text searches. Initial queries were simple usage counts of material categories, colours and descriptors. Tables were then created to investigate how colour and descriptors varied by material category. A comprehensive analysis of the colour descriptions used in the original water well records was completed to determine whether additional colours should be added to the pick-list. This process compared colours selected using the pick-lists with additional colour terms recorded in the notes field. Similar queries were conducted using data extracted from the WWIS data for comparison. Finally, the number of unique combinations of terms, and whether the proposed system contained more information than the WWIS, was assessed. ESRI® ArcGIS Pro® was used to visually compare unusual combinations of material categories, colours and descriptors with published Paleozoic bedrock (Armstrong and Dodge 2007) and surficial sediment (Ontario Geological Survey 2010) maps to determine if the description of the material in the original water well record was plausible.

Results and Recommendations

The test results show that the proposed system has the potential to provide meaningful geological descriptions while reducing the overall complexity (i.e., total number of unique combination of terms) of the resulting database. It was possible to assign a material category to 13 718 units (Table 21.1). The remaining 14 units within the test database did not have any geological information. Most units were assigned a material category with little difficulty; however, some vague or poorly defined terms were more challenging. It is anticipated that these issues will be resolved by the proposed system. The most common material category is sediment, representing 69% of the units in the test database, followed by bedrock, representing 27.5% units. Fill, previously constructed and weathered bedrock collectively represent the remaining 3.5%. Weathered bedrock is a new material category, created to capture the so-called interface aquifer zone of rubbly, weathered and unconsolidated rock between Quaternary sediments and competent bedrock, reflecting the language of the *Ontario Water Resources Act* R.R.O. 1990, Regulation 903 s. 13 (12) (Ontario 1990). Units explicitly described as weathered or units with both rock and sediment descriptors found between sediment and bedrock units were assigned to this category. It was observed that weathered bedrock units are typically associated with sedimentary and metamorphic rock types.

Table 21.1. Frequency of Step 1 material categories within the test database and the number of unique combinations of terms used to describe each category in the current and proposed systems. Note "previously constructed" refers to an existing well.

Material Type	Step 1 Count	Unique Combinations WWIS	Unique Combinations Proposed System
Fill	173	102	77
Previously constructed	104	NA	NA
Sediment	9495	1714	1385
Weathered bedrock	153	115	67
Bedrock	3793	596	282
No geological information	14	NA	NA
Total	**13 732**	**2527**	**1811**

Abbreviation: NA, not available.

A total of 5 pick-lists were tested for bedrock and weathered bedrock and 7 pick-lists for sediments (*see* Figure 21.1). This allowed for a 43% increase in the number of descriptors used for each unit compared to the current 3 material field system. Despite the increase in number of descriptors, the overall complexity was reduced. For example, for the number of unique combinations of terms has been reduced from 1714 in the WWIS to 1385 for sediments and from 596 to 282 for bedrock (*see* Table 21.1).

The test results validate most pick-list categories and terms. As previously described (Burt et al. 2023b), many terms currently used in the WWIS would be retired or modified in the proposed system. Many of these recommendations required little testing: 1) the use of pick-lists removes the need for "unknown type"; 2) specific mineral terms, such as feldspar and quartz, will be replaced by rock terms, such as granite or quartzite; and 3) terms well technicians are unlikely to identify correctly using cuttings will be retired.

Another recommendation that was investigated was the fact that the current system includes both "clay" and "clayey" as potential descriptors; however, the term "clayey" only appears in 20 original water well records and 9 WWIS formation descriptions, compared to the 4364 times "clay" was used. This suggests that removing the term "clayey" will not result in a significant loss of information. A similar pattern occurred with the terms gravelly, sandy, shaley, silty and stoney.

There are several examples of WWIS terms that lack clarity or a well-defined meaning. The existing system includes the terms "fine-grained", "medium-grained" and "coarse-grained" and these have been used where the original water well records describe anything from fine sand to medium-hard limestone. Based on these test results, it is recommended that the terms be replaced by the less ambiguous fine, medium, or coarse sand or gravel, with hardness recorded in a separate pick-list. Similarly, the terms "stones" and "stoney" would be retired because they do not specify size and could refer to anything from fine gravel to boulders.

Other terms, such as "hardpan", are used by well technicians to describe a range of materials. Hardpan is most often used to describe glacial till, but has occasionally been used to describe shale, or other soft bedrock. In the proposed system, selecting sediment in Step 1 will open a qualifier pick-list with the option to select "till" but not "hardpan". Neither option is available in the weathered bedrock or bedrock material categories. Another example of incorrect usage is the less common term "marl". Appearing in 11 original water well records, "marl" was also used incorrectly to describe both sediments and weathered bedrock and the recorded colours of grey, brown, black and blue are not consistent with the typical white, or very light brown appearance of most true marls. Furthermore, comparison with the surficial geology map shows the term being used in areas where significant marl accumulations are unlikely. A final example of improper usage is "soapstone", which occurred in 21 original water well records. Soapstone is a metamorphic rock that is localized in Ontario but, in the well records, was most often used in regions with shale-rich bedrock units.

The test results also revealed the need for further refinements to the proposed system. The original water well records contained information of potential hydrogeological significance to describe fill. It is recommended that an optional pick-list for a primary material type, including the terms clay, sand, gravel and cobbles, broken rock, and clay and gravel, be developed for the material category fill. However, a colour pick-list is not proposed, as this would not provide any meaningful geological information. Similarly, weathered bedrock will also contain a sediment pick-list, because many of the records for this material type include both bedrock and sediments. This will be a simplified sediment pick-list, containing only clay, silt, sand and gravel.

Other refinements focus on specific terms within pick-lists. The term "weathered", previously included in the qualifier pick-lists, has become redundant for bedrock with the introduction of the material category "weathered bedrock" in Step 1. The term was only used once to describe sediment (*see* Figure 21.1) and should be dropped. The term "mudstone" had been introduced as a potential new bedrock rock type; however, it only appeared in 8 original water well records, the mapped distribution shows that usage is highly localized, and it is likely that most well technicians would use the term "shale". Another refinement to the bedrock pick-lists is the re-introduction of "chert", but as a qualifier because it occurs with limestone and is never the primary rock type. As a final example, the term "wood" should be replaced with the more general term "organics" in the sediment material category qualifier pick-list.

More extensive refinements are recommended for the colour pick-lists. Testing revealed some proposed colours are rarely used (tan, blue-grey and orange), whereas other colours are exclusive to either sediment (yellow) or bedrock (pink) material categories. A detailed examination of original water well records revealed the need for a "brown-grey" option for all material categories and that a "pink, grey, black" colour option for bedrock and weathered bedrock would be more inclusive than "pink".

Rare materials, colours or qualifiers not within the picklists can be accommodated by selecting "other", which would open a short free-form text box.

NEXT STEPS

These test results have informed OGS Phase 1 recommendations to MECP. It is anticipated that these recommendations will form part of a broader review of the water well record form. After the system and the lists of terms have been finalized by MECP, development of educational materials will commence.

ACKNOWLEDGMENTS

The success of this project is dependent on the contributions by well technicians, managers and consultants representing the water supply, geotechnical and environmental industries. Riley Mulligan (OGS), Kei Yeung (OGS), Frank Brunton (OGS), Manuel Duguet (OGS) and Michael Easton (OGS) provided valuable guidance and discussions during earlier stages of the project. Former OGS students Adam Kelly and Kayla Tessier prepared the test database and their efforts are gratefully acknowledged. Kei Yeung (OGS) assisted with database management tasks and Julien Bonin (OGS) prepared maps and figures for publication. Riley Mulligan (OGS), Manuel Duguet (OGS) and Michael Easton (OGS) reviewed this article. The first draft of this article was written by the lead author, J.M. Galvao, as part of a co-operative education work term project.

REFERENCES

Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 219.

Burt, A.K., Grant, D., Kelly, A., Mulligan, R.P.M. and Yeung, K.H. 2023a. Lithological lock-down – Standardizing geological descriptions in well records; *in* Regional-scale groundwater geoscience in southern Ontario: The 2023 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House, Ontario Geological Survey, Open File Report 6387, p.7, oral presentation available at www.youtube.com/watch?v=sEXnYhE6gpk&t=9s. [accessed September 6, 2023]

Burt, A.K., Mulligan, R.P.M., Brunton, F.R., Yeung, K.H., Spina, N.E. and Cheng, T. 2021a. Improving geological nomenclature in Ontario well records; *in* Summary of Field Work and Other Activities, 2021, Ontario Geological Survey, Open File Report 6380, p.20-1 to 20-5.

——— 2021b. Towards a simplified, standardized nomenclature for geological materials in well records; *in* Regional-scale groundwater geoscience in southern Ontario: The 2021 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House, Ontario Geological Survey, Open File Report 6378, p.3, oral presentation available at www.youtube.com/watch?v=BjrmCXLRCGY&list=PLdapv5BeduhW-HO8AJbZU9qQjEENeCQ2M&index=9&t=77s. [accessed September 6, 2023]

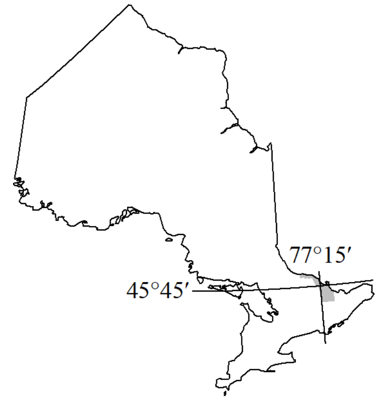
Burt, A.K., Yeung, K.H., Grant, D. and Mulligan, R.P.M. 2023b. Keeping it simple: Geological information on water well records; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p. 28-1 to 28-7.

——— 2024. Let's KISS – Geological information on water well records; *in* Ontario Groundwater Geoscience 2024 Open House, Ontario Geological Survey, Open File Report 6406, p.7, oral presentation available at https://www.youtube.com/watch?v=VGxfluaaGnw&list=PLdapv5BeduhW_-dsxzFsCOmoSYsgGZcoc&index=5. [accessed September 9, 2024]

Ontario 1990. *Ontario Water Resources Act*, Revised Regulations of Ontario 1990, Regulation 903 Wells, as amended 2020 O.Reg 461/19, under *Ontario Water Resources Act*, R.S.O. 1990, c. O.40, as amended 2021, c. 4, Sched. 10, s. 4; available at www.ontario.ca/laws/regulation/900903. [accessed October 6, 2023]

Ontario Geological Survey 2010. Surficial geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 128 – Revised.

22. Project SO-24-001. Groundwater Geochemistry Mapping Across the Ottawa Valley



L.M. Colgrove[1]

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

INTRODUCTION

Groundwater is a critical source of fresh water 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 AGGP aims to map the chemistry of groundwater at the regional scale in order to establish a baseline, study geological controls on groundwater chemistry and better understand aquifer flow and conditions. It functions by collecting data on a large suite of parameters at a consistent spacing density using a standardized protocol (Bocking, Hamilton and Dell 2023).

Between July and August 2024, samples of groundwater were collected in a previously unmapped region across the Ottawa Valley to further extend the coverage of the AGGP. 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 22.1; 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 22.1; Dell, Fudge and Hamilton 2016; Dell, Francis and Hamilton 2017; Dell and Francis 2018; Dell 2024; Dell and Hamilton 2024). The Ottawa Valley program connects the northeastern and southern AGGP project areas and will yield data that allow the characterization of the groundwater quality and provide insight into the corresponding geological controls (*see* Figure 22.1).

STUDY AREA

The 2024 Ottawa Valley study area extends between Renfrew in the east, Matawatchan in the south, and Mattawa, Algonquin Park and Eganville in the west, and is bounded by the Ottawa River in the north (Figure 22.2).

The Ottawa Valley sits in the 55 km wide Ottawa–Bonnechere Graben (Kay 1942). The Graben has extensive vertical faulting resulting from extensional rifting and is still a seismically active structure today (Rimando and Benn 2005).

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.22-1 to 22-6.

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). 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 invaded 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). 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 at the eastern side of the 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).

Overburden is generally thin and discontinuous across the study area (commonly consisting of till and organic deposits), though there is greater accumulation of drift closer to the Ottawa River. Thicker deposits include glaciomarine clays and sands from the Champlain Sea, and glaciolacustrine and glaciofluvial sand and gravel deposits (Ontario Geological Survey 2010). Drift thickness and Champlain Sea deposits were found to be important controls on groundwater chemistry in eastern Ontario nearby (Colgrove 2016).

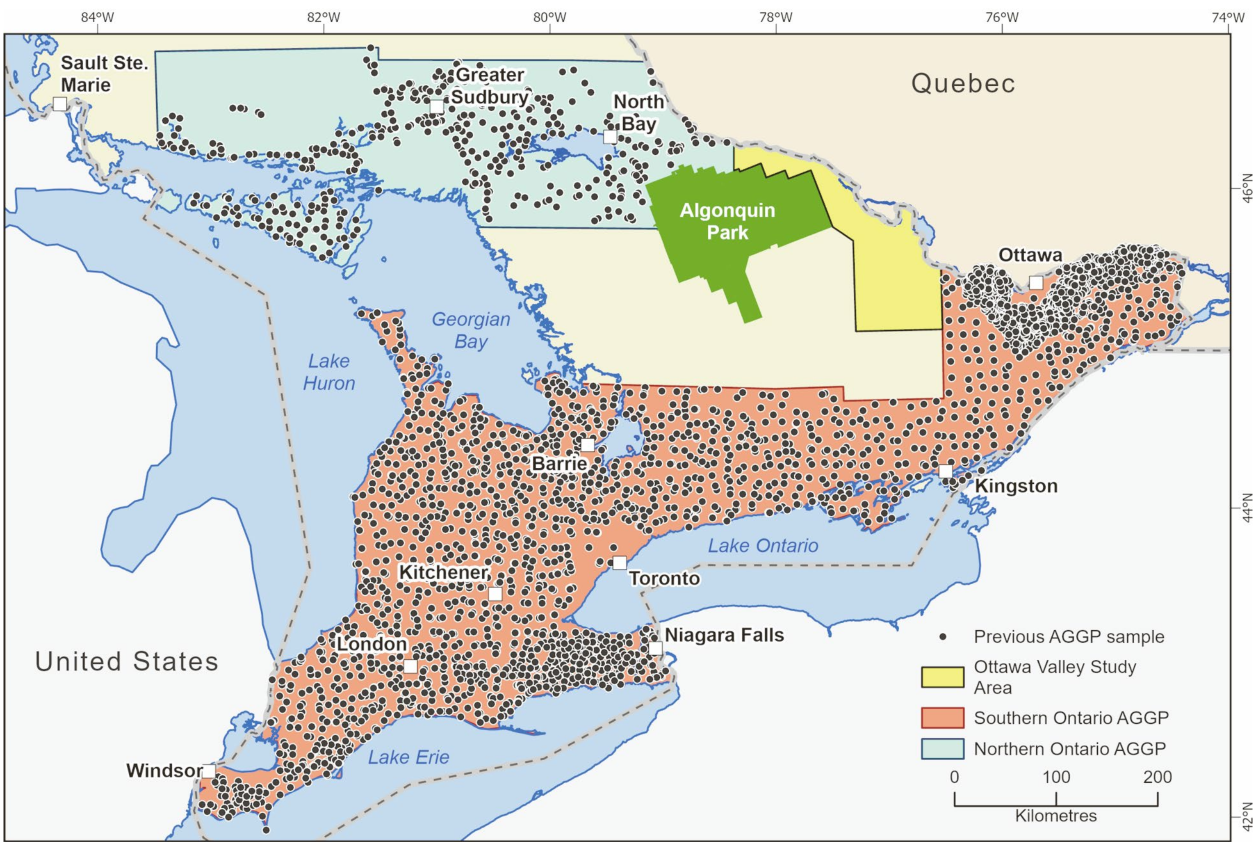


Figure 22.1. Location of the Ottawa Valley study area relative to previous sampling in the southern and northeastern AGGP areas (Hamilton 2021; Dell 2024; Dell and Hamilton 2024).

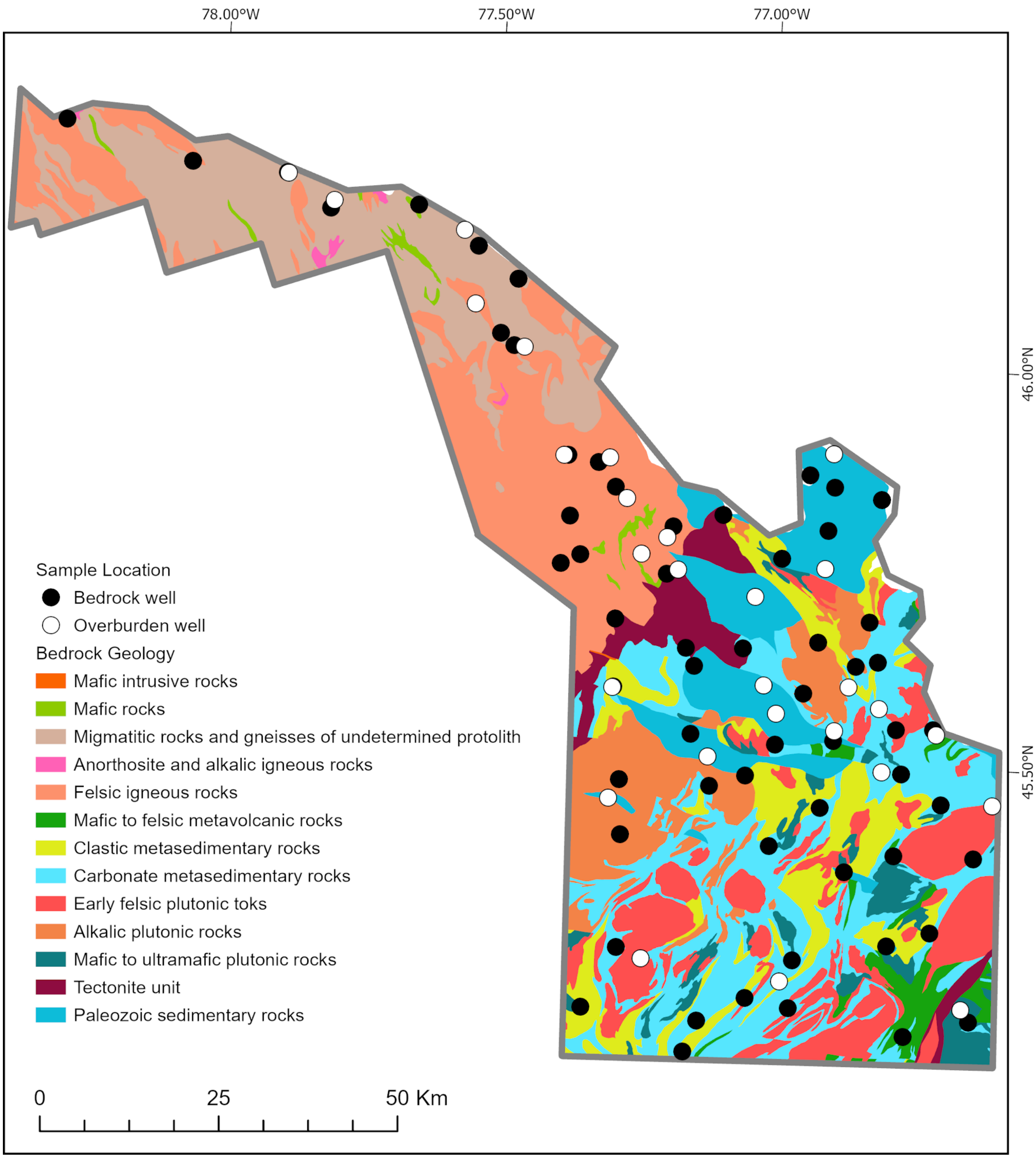


Figure 22.2. Distribution of samples across the Ottawa Valley study area relative to the bedrock geology (*from* Ontario Geological Survey 2011). The tectonic unit (deep purple) approximates the boundary between the Central Metasedimentary Belt to the south and the Central Gneiss Belt to the north.

METHODS AND ANALYTES

The study area was divided into a 10 by 10 km sampling grid. Within each 100 km^2 grid square, 2 samples were collected (or attempted): 1 from a well drilled into bedrock and 1 from a well completed in overburden sediment. Samples were collected from private domestic and farm wells where members of the public volunteered to assist the program. Sampling was conducted consistent with AGGP field protocols (Bocking, Hamilton and Dell 2023), with some updated methods, as follows:

- The bottle for mercury analysis was frozen the day of sampling to be preserved until acidification with bromine chloride acid and analysis by the laboratory. This protocol change was instituted to reduce volatilization of mercury 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 analytes and associated information on collection, preservation and laboratories can be found in Table 22.1. The Ottawa Valley 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).

SAMPLE COVERAGE

The program resulted in 96 samples across the Ottawa Valley, including 29 from wells finished in overburden aquifers and 67 from wells finished in bedrock aquifers (*see* Figure 22.2). Gaps in the sample density resulted for various reasons:

- Lack of or very few residents (and therefore few available wells) in undeveloped rural areas, especially in the northwestern arm of the study area.
- Absent or thin drift leading to a lack of wells completed in an overburden unit, especially in the south end of the study area.
- Low permeability clay overburden leading to a bias toward installing bedrock wells and a lack of viable overburden wells, for example in the peninsula where Westmeath is located.
- The presence of the Petawawa Military Base and Canadian Nuclear Laboratories (CNL) created a large inaccessible region northwest of Petawawa.

The 96 samples included 5 duplicates and were submitted alongside 12 blind standards and blanks to evaluate analytical precision and accuracy. 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. Future field activities may include returning to infill gaps in the Ottawa Valley study area.

Table 22.1. Information on analytes, laboratories, collection and preservation of the Ottawa Valley samples.

Laboratory	Bottle Name	Analyte(s)	Volume	Preservation
OGS Geoscience Laboratories	Metals	ICP–MS and ICP–AES suite of metals and trace elements	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, HC filtered	Frozen, BrCl acid
	DIC/DOC	Dissolved Inorganic carbon, dissolved organic carbon	60 mL, HC filtered	Refrigeration
Field Laboratory	Iodide	Iodide	60 mL, unfiltered	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, sulfuric 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, unfiltered	Zinc acetate, sodium hydroxide
Saskatchewan Research Council	Gross Alpha Beta	Gross alpha, gross beta	1000 mL, unfiltered	Nitric acid
	Radon	Radon	2 x 40 mL, unfiltered	None
Isotope Tracer Technologies	Isotopes	$\delta^{18}O$-H_2O, $\delta^{2}H$-H_2O	120 mL, unfiltered	Refrigeration
	Tritium	^{3}H	250 mL, unfiltered	None
Jan Veizer	Sulphur Isotopes	$\delta^{34}S$-S^{2-}, $\delta^{34}S$-SO_4, $\delta^{18}O$-SO_4	250 mL, unfiltered	Zinc acetate

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

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. My colleague Kayla Dell, who originally proposed the project, was a major support getting the field program off the ground and provided guidance throughout. Thank you to the summer students Lucas, Shahan, Maggie, Rory and Charlotte, who worked hard to make the program a success. Thank you to Laura Handley for visiting and helping out on the program, and to Stew Hamilton and Chris Beckett-Brown for providing advice and support. The 2024 AGGP utilized a new outreach and recruitment strategy, which was made possible by ideas and technical support from Kei Yeung, Kayla Kalmo 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, Michael Easton and Julien Bonin for editorial and drafting support.

REFERENCES

Bocking, C.N., Hamilton S.M. and Dell, K.M. 2023. Ambient Groundwater Geochemistry Project field methods and procedures; Ontario Geological Survey, Groundwater Resources Study 21, 44p.

Colgrove, L.M. 2016. A regional chemical characterization and analysis of groundwater in eastern Ontario; unpublished MSc thesis, University of Western Ontario, London, Ontario, Electronic Thesis and Dissertation Repository, Paper 4203

Dell, K.M. 2024. Water-rock interactions in geologically diverse regional aquifers of northeastern Ontario; unpublished MSc thesis, Queen's University, Kingston, Ontario, 106p.

Dell, K.M. and Francis, M.A. 2018. The Ambient Groundwater Geochemistry Project: North Bay area; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.24-1 to 24-10.

Dell, K.M., Francis, M.A. and Hamilton, S.M. 2017. The Ambient Groundwater Geochemistry Project: Manitoulin Island and North Shore areas; *in* Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p.26-1 to 26-10.

Dell, K.M., Fudge, S.P. and Hamilton, S.M. 2016. The Ambient Groundwater Geochemistry Project: Sudbury area; *in* Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p.32-1 to 32-11.

Dell, K.M. and Hamilton, S.M. 2024. Ambient groundwater geochemical and isotopic data for northeastern Ontario, 2016–2018; Ontario Geological Survey, Miscellaneous Release—Data 401.

Easton, R.M. 1992. The Grenville Province and the Proterozoic history of central and southern Ontario; Chapter 19 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.714-904.

Freckelton, C.N. 2013. A physical and geochemical characterization of southwestern Ontario's breathing well region; unpublished MSc thesis, University of Western Ontario, London, Ontario, Electronic Thesis and Dissertation Repository, Paper 1105.

Hamilton, S.M. 2021. Ambient groundwater geochemical and isotopic data for southern Ontario, 2007–2019; Ontario Geological Survey, Miscellaneous Release—Data 283 – Revision 2.

Kay, G.M. 1942. Ottawa–Bonnechere graben and Lake Ontario homocline; Geological Society of America, Bulletin, v.53, p.585-646.

McIntosh, J.C., Grasby, S.E., Hamilton, S.M. and Osborne, S.G. 2014. Origin, distribution and hydrogeochemical controls on methane occurrences in shallow aquifers, southwestern Ontario, Canada; Applied Geochemistry, v.50, p.37-52.

Ontario Geological Survey 2010. Surficial geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 128 – Revised

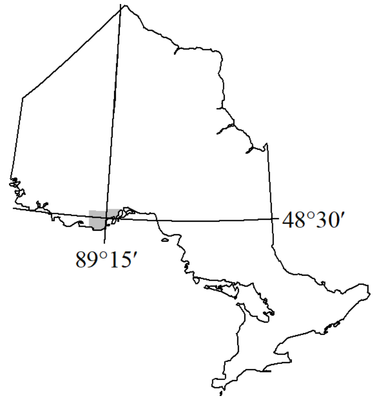
——— 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Priebe, E.H. and Hamilton, S.M. 2022. Tritium in shallow groundwater of southern Ontario; Ontario Geological Survey, Groundwater Resources Study 20.

Rimando, R.E. and Benn, K. 2005. Evolution of faulting and paleo-stress field within the Ottawa graben, Canada; Journal of Geodynamics, v.39, p.337-360.

Smal, C.A. 2017. Regional groundwater geochemistry on the Niagara Peninsula; unpublished MSc thesis, McMaster University, Hamilton, Ontario, 288p.

23. Project NW-24-001. The Ambient Groundwater Geochemistry Project: Thunder Bay Area



K.M. Dell[1]

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

INTRODUCTION

The Ambient Groundwater Geochemistry Project (AGGP) expanded into northern Ontario in 2016 to delineate natural chemical trends in groundwater in Precambrian shield terrains, similar to the work that has been undertaken in the Paleozoic rocks of southern Ontario since 2007 (Hamilton 2021). The northern Ontario program thus far has been successful in characterizing numerous controls on groundwater chemistry, including brine mixing, Quaternary deposit thickness and composition, and in some cases, bedrock geology (Dell 2024). This year's project in the Thunder Bay area represents the farthest north in Ontario that the project has been implemented. The main sampling area covers approximately 3500 km^2 and extends from Kakabeka Falls in the west to Navilus in the east; however, outlying samplings were collected as far as Shebandowan in the west and Dorian to the east (Figure 23.1). The objectives of the Thunder Bay area study are as follows:

1. to expand on the existing AGGP database and continue the ongoing water-quality mapping of major bedrock and overburden units in northern Ontario;
2. to further investigate potential groundwater quality issues related to bedrock geology that have already been identified in the Thunder Bay area, including elevated iron, manganese, chloride and fluoride (Puumala 2013, 2008) and provide supplementary minor element, trace element and isotopic data;
3. to provide additional data to support the investigation of elevated uranium and radionuclide contents in groundwater in northwestern Ontario completed by Puumala (1992); and
4. to examine the possible influence on groundwater chemistry of polymetallic veins, which were historically mined for silver in the area and locally contain metals such as lead, zinc, cobalt and arsenic (Franklin et al. 1986).

STUDY AREA

The study area lies along the boundary between the Superior and Southern provinces (*see* Figure 23.1). The northwestern section of the study area is underlain by Archean rocks of the Quetico and Wawa–Abitibi subprovinces. The Paleoproterozoic Animike Group comprises the Rove and Gunflint formations and covers the southern section of the study area along with younger igneous rocks associated with the Midcontinent Rift. To the east lie Mesoproterozoic sedimentary rocks of the Sibley Group (Sutcliffe 1991).

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.23-1 to 23-4.

The 2024 Thunder Bay study area was divided into a sample grid where each grid cell measured 25 km^2 (*see* Figure 23.1). The target sample density was 1 sample collected from a bedrock aquifer and 1 sample from an overburden aquifer in each grid cell. When field work was completed in early July, samples had been collected from a total of 56 grid cells. As with previous years, there was some difficulty locating both types of wells (bedrock and overburden) in every cell. In most nodes, at least 1 bedrock well was sampled; however, in some nodes, overburden wells could not be located. In some areas, extra bedrock wells were sampled to fill obvious gaps in the sample distribution or to augment the number of wells sampled in a particular formation. In total, 50 overburden and 64 bedrock wells were sampled. Additional sampling is planned for future years to infill sizeable sample gaps in developed areas where wells exist.

SAMPLING AND METHODS

Groundwater samples were collected mainly from domestic wells, as well as from 8 monitoring wells from the Provincial Groundwater Monitoring Network. In addition, 17 quality-control (QC) samples (approximately 13% representing blanks, reference materials and duplicates) were prepared for submission to the participating laboratories to evaluate analytical accuracy and precision. A total of 131 samples were submitted to the laboratories, including quality-control samples.

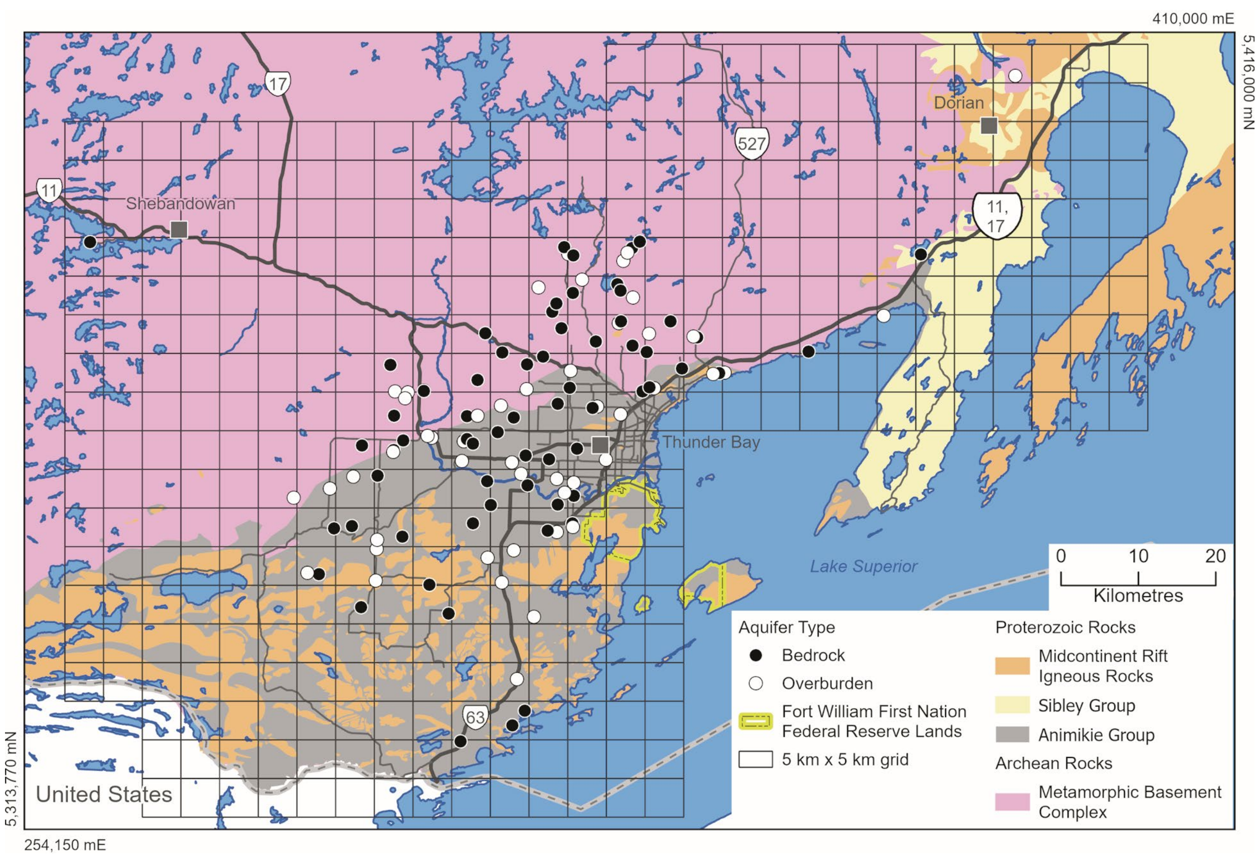


Figure 23.1. Map of the Ambient Groundwater Geochemistry Project–Thunder Bay area showing the study area, sampling grid (light grey grid), bedrock and overburden aquifer sample locations and simplified bedrock geology. Precambrian bedrock geology *modified from* Ontario Geological Survey (2011). Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 16. Thick black lines represent major highways.

Approximately 91 parameters are determined for each site. Field parameters were measured during the collection of each groundwater sample; these consisted of temperature, dissolved oxygen (DO), pH, conductivity and oxidation–reduction potential (ORP), which are measured using multi-parameter instruments equipped with flow cells. Notes were recorded regarding the well type and well-head security, the plumbing and the sampling point. Observations about the water were also collected (e.g., gas phase, odours, colour, turbidity, etc.). Additional parameters measured in the field include bicarbonate (HCO_3^- from alkalinity), hydrogen sulphide (H_2S), dissolved gases (CO_2, O_2, CH_4) and iodide (I^-). The majority of parameters are to be determined by several different laboratories, including metals, anions, mercury, isotopes, tritium, nitrates and nitrite, total Kjeldahl nitrogen (TKN), organic nitrogen, colour, bacteria (total and fecal coliform), and dissolved inorganic and organic carbon. Many of these analyses are being completed by the Ontario Geological Survey (OGS) Geoscience Laboratories. However, samples for specific analyses were submitted to several external laboratories: 1) Saskatchewan Research Council Environmental Analytical Laboratories for radiological and radiochemical samples; 2) SGS Canada Inc. for time-sensitive parameters, including bacteria, nitrogen parameters; 3) IT2 Isotope Tracer Technologies Inc. for tritium (^3H) and water isotopes ($\delta^{18}O$-H_2O, δ^2H-H_2O); and 4) Ján Veizer Stable Isotope Laboratory for sulphur isotopes ($\delta^{34}S$-S^{2-}, $\delta^{34}S$-SO_4, $\delta 18O$-SO_4).

For a more detailed description of the general field methods employed by the AGGP, see Bocking, Hamilton and Dell (2023), Hamilton, Brauneder and Mellor (2007) and Hamilton and Brauneder (2008).

ACKNOWLEDGMENTS

The author would like to express her gratitude to the staff at the Lakehead Region Conservation Authority, specifically Scott Drebit, Tammy Cook and Michelle Willows, for their time and assistance while sampling wells from the Provincial Groundwater Monitoring Network and for their support of the northern Ontario expansion of the Ambient Groundwater Geochemistry Project. Thank you to Shannon Heggie and Brent Trevisan from the Ministry of the Environment, Conservation and Parks for providing knowledge related to the Thunder Bay area hydrogeology and for supplying numerous local groundwater geochemistry resources. Summer students Lucas Perreault, Shahan Ahmad Khan, Charlotte Eberlein, Maggie Laird and Rory Yantha are thanked for their professional and capable field assistance. None of this work would have been possible without the efforts of OGS colleagues Laura Colgrove, Laura Handley, Chris Beckett-Brown, Kei Young and Riku Metsaranta. Laura Colgrove, Chris Beckett-Brown, Michael Easton and the OGS Publications Services Unit are also appreciated for their edits and improvements to the article.

REFERENCES

Bocking, C.N., Hamilton S.M. and Dell, K.M. 2023. Ambient Groundwater Geochemistry Project field methods and procedures; Ontario Geological Survey, Groundwater Resources Study 21, 44p.

Dell, K.M. 2024. Water-rock interactions in geologically diverse regional aquifers of northeastern Ontario; unpublished MSc thesis, Queen's University, Kingston, Ontario, 106p.

Franklin, J.M., Kissin, S.A., Smyk, M.C. and Scott, S.D. 1986. Silver deposits associated with the Proterozoic rocks of the Thunder Bay District, Ontario; Canadian Journal of Earth Sciences, v.23, p.1576-1591.

Hamilton, S.M. 2021. Ambient groundwater geochemical and isotopic data for southern Ontario, 2007–2019; Ontario Geological Survey, Miscellaneous Release—Data 283 – Revision 2.

Hamilton, S.M. and Brauneder, K. 2008. The ambient groundwater geochemistry project: Year 2; *in* Summary of Field Work and Other Activities, 2008, Ontario Geological Survey, Open File Report 6226, p.34-1 to 34-7.

Hamilton, S.M., Brauneder, K. and Mellor, K.J. 2007. The ambient groundwater geochemistry project – southwestern Ontario; *in* Summary of Field Work and Other Activities, 2007, Ontario Geological Survey, Open File Report 6213, p.23-1 to 23-5.

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

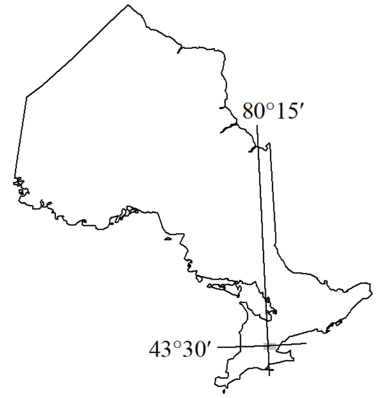
Puumala, M.A. 1992. Thunder Bay District groundwater uranium study; Technical Assessment Section, Northwestern Region, Ontario Ministry of the Environment, unpublished report, 16p.

——— 2008. Natural groundwater quality in bedrock wells of the Thunder Bay area; Ministry of the Environment, Northern Region, Thunder Bay, unpublished report, 25p.

——— 2013. Natural groundwater geochemistry in bedrock of the Thunder Bay area; abstract *in* Institute on Lake Superior Geology Proceedings, 59th Annual Meeting, Houghton, Michigan, v.59, Part 1, p.67-68.

Sutcliffe, R.H. 1991. Proterozoic Geology of the Lake Superior area; Chapter 16 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.627-658.

24. Project SO-22-005. Glimpsing Gorgeous Glacial Geology in Guelph



L.E. Brunton[1] and A.K. Burt[2]

[1]Department of Earth Sciences, Carleton University, Ottawa, Ontario K1S 5B6
[2]Earth Resources and Geoscience Mapping Section, Ontario Geological Survey, Sudbury, Ontario P3E 6B5

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 and includes parts of the County of Wellington, the Regional Municipality of Halton, the Regional Municipality of Waterloo and the City of Hamilton (Figure 24.1). 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 which are recharge pathways for underlying regional bedrock aquifers and, in the process, refine existing 1:63 360 and 1:50 000 scale surficial maps in the region as summarized in Burt and Hagedorn (2022).

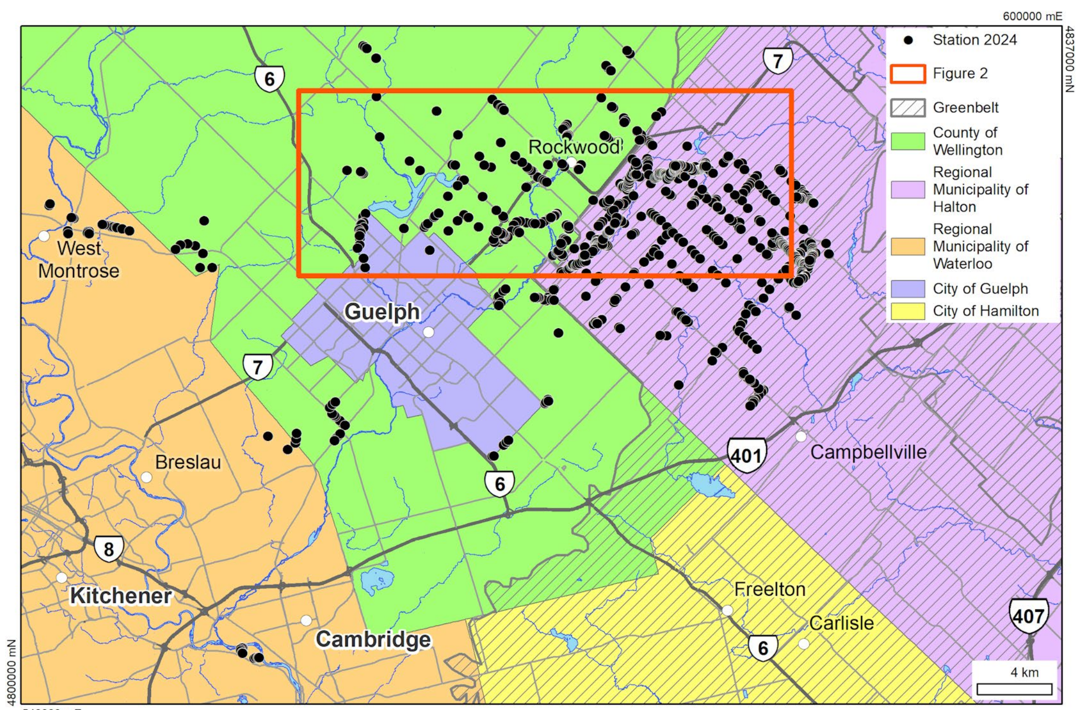


Figure 24.1. Map of the Guelph area showing the locations of 2024 field observations. Municipal boundaries are also shown. The orange rectangle corresponds with the area of the lidar image in the centre of Figure 24.2.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.24-1 to 24-6.

SURFICIAL MAPPING

Lidar (light detection and ranging) derived bare-earth digital terrain models (DTMs), with a 50 cm spatial resolution and non-vegetated vertical accuracy of 5 to 10 cm, were recently released for the project area (Ministry of Natural Resources 2024) and they reveal numerous subtle glacial landforms. Field work to date has focussed on confirming landforms by field observations and studying their internal sediment compositions in preparation for surficial mapping and for obtaining shallow subsurface stratigraphic information. The 2022 field season focussed on the southeastern portion of the study area (Burt and Hagedorn 2022), whereas the 2024 season continued into the northeastern portion of the study area (*see* Figure 24.1). Over 900 landform observations, section descriptions (predominantly roadcuts) and descriptions of hand-auger cores, up to 6.25 m deep, were made from June to August of 2024 (*see* Figure 24.1).

Terrain in the study area is divided into 2 zones: 1) the Niagara Escarpment cuesta in the east, characterized by small drumlins, low moraine and bedrock ridges separated by linear wetlands and areas of bedrock with a thin veneer of sediments, and 2) a thicker sediment zone in the west, with larger drumlins and other subglacial bedforms, extensive outwash and larger moraine systems. Figure 24.2 shows a portion of the area and representative landforms are displayed in a series of 5 inset images which were presented by Brunton, Burt and Cousens (2024). In general, surficial sediments are older in the west becoming progressively younger toward the east. In the west, stony, sandy to silty Port Stanley Till (bedforms highlighted by dark green arrows on Figures 24.2A and 24.2D) is the oldest laterally extensive sediment exposed at surface and records the northwestward advance of Ontario–Erie lobe ice. A clast macrofabric measured approximately 1 m below surface in a drumlin composed of Port Stanley Till (location marked by the pink star on Figure 24.2D) shows a strong relationship between preferred clast long-axes and the northwest-southeast crest of the landform. Also shown on Figure 24.2D is a small esker oriented parallel to the long-axes of the bedforms. Later, ice flow shifted to a more westward direction as shown by the change in drumlin orientation as shown by light green arrows on Figures 24.2C and 24.2E. Ice retreat is recorded by deposition of large moraine and glaciofluvial systems consisting of broad zones of hummocky topography, ice-walled lake plains, moraine ridges, eskers, ice-supported and ice-marginal fans and proglacial outwash (Burt and Hagedorn 2022; Arnaud et al. 2018), the Paris–Galt Moraine (*see* Figures 24.2B and 24.2E), and a series of narrow moraine ridges collectively referred to as the Moffat moraines (*see* Figure 24.2C). Obtaining sufficient field data to enhance remote differentiation of between bedrock and moraine ridges in the Niagara Escarpment cuesta zone was a high priority. The influence of meltwater on the landscape is shown by the erosion of large and small meltwater channels. For example, multiple inset channels, the lowest of which is eroded to bedrock, are shown in Figure 24.2A. Hand-auger sites in lows between moraine and bedrock ridges and between drumlins revealed the presence of fine-grained glaciolacustrine deposits overlying the till, indicating ponding of glacial meltwater (*see* Figure 24.2E). Sand and gravelly sand was observed underlying glaciolacustrine deposits in other lows, suggesting deposition in meltwater channels.

The complexity of ice retreat in the study area is demonstrated by the presence of compound, overprinted and palimpsest landforms. For example, on Figure 24.2B, a low moraine ridge (green dashed line) and series of small eskers (dashed yellow arrows) can be seen within a broad meltwater channel (western margin is marked with a blue dashed line). Also visible are the outer margins of broader hummocky zones (green dotted lines), which, in places, overlie older “Port Stanley Till” drumlins (dark green arrow), or bedrock ridges exposed within the meltwater channel (pink dashed line). Near the Niagara Escarpment (*see* Figure 24.2C) “Wentworth” drumlins overlie bedrock ridges and, in turn, narrow moraine ridges overlie the drumlins. Similarly, younger “Wentworth Till” drumlins (light green arrows) can be seen through zones of hummocky moraine on Figure 24.2E.

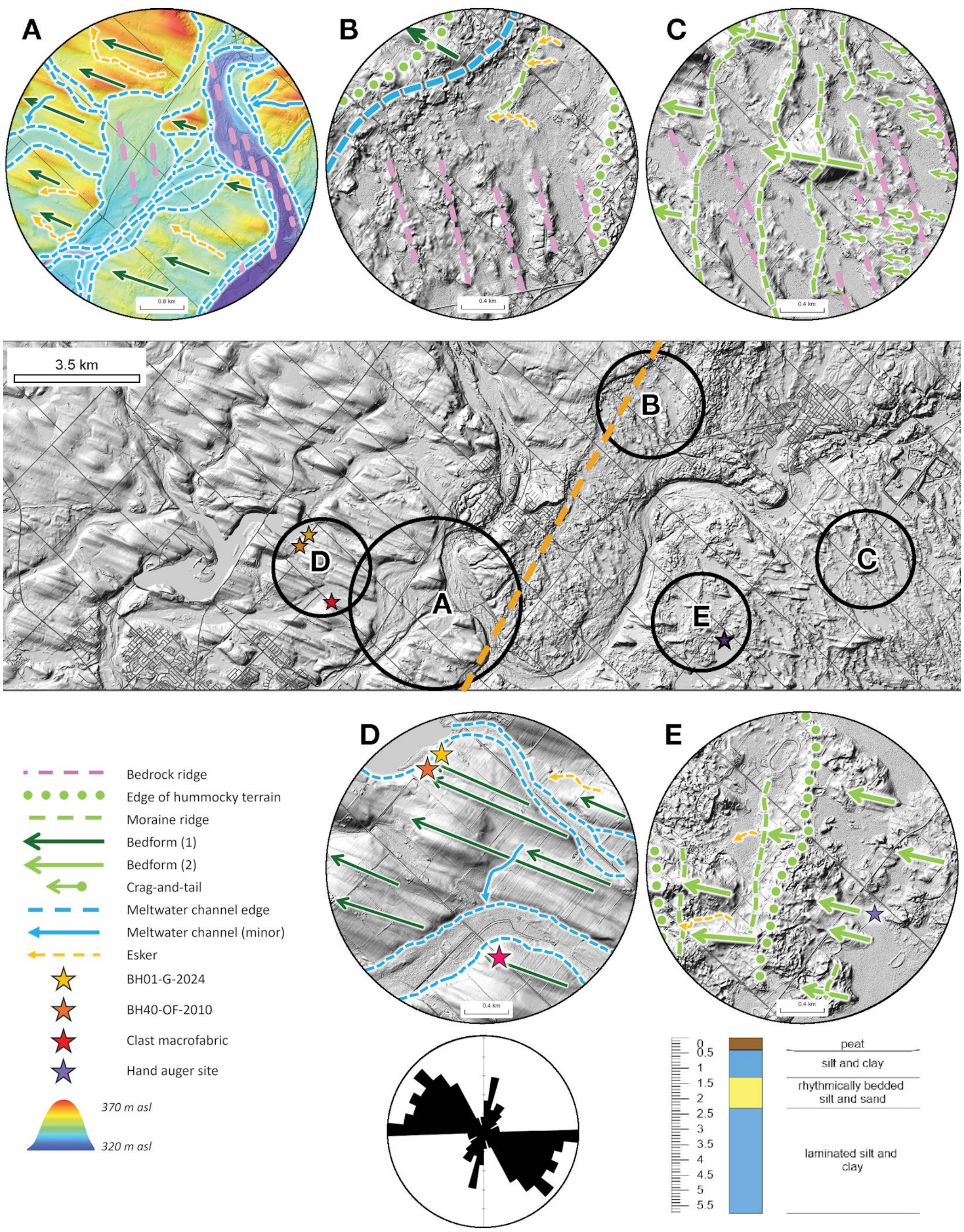


Figure 24.2. **A)** to **E)**, and the centre image, are annotated lidar images of the detailed study area indicated in Figure 24.1 (figures *from* Brunton, Burt and Cousens 2024; lidar data *from* Ministry of Natural Resources 2024). In the centre image, the dashed orange line separates thin drift of the Niagara Escarpment cuesta zone from thicker drift to the west. The circled areas indicate the location of the more detailed images shown in images **A** to **E**. **A)** "Port Stanley" drumlins incised by multiple inset meltwater channels, some of which are cut down to bedrock. **B)** Bedrock ridges exposed in a broad meltwater channel incised through "Port Stanley" drumlins; eskers and moraines record a later ice advance. **C)** Recessional Moffat moraines deposited over "Wentworth" drumlins and bedrock ridges. **D)** Overprinted "Port Stanley" drumlins (select bedforms labelled with dark green arrows) incised by meltwater channels. The Rose diagram from a clast macrofabric in a drumlin (location marked by the pink star) shows a strong relationship between clasts long-axes and long-axis with the landform. The City of Guelph drill site (BH01-G-2024) is also shown (yellow star). **E)** Area of hummocky moraine overlying "Wentworth" drumlins. At the hand-auger site, indicated by the purple star, 5.6 m of glaciolacustrine deposits overlain with peat were observed, as shown in the graphic log in the lower right of the figure.

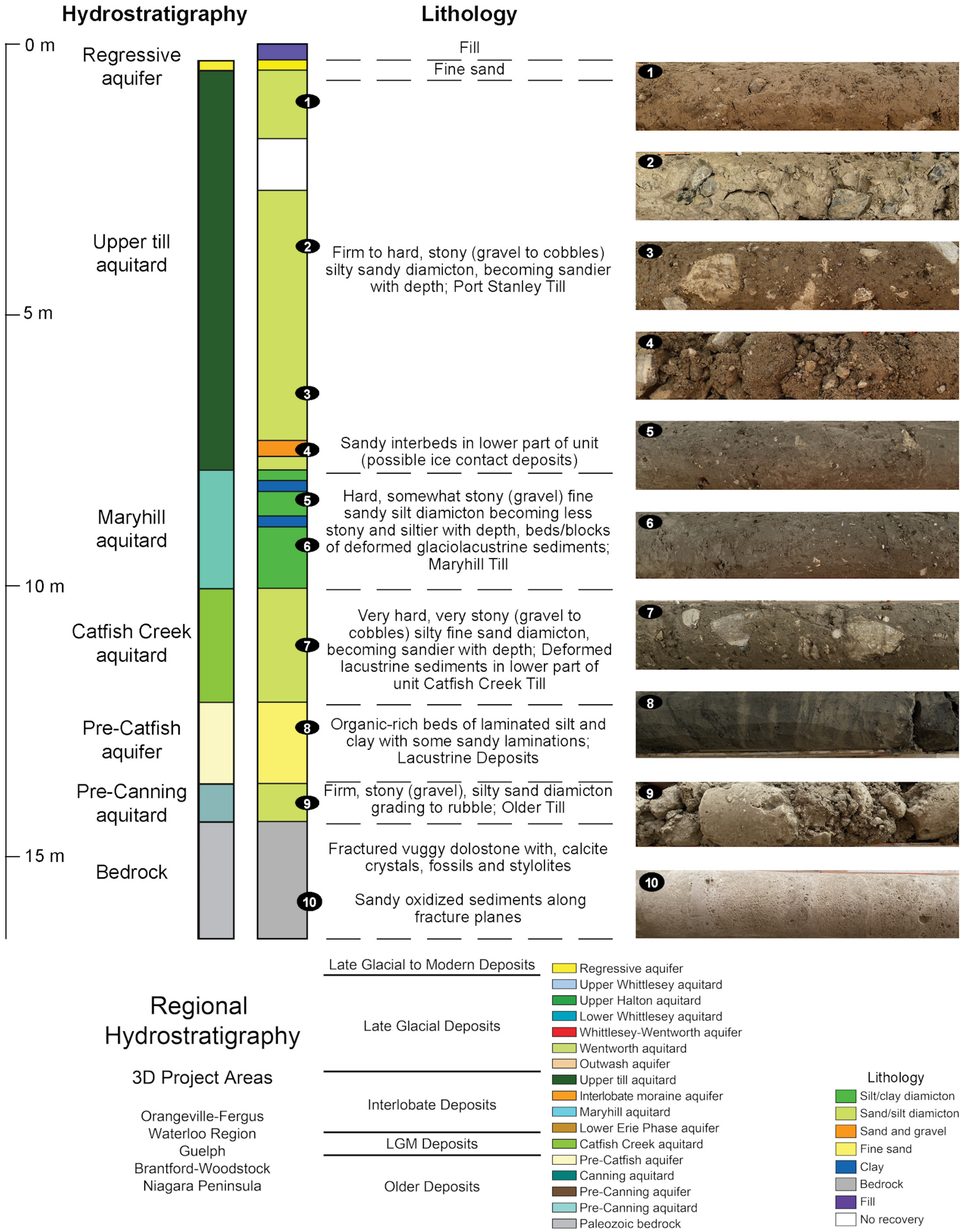


Figure 24.3. Preliminary graphic log for the Quaternary sediment and upper bedrock core obtained by the City of Guelph (BH01-G-2024) (Brunton, Burt and Cousens 2024). The regional hydrostratigraphic units shown on the left are correlated with units from adjacent Waterloo Region (Bajc and Shirota 2007), Brantford–Woodstock (Bajc and Dodge 2011), Orangeville–Fergus (Burt and Dodge 2016) and Niagara Peninsula (Burt 2020) 3-D project areas west (above) of the Niagara Escarpment. Each photographed core is 45 cm long and the top of each core is to the left. Abbreviation: LGM, last glacial maximum.

DRILLING

In August 2024, the City of Guelph cored a hole and installed overburden and bedrock monitoring wells to support development of the Logan Test Well as a future water supply well (Moffat, Alexander and Quackenbush 2022). A PQ (8.5 cm inner diameter) continuously cored mud-rotary borehole was drilled, penetrating 14.15 m of Quaternary sediments and the upper 2.45 m of underlying bedrock (Figure 24.3). Below this level, the lower 63 m of the borehole was drilled by air hammer and rock chips were collected at 1.5 m intervals for later analysis. The sediment core was logged on site, photographed at 0.25 m increments and representative intervals were sampled in the field. A pocket penetrometer was used to perform field penetration tests on the core. Samples were collected for particle size analysis (diamicton and stratified sediments), carbonate content (diamicton and fine-textured stratified sediments) and pebble counts (diamicton and gravelly stratified sediments). Detrital terrestrial plant material obtained from stratified sediments will be submitted for radiocarbon age determination.

The continuously cored borehole intersected 4 diamicton units that are tentatively correlative with, from top to bottom, the interlobate Upper Till (ATB1) and Maryhill (ATB3) aquitards, the last glacial maximum Catfish Creek aquitard (ATC1) and the older Pre-Canning aquitard (ATG1) observed previously in the adjacent 3-D project areas (*see* Figure 24.3)(Bajc and Dodge 2011; Bajc and Shirota 2007; Burt 2017, 2018, 2020; Burt and Dodge 2016; Burt and Bajc 2020). Organic-rich fine-grained lacustrine sediments were observed between the Catfish Creek and the Pre-Canning aquitards. Organic-rich deposits were observed in the same stratigraphic position in several cored boreholes drilled as part of the Orangeville–Fergus project (Burt and Dodge 2016). For example, borehole BH40-OF-2010, located less than 200 m west of the current borehole, intersected organic-rich silty sand and gravel, pebbly sand and silty sand interpreted as an alluvial sequence, with reported ages of more than 52 200 ^{14}C years BP and 54 500±2900 ^{14}C years BP. Although both ages are considered beyond the limits of radiocarbon analysis, nevertheless, they provide a minimum age for the Catfish Creek aquitard and underlying units.

NEXT STEPS

Information gathered during the 2024 field season will be used to create a surficial geological map for a portion of the study area as part of a Carleton University Bachelor of Science (Honours) project. Other aspects of the project include logging rock chips from the borehole to establish the Paleozoic stratigraphy and producing a report outlining the Quaternary history of the area. Further drilling by the OGS is planned for the fall of 2024.

ACKNOWLEDGMENTS

The authors would like to thank Chippewas of Nawash Unceded, Chippewas of Saugeen, Mississaugas of the Credit First Nation, and Six Nations of the Grand River 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 authors thank J.M. Galvao for her cheerful and thorough assistance in the field. As ever, K.H. Yeung and J.E. Chartrand provided much needed technical support. J. Bonin drafted figures and R.P.M. Mulligan and R.M. Easton provided helpful comments on this summary report. The first draft of this article was written by the lead author (L.E.B.) as part of a Carlton University Bachelor of Science Honours project.

REFERENCES

Arnaud, E., McGill, M., Trapp, A. and Smith, J.E. 2018. Subsurface heterogeneity in the geological and hydraulic properties of the hummocky Paris Moraine, Guelph, Ontario; Canadian Journal of Earth Sciences, v.55, p.768-785. doi.org/10.1139/cjes-2016-0161 [accessed November 6, 2024]

Bajc, A.F. and Dodge, J.E.P. 2011. Three-dimensional mapping of surficial deposits in the Brantford–Woodstock area, southwestern Ontario; Ontario Geological Survey, Groundwater Resources Study 10, 86p.

Bajc, A.F. and Shirota, J. 2007. Three-dimensional mapping of surficial deposits in the Regional Municipality of Waterloo, southwestern Ontario; report *in* Ontario Geological Survey, Groundwater Resources Study 3, 42p.

Brunton, L.E., Burt, A.K. and Cousens, B. 2024. Surficial mapping with a twist; abstract, Geological Society of America, Abstracts with Programs, v.56, no.5. doi.org/10.1130/abs/2024AM-405176 [accessed November 6, 2024]

Burt, A.K. 2017. Digging deep on the Niagara Peninsula: A drilling update; *in* Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p.24-1 to 24-16.

——— 2018. Three-dimensional hydrostratigraphy of the Orangeville Moraine area, southwestern Ontario, Canada; Canadian Journal of Earth Sciences, v.55, p.802-828. doi.org/10.1139/cjes-2017-0077 [accessed November 6, 2024]

——— 2020. Results of the 2014–2017 drilling programs on the Niagara Peninsula: Graphic logs, descriptions and analytical data; Ontario Geological Survey, Miscellaneous Release—Data 383.

Burt, A.K. and Bajc, A.F. 2020. A regional stratigraphic framework for hydrogeologic studies above the Niagara Escarpment in southern Ontario; *in* Regional-scale groundwater geoscience in southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House, Ontario Geological Survey, Open File Report 6361, p.6-7.

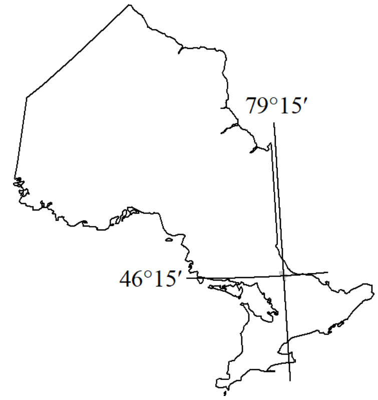
Burt, A.K. and Dodge, J.E.P. 2016. Three-dimensional modelling of surficial deposits in the Orangeville–Fergus area of southern Ontario; report *in* Ontario Geological Survey, Groundwater Resources Study 15, 155p.

Burt, A.K. and Hagedorn, G.W. 2022. From mighty moraines to dramatic drumlins: Introducing the Guelph three-dimensional sediment mapping project; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.24-1 to 24-10.

Ministry of Natural Resources 2024. Ontario digital terrain model (lidar-derived); Ministry of Natural Resources, Science and Research Branch, Provincial Mapping Unit, online data, September 5, 2024 update, https://geohub.lio.gov.on.ca/maps/mnrf::ontario-digital-terrain-model-lidar-derived [accessed November 6, 2024]

Moffat, P., Alexander, M. and Quackenbush, P. 2022. Final Water Supply Master Plan Update (2022), prepared for the City of Guelph by Gauley Associates Ltd., Matrix Solutions Inc. and AECOM Canada Ltd.; July 2022, 226p., https://guelph.ca/plans-and-strategies/water-supply-master-plan, *see* report under Resources. [accessed November 6, 2024]

25. Project NE-23-006. Update on the Aggregate Resources of the North Bay Area, Central Nipissing District, Northeastern Ontario



L.A. Handley[1]

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

INTRODUCTION

Mineral aggregate resources, which include bedrock-derived crushed stone as well as naturally formed sand and gravel, constitute the major raw material in Ontario's road building and construction industries. According to the Ontario Stone, Sand and Gravel Association (OSSGA), the average usage of sand and gravel for a single person living in Ontario is over 12 tonnes every single year. To better understand this important resource, the Ontario Geological Survey (OGS) has been mapping potential aggregate deposits since the early 1970s, through the Aggregate Resources Inventory Program. The purpose of the aggregates program is to convey key geological information to planners and decision-makers in an accessible format to include as a component in planning strategies to safeguard public well-being and to ensure that adequate resources remain available for future use.

During the summer of 2024, field work for an aggregate resources study continued in the North Bay area of northeastern Ontario to update and extend the program's coverage in Ontario. The study area covers approximately 940 km^2 of the Statistics Canada Nipissing Census Division and is centred on the city of North Bay on the eastern shores of Lake Nipissing in northeastern Ontario (Figure 25.1; Handley 2023). Field observations were made at 95 locations, including 48 auger or roadcut sections of surficial materials, 47 bedrock outcrops and 7 existing pits or quarries (Figure 25.2). These observations will be integrated with historical aggregate quality and gradation tests collected by the Ministry of Transportation (MTO), as well as water well records from the Ministry of the Environment, Conservation and Parks (MECP), to evaluate both the quantity and quality of aggregate resources within the North Bay area.

PREVIOUS WORK

Previous work on the inventory of aggregate resources for the North Bay area was completed in 1984 by the OGS (Ontario Geological Survey 1984). This older study does not follow the current *Aggregate Resources Inventory Paper* (ARIP) standard format of the OGS, but does include relevant data which has been incorporated into the current study. New high-resolution digital terrain model (DTM) data derived from light detection and ranging (Lidar) imagery, acquired from the Ministry of Natural Resources (MNR), has also been referenced to help delineate and refine aggregate deposit boundaries. Data and observations from the most recent compilation of OGS bedrock geology mapping (Ontario Geological Survey 2011) and regional Quaternary mapping from the Geological Survey of Canada (Harrison 1972) have also been referenced in the current study. A concurrent OGS-led Quaternary mapping project covering the entire study area will further complement this aggregate assessment (Marich 2022, 2023).

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.25-1 to 25-6.

GEOLOGY OF THE STUDY AREA

The study area includes portions of 3 physiographic regions: the Nipissing–Mattawa lowland, the Northern upland and the Algonquin highland (Chapman and Putnam 1984).

The Nipissing–Mattawa lowland physiographic region is characterized by flat terrain with numerous lakes and rivers, and is located in the western portion of the study area. It includes extensive lake sediments draped in low topographic relief areas between bedrock outcrops. The lake sediments consist chiefly of varved clays with some rhythmically banded sands (Harrison 1972). Minor ridges and several large end moraine segments, drumlins and eskers are important elements of the surface topography within the study area (Harrison 1972).

Both the Northern upland and the Algonquin highland physiographic regions are dominated by a more rugged Precambrian Shield landscape with characteristic thin drift areas with rock knobs and bare outcrops. The Northern upland physiographic region is bounded by the Ottawa–Bonnechere Graben (OBG) scarp to the south and has moderate relief (~90 m, Harrison 1972). The higher elevations in the Northern upland region also have a thin till cover, and Precambrian bedrock outcrops are exposed in many areas within the southern portion of the study area.

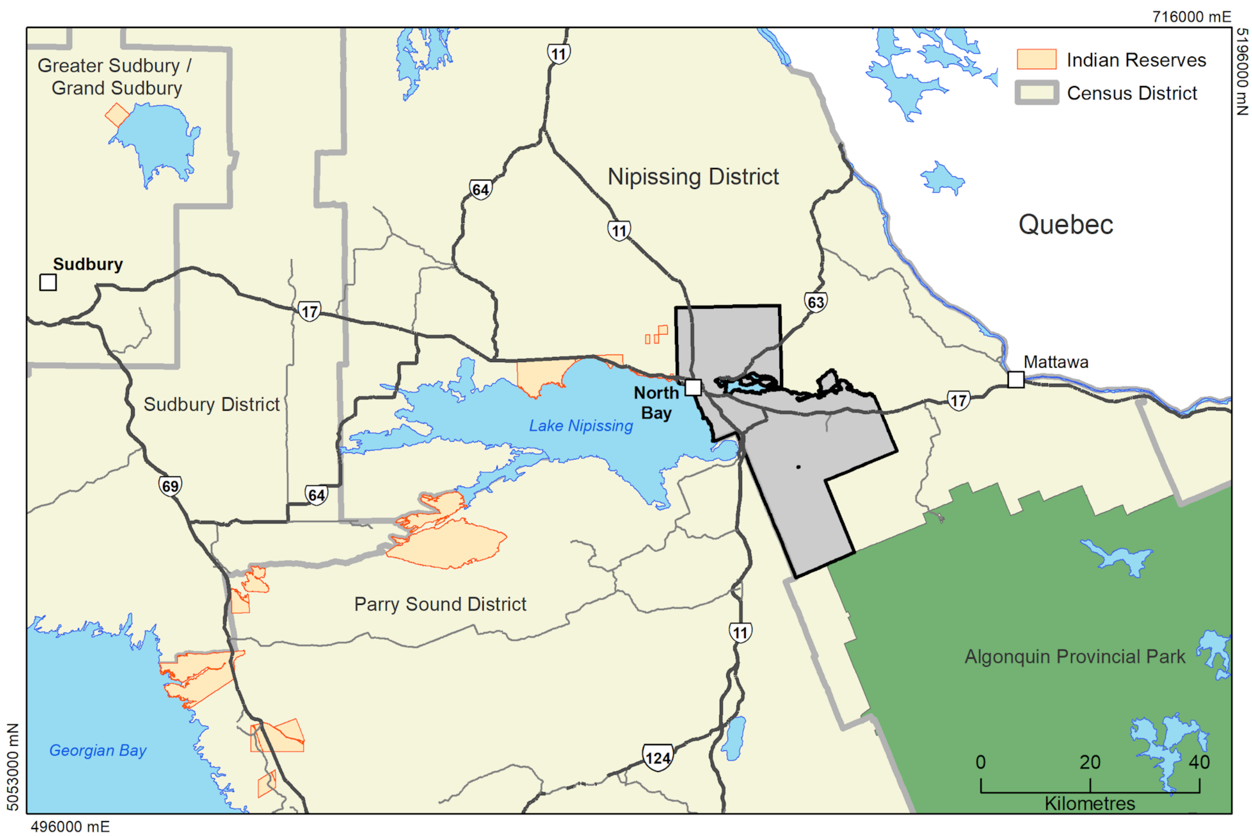


Figure 25.1. Location map showing the study area (grey) within the Nipissing District and surrounding area, northeastern Ontario (*from* Handley 2023). Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 17.

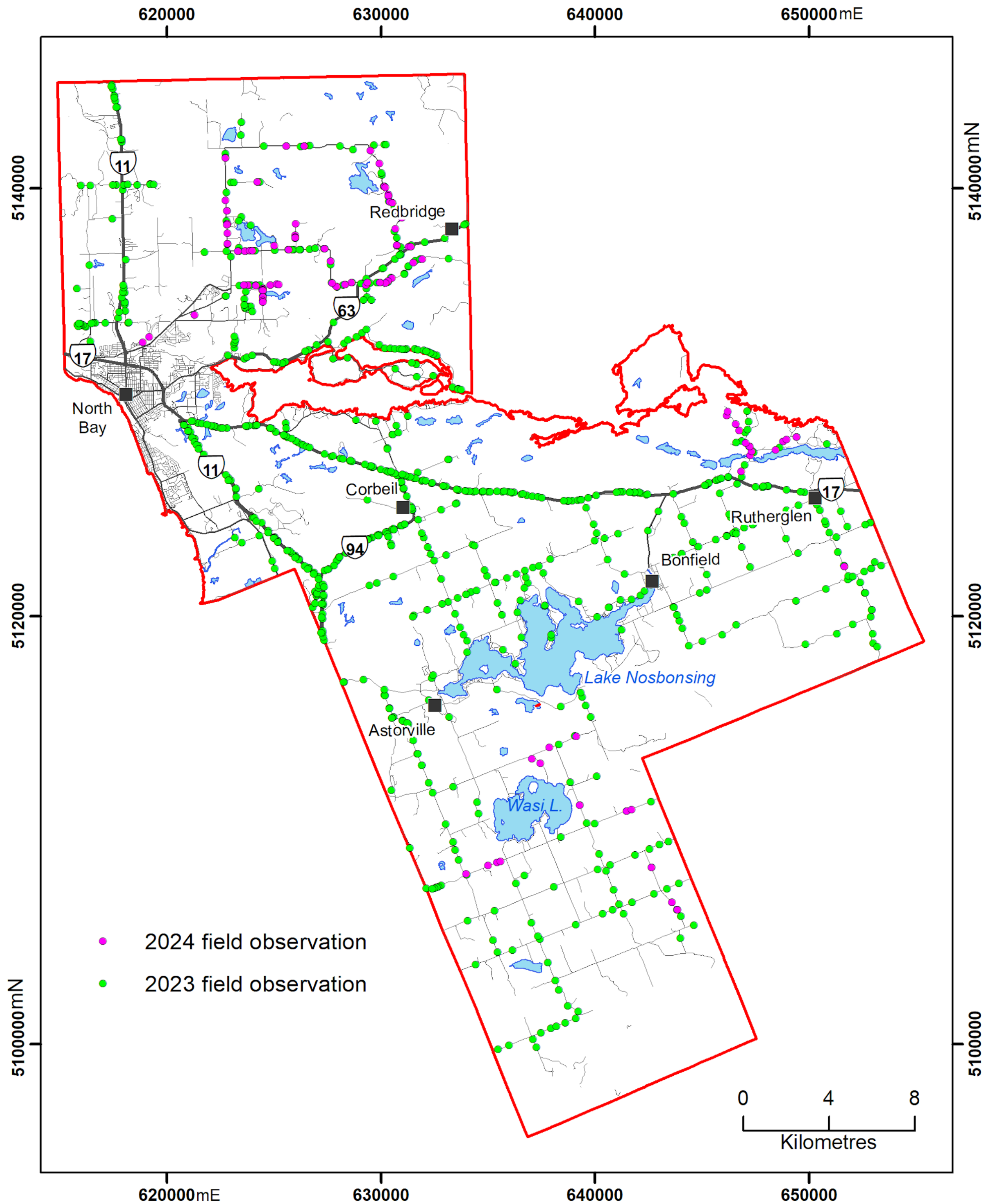


Figure 25.2. Map showing the locations of field observations in the study area from 2023 (green dots) and 2024 (pink dots). Observation sites are located along transportation and forest resource access roads. All UTM co-ordinates provided using NAD83 in Zone 17.

The Algonquin highland physiographic region is characterized by knolls of Precambrian (Grenville Province) bedrock locally overlain by a thin veneer of glacial sediments. Relief is typically highly varied, with exposed rounded bedrock knobs and ridges ranging from 15 to 60 m high (Chapman and Putnam 1984). Many of the valleys, depressions and low-lying areas within this physiographic region are filled with outwash sand and gravel which could potentially become an increasingly more important aggregate resource as other major deposits become depleted.

The study area lies within the northwestern portion of the Central Gneiss Belt of the Grenville Province. These rocks are highly metamorphosed gneisses that are between 1.2 to 2.7 billion years old and have been intruded by 1.4 to 1.5 billion year old granitic and monzonitic plutons (Easton 1992, 2006). Small bodies of mafic plutonic rocks, including amphibolite, gabbro, diorite and mafic gneisses, occur in the central portion of the study area.

The thickness and distribution of surficial materials in the study area, including sand and gravel deposits, are largely the result of glacial activity during the Late Wisconsin when the Laurentide Ice Sheet advanced and retreated from the area. Post-glacial erosional and depositional processes such as eolian dunes, deltas and alluvial deposits, have played a minor role in modifying the landscape of the North Bay area. The youngest sediments observed within the study area are peat and muck accumulating in poorly drained low-lying topographic areas and organic-rich alluvial silt and sands on active river floodplains (Handley 2023). Previous work suggests sediment thickness in the study area is generally less than 5 m; however, it is known to locally exceed 30 m in thickness in some low-lying bedrock valleys, as well as where ice-contact deposits occur (Harrison 1972).

SAND AND GRAVEL RESOURCES

As glaciers advanced and retreated, they transported and deposited significant amounts of sediment. Compact, stony sandy till (Ontario Geological Survey 1984) is found commonly in the lee of exposed bedrock knobs, in drumlins, moraines and smaller low-relief ridges, and is the oldest sediment observed in the study area (Handley 2023).

Sediment laden meltwater and subsequent glaciofluvial activity deposited sand and gravel throughout the region, as described in greater detail in Handley (2023). Gravel resources in the study area are locally thick, but typically are not extensive, thus posing challenges for the production of crushed aggregate products. The main crushable aggregate resources are found predominantly in 3 north-trending eskers in the northern portion of the city of North Bay or concentrated in smaller esker complexes south of the city of North Bay in Bonfield and Chisolm townships (Photos 25.1A and 25.1B), as described by Handley (2023).

The textural and lithological quality of the gravel deposits in the study area are generally good. The initial aggregate quality assessment suggests that the coarse aggregate found in most of the deposits are derived from locally sourced crystalline rocks of the Grenville Province (good quality) with only some farther travelled Huronian Supergroup clasts (lower quality). Most of the aggregate resources in the area are suitable for higher grade load-bearing aggregate products. Some aggregate quality limitations include localized high proportions of oversized clasts and/or coarse-grained gneissic rock clasts that are susceptible to rapid weathering (Ontario Geological Survey 1984). Furthermore, deposits rich in Huronian Supergroup clasts may be susceptible to alkali–silica reactivity (ASR) (Rogers et al. 2000). Alkali–silica reactivity is known to cause a reaction between highly alkaline cement paste and reactive non-crystalline silica, which results in premature concrete deterioration (Rogers et al. 2000).

Sand resources, however, are plentiful in the study area and several pit operations have recently opened. These new operations exploit sandy glaciofluvial outwash complexes and glaciolacustrine deltaic deposits. Larger pits have also been developed in the sandy flanks of the southern portion of the esker complexes north of Thibeault Hill and the city of North Bay (Photo 25.1C) (Ontario Geological Survey 1984). Some of these pits have permanent onsite processing facilities and produce blending sand for hot-mix asphalt and concrete aggregate applications. Large resources of material are still available and unexploited; however, excess fines (silt and clay) severely limit the uses of the sand in some areas (Handley 2023).

BEDROCK RESOURCE POTENTIAL

The most dominant rock type in the study area consists of migmatitic rocks, including gneisses of unknown protoliths, encompassing most of the central and northern portions of the study area (Ontario Geological Survey 2011). Although these units have not been known to be quarried in the past, they may be suitable for some crushed products (Ontario Geological Survey 1984). However, coarse-grained gneisses, which contain large amounts of biotite with well-developed foliation, are susceptible to chemical and mechanical weathering and, therefore, may not be well suited for load-bearing aggregate products.

Younger intrusive plutonic rocks dominate the southern and western portions of the study area and consist of felsic igneous rocks including tonalite, granodiorite, monzonite and granite that have undergone metamorphism and display gneissic and recrystallization textures (Ontario Geological Survey 1984; Easton 2006). In the North Bay area, these rock types are the most favourable for a variety of road-base, asphaltic and concrete products. Careful selection of bedrock is important for concrete products because felsic rocks typically contain feldspar and quartz which are known to cause deleterious chemical reactions such as ASR (Rogers et al. 2000).

Using bedrock-derived crushed stone resources may become increasingly more important in the future as new provincial policies may impact the distance that gravel trucks can drive between the pit or quarry and their job site.

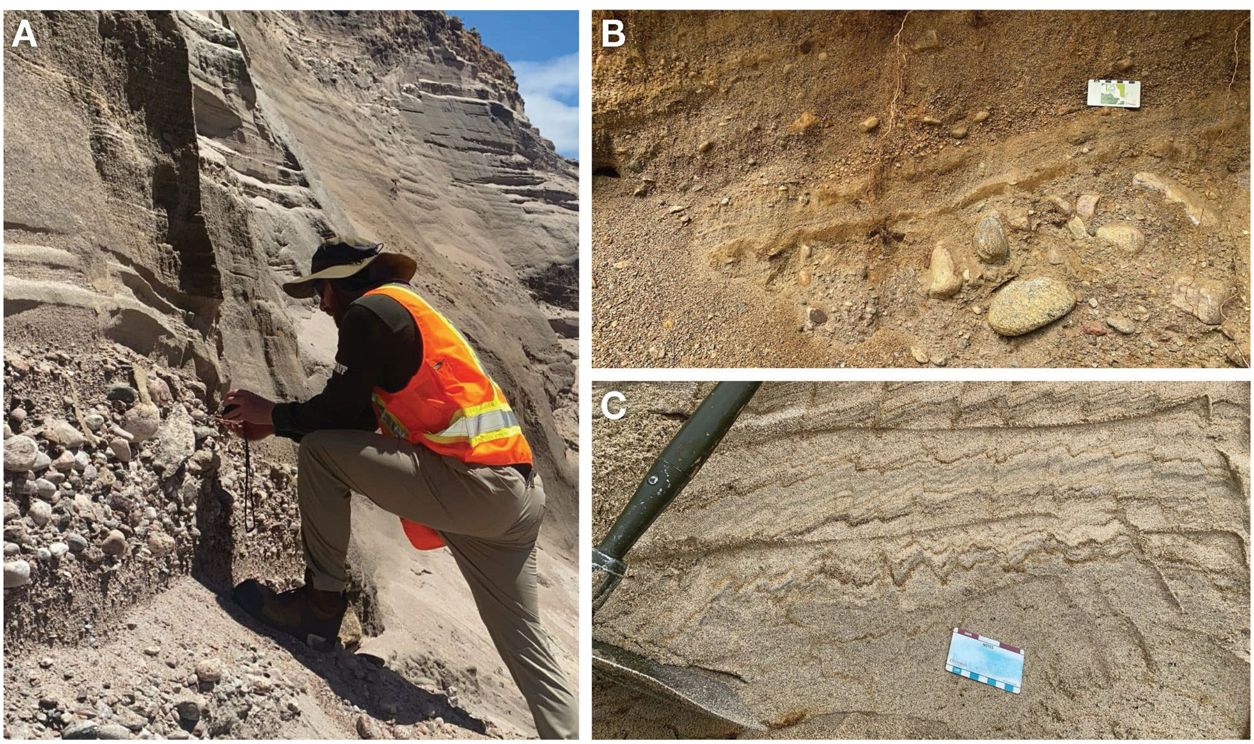


Photo 25.1. Photographs **A)** and **B)** show typical glaciofluvial-type material found in the Bonfield esker, Bonfield Township. **C)** Characteristic fine-to medium-textured sand overlying medium- to coarse-textured sand observed in deltaic deposits situated north of the city of North Bay. There are also some visible darker silty and/or clayey laminations in the upper portion of the photograph. Scale cards in **B** and **C** are marked in centimetres.

NEXT STEPS

The information gathered during the 2023 and 2024 field seasons will be used to complement the existing Aggregate Resources Inventory Program (Ontario Geological Survey 1984), providing much needed up-to-date aggregate resource information for the North Bay area. It is anticipated that this study will confirm many of the subdivisions of the existing aggregate deposits and will be used in conjunction with the most recent Quaternary mapping (Marich 2022, 2023) to provide up-to-date aggregate resources maps delineating primary, secondary and tertiary resources available for future use. An accompanying report will include detailed descriptions and assessments of sand and gravel and bedrock-derived aggregate resources in the study area.

ACKNOWLEDGMENTS

The author would like to thank all of the landowners and pit and quarry operators for granting access to their lands and operations that were covered during this field study. The author would also like to thank Nipissing First Nation, Henvey Inlet First Nation, Dokis First Nation and the Algonquins of Ontario for allowing the OGS to map their traditional land-use areas. Thanks are also extended to Abigail Burt and Michael Easton for their review of this article and to James Thayer (University of Western Ontario) for his excellent assistance in the field. A big shout out to Sara and Mitch who provided fantastic accommodations at Beaverland Camp!

REFERENCES

Chapman, L.J. and Putnam, D.F. 1984. The physiography of southern Ontario; Ontario Geological Survey, Special Volume 2, 270p.

Easton, R.M. 1992. The Grenville Province and the Proterozoic history of central and southern Ontario; Chapter 19 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.714-904.

——— 2006. Precambrian geology, Songris area; Ontario Geological Survey, Preliminary Map P.2847, scale 1:50 000.

Handley, L.A. 2023. Aggregate resources inventory of the North Bay area, central Nipissing District, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.31-1 to 31-9.

Harrison, H.E. 1972. Quaternary geology of the North Bay–Mattawa region, Ontario – Quebec; Geological Survey of Canada, Preliminary Map 3-1971, scale 1:125 000.

Marich, A.S. 2022. Quaternary geological mapping of the Lake Nipissing Basin, Highway 17 corridor, northeastern Ontario; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.17-1 to 17-9.

——— 2023. Quaternary geological mapping of the eastern part of the Lake Nipissing Basin, northeastern Ontario: An update half a century in the making; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.22-1 to 22-10.

Ontario Geological Survey 1984. Aggregate resources inventory of the North Bay area, districts of Nipissing and Parry Sound; Ontario Geological Survey, Aggregate Resources Inventory Paper 70, 82p.

——— 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Rogers, C., Grattan-Bellew, P.E., Hooton, R.D., Ryell, J. and Thomas, M.D.A. 2000. Alkali-aggregate reactions in Ontario; Canadian Journal of Civil Engineering, v.27, p.246-260.

Statistics Canada 2023. 2021 Census of Population; Statistics Canada Catalogue no. 98-316-X2021001, Ottawa, www12.statcan.gc.ca/census-recensement/2021/dp-pd/prof/index.cfm?Lang=E. [accessed November 15]

This page left blank intentionally

Geoscience Laboratories

26. Determination of Ferrous Iron in Geological Samples by Automated Potentiometric Titration: Verifying Method Capabilities on New Instrumentation

O.M. Burnham[1] and V.L. Hingst[1]

[1]Geoscience Laboratories, Ontario Geological Survey

INTRODUCTION

Iron is the fourth most common element in the Earth's upper crust after oxygen, silicon and aluminum and can found be in a variety of minerals including carbonates, silicates, oxides and sulphides. Whereas most elements occur in a single valence state in most geological environments, iron can exist as either ferrous iron (Fe(II)), or ferric iron (Fe(III)), or mixtures thereof and, as such, is a sensitive indicator of redox conditions during geological processes. However, most instrumental methods of analysis (e.g., X-ray fluorescence, XRF; atomic absorption spectrophotometry, AAS; and inductively coupled plasma atomic emission or mass spectrometry, ICP–AES and ICP–MS) only analyze for and report total iron content. For more than 30 years, the Geoscience Laboratories (Geo Labs) have therefore employed an automated ferrous iron titration system (AFITS) to perform separate determinations of ferrous iron by potentiometric analysis of samples after a non-oxidizing acid digestion (method code FEO-ION; ferrous iron, reported as iron(II) oxide, FeO). When combined with a total iron determination, the determination of ferrous iron yields the amounts of both ferrous and ferric iron (by difference).

In April 2021, the Metrohm 700 series titroprocessor system employed by the Geo Labs since March 2001 was replaced with an 800 series system (Metrohm 855 Robotic Titrosampler, 843 pump station, 800 Dosino, and 807 dosing unit) leading to a reassessment of the technique and the method capabilities. This article summarizes the results of this assessment and the results of an investigation into the mineralogical controls on analyses.

METHODOLOGY

The methodology used for sample digestion and potentiometric titration of ferrous iron at the Geo Labs has been described in detail by Tait and Richardson (1992). Samples are decomposed by adding a 1:1:1 mixture of concentrated hydrofluoric acid, concentrated sulphuric acid, and reverse osmosis water to 0.25 g of material in a platinum crucible and the crucible covered and heated to 250°C for 12 to 15 minutes. The crucible lid and contents are then placed in a mixture of saturated boric and sulphuric acids (to remove the excess fluorine ions) and the resulting solution is titrated against standardized potassium permanganate solution, which oxidizes the ferrous iron to ferric iron (Equation 1).

$$MnO_4^- + 5Fe^{2+} + 8H^+ \rightarrow Mn^{2+} + 5Fe^{3+} + 4H_2O \qquad \text{Eqn. 1}$$

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.26-1 to 26-9.

Tait and Richardson (1992) identified 3 main problems associated with the procedure:

- Oxidation of samples during decomposition, but prior to titration, leading to an under-estimation of FeO.
- Reduction of ferric iron to ferrous iron by excess sulphur (>8 sulphide minerals in the sample) leading to an over-estimation of FeO.
- Incomplete digestion of iron-bearing minerals, in particular tourmaline, staurolite, ilmenite, magnetite and pyrite.

Whereas it is possible to minimize the effects of oxidation during decomposition by ensuring that the platinum crucibles are equipped with tight-fitting lids and titrating the samples as soon as decomposition is complete, the suggested effect of sulphur on ferrous iron analyses and the possibility that ferrous iron is incompletely recovered from common ferrous iron-bearing minerals, such as magnetite and ilmenite, is troubling, especially in light of an increase in requests for ferrous iron determinations in samples that contain sulphide or oxide mineralization. The effect of sulphide sulphur and the efficacy of sample digestion were therefore investigated as part of the transfer of the FEO-ION method to the new titration system.

ANALYTICAL RESULTS

The performance of the transferred method was assessed using a selection of interlaboratory reference materials, in-house quality-control materials and routine client samples. Although the selection of reference materials focussed on rock types and ferrous iron contents that were representative of those routinely analyzed by the Geo Labs (95% of which contain between 0.23 and 13 weight % FeO), several additional materials, with higher FeO contents, were prepared and run alongside the routine samples to extend the validated concentration range. For the purposes of the validation, each reference or quality control material was generally analyzed between 3 and 5 times over a two-month period following method transfer. Longer term precision and accuracy can be assessed from the summary of quality control data presented by Hargreaves (this volume).

Precision and Lower Reporting Limits

The precision of ferrous iron analysis by the FEO-ION method was estimated from duplicate analyses of interlaboratory reference materials and client samples carried out during the 2021 validation period. Samples and reference materials were prepared and analyzed between 4 days and 2 weeks apart to obtain estimates of the overall method uncertainty as a function of concentration and its lower reporting limit. By using data obtained on different days with variable separation, the estimate of precision includes most major sources of variation (in particular, those from sample digestion and within-run or between-run instrumental variations). Data reduction was based on the methodology described by Thompson and Howarth (1976), with the data grouped into 9 groups of 13 duplicate pairs each, each duplicate pair averaged, and their absolute differences calculated. For each group, the mean concentration, group median difference, relative difference (%) and expected difference (95% relative uncertainty) were then calculated and the lower reporting limits and optimal precisions achievable by the method estimated from a regression of the group median differences against the group means. The estimated precision obtained for the transferred FEO-ION test method over the operating range of the method is illustrated in Figure 26.1. The three-sigma (3σ) lower reporting limit for the method was estimated to be 0.13 weight % FeO, covering all except the lowest FeO contents seen in samples received for analysis.

Method Accuracy

The overall accuracy of FeO analysis by the FEO-ION method was estimated in 2 ways (Figure 26.2):

- From a weighted linear regression of the measured values against the reference values, weighted according to the uncertainties in the reference values (Reed 1989) to give a measure of overall bias in the measurement.
- From the average absolute deviation of the mean measured concentration relative to the reference value to give a measure of the "average" accuracy (trueness) at concentrations greater than 3 times the precision-controlled limit of quantification (LoQ).

Based on the average concentrations for interlaboratory reference materials analyzed in June and July 2021 (Table 26.1), ferrous iron determined by the FEO-ION method shows an overall bias of -2.5% and trueness of ±2.3% at greater than 1.4 weight % FeO (3×LoQ) (*see* Figure 26.2).

Upper Working Limit

An upper working limit of 35 weight % FeO for the FEO-ION method was set at approximately 110% of the highest concentration successfully analyzed in the interlaboratory reference materials used in the validation study (NCS DC 19004a at 32.36 weight % FeO: *see* Table 26.1). Upper limits 10% greater than the highest reference material successfully analyzed were used to allow data for routine quality control samples to be reported in cases where they exceed the reference value but remain within the laboratories target accuracies. Because the upper working limit for the transferred method was based on what could be proven, rather than what might be possible for the method, it is dependant on the choice of reference

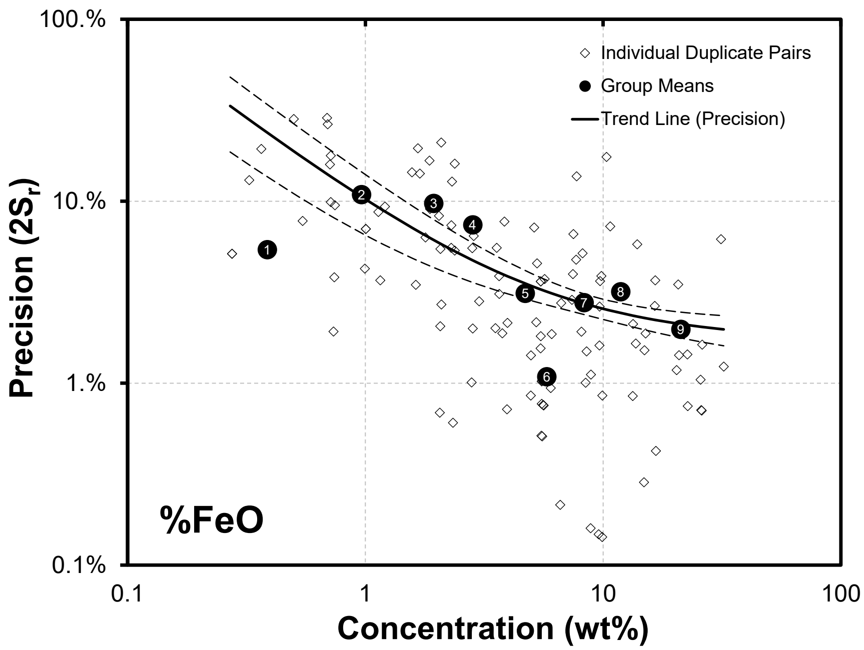


Figure 26.1. Estimated variation of precision as a function of concentration for ferrous iron determined by automated potentiometric titration (method code FEO-ION). All group means were used in the estimate of the lower reporting limit. At concentrations greater than 1 weight % FeO, precision is expected to be ±10% (2σ), or better.

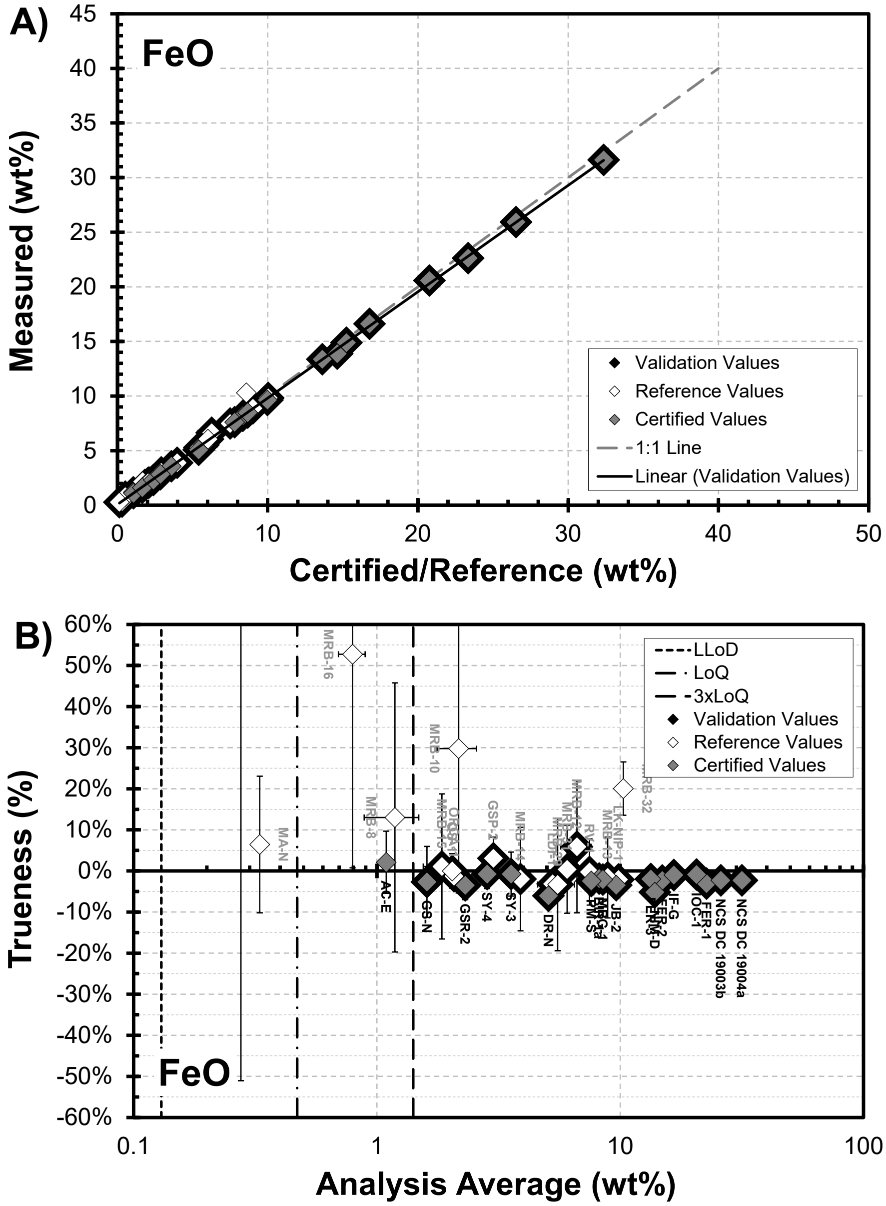


Figure 26.2. Comparison of measured and either certified or reference ferrous iron concentrations in interlaboratory reference materials, determined by automated potentiometric titration (method code FEO-ION). Grey symbols: certified values. Open symbols: reference or consensus values. Black outlines: materials with greater than 3 times the limit of quantification (LoQ), used for the assessment of accuracy. **A**) Plot illustrating -2.4% bias (solid line) from weighted linear regression relative to 1:1 agreement (grey dashed line). **B**) Plot illustrating trueness (deviation of the average measured value from the certified or reference value) relative to limits of detection (LLoD) and quantification (LoQ).

Table 26.1. Accuracy and precision of ferrous iron concentrations determined in reference materials during validation of the FEO-ION method (June 2021 to July 2021).

Material	Description	Certified/Reference Values (ppb)	Analysis Mean ±1sd (ppb)	n	$2S_r$
Interlaboratory Reference Materials					
AC-E	Granite	1.07 ± 0.04	1.09 ± 0.07	4	13%
BIR-1a	Basalt	8.34 ± 0.10	8.19 ± 0.15	3	4%
DR-N	Diorite	5.40 ± 0.10	5.07 ± 0.14	5	5%
FER-1	Iron Formation	23.34	22.62 ± 0.12	3	1%
FER-2	Iron Formation	15.24 ± 0.20 [a]	14.89 ± 0.12	6	2%
FER-3	Iron Formation	13.63	13.36 ± 0.10	3	2%
GS-N	Granite	1.65 ± 0.07	1.61 ± 0.13	5	16%
GSP-2	Granodiorite	2.92 ± 0.14 [b]	3.01 ± 0.04	2	3%
GSR-2	Andesite	2.39 ± 0.07	2.31 ± 0.05	3	4%
IF-G	Iron Formation	16.78 ± 0.18	16.61 ± 0.16	5	2%
IOC-1	Iron Ore	20.76 ± 0.17	20.58 ± 0.27	5	3%
JB-2	Basalt	9.98 ± 0.31	9.63 ± 0.10	3	2%
MA-N	Granite	0.31 ± 0.09	0.33 ± 0.05	4	28%
MRG-1	Gabbro	8.66 ± 0.23 [c]	8.48 ± 0.08	3	2%
NCS DC 19003b	Ti-V-Fe Concentrate	26.53 ± 0.15	25.93 ± 0.24	5	2%
NCS DC 19004a	Ti-V-Fe Concentrate	32.36 ± 0.12	31.6 ± 0.9	3	6%
NIM-D	Dunite	14.6 ± 0.4	13.87 ± 0.29	3	4%
PM-S	Microgabbro	7.80 ± 0.20	7.61 ± 0.17	6	5%
SY-3	Syenite	3.59 ± 0.18 [c]	3.56 ± 0.07	3	4%
SY-4	Diorite Gneiss	2.86 ± 0.09	2.84 ± 0.05	8	3%
In-house Quality Control Materials					
LDI-1	Mineralized gabbro	5.45 ± 0.02 [d]	5.27 ± 0.09	3	3%
LK-NIP-1	Diabase	10.04 ± 0.03 [d]	9.83 ± 0.13	9	3%
MRB-8	Rhyolite	1.05 ± 0.30 [e]	1.19 ± 0.06	3	10%
MRB-10	Peridotite	1.67 ± 0.40 [e]	2.17 ± 0.27	7	25%
MRB-12	Altered diabase	6.27 ± 0.95 [e]	6.64 ± 0.08	3	2%
MRB-13	Sedimentary Fe formation	9.02 ± 0.90 [e]	8.88 ± 0.04	3	1%
MRB-14	Andesite	3.97 ± 0.50 [e]	3.89 ± 0.10	6	5%
MRB-15	Rhyolite	1.83 ± 0.30 [e]	1.85 ± 0.11	3	12%
MRB-16	Tourmaline pegmatite	0.52 ± 0.10 [e]	0.79 ± 0.22	7	56%
MRB-17	Nb-bearing pegmatite	0.13 ± 0.10 [e]	0.276 ± 0.005	5	4%
MRB-29	Basalt	5.72 ± 0.95 [e]	5.53 ± 0.06	20	2%
MRB-31	Granophyre (GR-1)	6.03 ± 0.64 [e]	6.05 ± 0.06	3	2%
MRB-32	Peridotite	8.58 ± 0.22 [e]	10.3 ± 0.5	5	10%
ORCA-1	Calc-alkaline rhyolite	2.10 ± 0.01 [d]	2.073 ± 0.028	9	3%
QS-1	Calcareous shale	2.04 ± 0.01 [d]	2.04 ± 0.08	2	8%
RV-1	Gabbronorite	7.50 ± 0.09 [d]	7.5 ± 0.6	5	16%

n: number of analyses. $2S_r$: 2 relative standard deviations.
Reference values taken from certificates of analysis unless source indicated as follows: [a] Abbey, McLeod and Liang-Guo (1983); [b] Xue et al (2017); [c] Gladney and Roelandts (1990); [d] Hargreaves (2019); [e] Richardson (1995).

materials used in the validation study. It may be increased if and/or when samples with higher trace element contents are shown to be successfully analyzed. However, all except one of over 1700 samples analyzed in 2022 and 2023 contained less than the validated upper limit, indicating that it is adequate.

MINERALOGICAL CONTROLS ON FERROUS IRON ANALYSIS

To investigate the mineralogical controls on ferrous iron analyses, 2 sets of tests were undertaken. For each test, samples were spiked with known quantities of selected minerals, the ferrous iron contents of the mixtures measured and any residues after hydrofluoric–sulphuric acid ($HF–H_2SO_4$) digestion examined.

For the first test, ultrapure quartzite (in-house quality control material MRB-40) was spiked to contain 2 and 10 weight % crushed arsenopyrite, marcasite, ilmenite, pyrite, pyrrhotite, magnetite, hematite, nickel sulphide[2], staurolite, or tourmaline (dravite), pulverized to homogenize, and digested using the routine hydrofluoric–sulphuric acid digestion. The residues from the digestions were separated, washed thoroughly with deionized water, dried and submitted for X-ray diffraction (XRD) analysis. Although the digestion solutions were analyzed by the FEO-ION method, because priority was given to the recovery of residues, the recovery of solution may have been incomplete. The ferrous iron contents from these analyses are therefore considered semiquantitative. Prior to use, the crushed minerals were each screened by scanning electron microscope (SEM) to obtain bulk composition and identify inclusions. Whereas the arsenopyrite, pyrite, magnetite, hematite and tourmaline spikes were relatively free of inclusions, the marcasite spike appeared to be mixed with one or more iron–titanium oxides, the ilmenite contained exsolutions of a nonstoichiometric iron–titanium oxide, the pyrrhotite spike contained inclusions of pentlandite and other iron–nickel sulphides, as well as intergrowths with an iron oxide and a variety of silicates, and the staurolite contained many inclusions of quartz, monazite, xenotime, ilmenite, zircon and apatite.

For the second test, aliquots of the LK-NIP-1 diabase in-house quality control material were spiked to contain 2 and 10 weight % crushed pyrite or nickel sulphide, pulverized to homogenize and analyzed by the FEO-ION method.

Mineral Solubilities

The results of the XRD analyses of the digestion residues are summarized in Table 26.2. The FeO contents measured in the digestion solutions are shown in Figure 26.3.

Whereas abundant arsenopyrite, pyrite, hematite, staurolite and tourmaline were observed in the XRD spectra of the digestion residues of the samples into which these minerals were spiked and little or no ferrous iron was measured in the solutions produced by their digestion (consistent with the inferred insolubility of these minerals during $HF–H_2SO_4$ attack), no ilmenite or magnetite was observed in the XRD spectra of the residues for these samples, the residues for both ilmenite and magnetite-spiked samples were pale, and the associated digestion solutions contained appreciable FeO, all consistent with the digestion of these minerals during hydrofluoric–sulphuric acid attack. The residues after digestion of the pyrrhotite and nickel sulphide spiked samples were also distinctly grey and SEM analysis of the original and residual material for the nickel sulphide-spiked samples indicated the presence of a nickel- and sulphur-rich material, with a lower Ni:S ratio than the original material. However, XRD analysis failed to identify any sulphide-bearing crystalline phases in these residues, suggesting that the nickel sulphide reacts to form an amorphous or nanocrystalline material during digestion. The residue from the digestion of pyrrhotite-spiked sample has yet to be examined to determine whether a similar iron- and

[2] *An iron-free nickel sulphide (millerite, NiS, and/or godlevskite, Ni_9S_8) was produced by reaction of carbonyl nickel with elemental sulphur using the routine nickel sulphide fusion method (method code IMP-200).*

Table 26.2 Minerals identified by X-ray diffraction analysis of residues after hydrofluoric–sulphuric acid digestions of spiked quartzite.

Spiked Mineral	**Residuum**
Arsenopyrite (apy)	Quartz, Arsenopyrite
Marcasite (mrc)	Quartz, Pyrite †
Ilmenite (ilm)	Quartz
Pyrite (py)	Quartz, Pyrite
Pyrrhotite (po)	Quartz, Vermiculite ‡
Magnetite (mag)	Quartz
Hematite (hem)	Quartz, Hematite
Nickel Sulphide (NiS)	Quartz
Staurolite (st)	Quartz, Staurolite
Tourmaline (tur)	Quartz, Dravite

†*Presumed to be from the transformation of marcasite during digestion or treatment of the residue prior to XRD analysis.*
‡*Vermiculite or a related mineral species.*

sulphur-bearing material is present. Based on the ferrous iron concentrations determined in the digestion solutions for the pyrrhotite- and marcasite-spiked samples (*see* Figure 26.3), it appears that some ferrous iron was present and/or extracted from these samples. However, it is unclear whether this was derived from the dissolution of the sulphide minerals or that of an iron oxide contaminant in the spike.

While the results of this study confirm the poor recovery of ferrous iron from difficult or slow to digest minerals, such as staurolite and tourmaline, by the hydrofluoric–sulphuric acid digestion employed by the FEO-ION method, as suggested by Tait and Richardson (1992), they contradict the suggestion that the major ferrous iron-bearing minerals ilmenite and magnetite are not solubilized during the FEO-ION digestion and indicate that the method is less limited than originally suggested. However, given the potentially high proportions of staurolite and tourmaline in metapelitic rocks and/or granitic pegmatites and their relatively high FeO contents (12–20 weight %), the failure to digest these minerals could significantly impact the utility of the method for certain rock types. If such minerals are present, the effect of their nondigestion will need to be considered when interpreting whole-rock FeO data. Further work on other slow-to-digest ferrous iron-bearing minerals (e.g., almandine garnet or chromite) may be warranted to investigate whether additional minerals need to be included in this consideration.

Effect of Sulphide Sulphur on Ferrous Iron Analyses

As noted above, when discussing the solution preparation associated with the determination of ferrous iron by potentiometric titration, Tait and Richardson (1992) suggested that, when excess sulphur is present in the sample (i.e., sample contains greater than 8% sulphide minerals), ferric iron is reduced to ferrous iron by sulphur during the digestion procedure, leading to the determination of falsely high ferrous iron contents. When spiked with different sulphides, the LK-NIP-1 diabase in-house quality control material (10.03 weight % FeO, 13.54 weight % $Fe_2O_3^T$) showed very different behaviours depending on the sulphide added. Whereas the concentrations of FeO measured for the materials spiked with pyrite showed a decrease with increasing pyrite contents that was consistent with the trend expected for simple dilution with a non-ferrous iron–yielding phase, those measured for the materials spiked with nickel sulphide showed a mild enhancement of ferrous iron content relative to the simple dilution trend. Because the nickel sulphide phase used in the experiment was, by design, iron free, the enhancement of the measured ferrous iron contents is most easily accounted for by reduction of a fraction of the ferric iron in LK-NIP-1 to ferrous iron by the oxidation of sulphur from the spiked sulphide. When the results for the spiked LK-NIP-1 material are compared to those for the spiked quartzite above, it is notable that the enhancement was only seen for the sulphide for which there was evidence of reaction during analysis, suggesting that enhancement might be restricted to specific sulphide minerals and that a similar effect might be expected for pyrrhotite- and/or pentlandite-bearing samples but not those dominated by pyrite or arsenopyrite. Additional spiking experiments, using inclusion-poor sulphide separates, will be used to investigate this question further.

SUMMARY

The new Metrohm 800 series automated ferrous iron titration system has been shown to produce ferrous iron data with a trueness of better than ±2.3% and an average precision better than ±8% at 3 times the lower limit of quantification (1.4 weight % FeO), consistent with the Geo Labs' quality objectives.

Based on the reproducibility of duplicate analyses and the most ferrous iron-rich interlaboratory reference material analyzed during method validation, in April 2022, the lower reporting limit for the method was revised from 0.06 to 0.13 weight % FeO and an upper reporting limit was set at 35 weight % FeO. The revised working range covers 98.6% of the 1700 samples received during the 2022–2023 and 2023–2024 fiscal years.

Analysis of spiked samples indicate that, while the range is less than previously believed, some ferrous iron-bearing minerals are resistant to the hydrofluoric–sulphuric acid digestion employed as part of the FEO-ION method. While tourmaline and staurolite were specifically identified as resistant during the current study, other minerals merit further investigation.

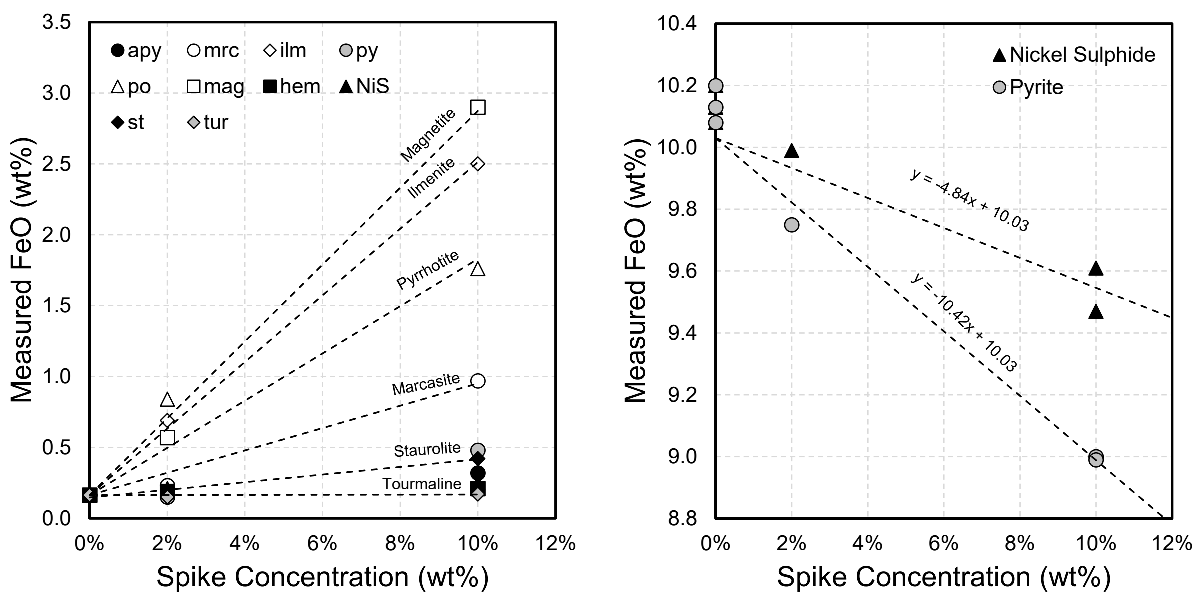


Figure 26.3. Measured ferrous iron concentrations in mineral-spiked samples. **Left**) Ferrous iron concentrations determined in spiked high-purity quartzite. Solution concentrations may be low because of incomplete recovery of solution during the separation of residues. For abbreviations, *see* Table 26.2. **Right**) Ferrous iron concentrations determined in spiked LK-NIP-1 diabase in-house quality control material showing possible enhancement of the determined ferrous iron content resulting from the reduction of ferric to ferrous iron by nickel sulphide.

Some sulphide minerals may be partially attacked by the hydrofluoric–sulphuric acid mixture used during acid digestion, leading to the liberation of sulphur, the reduction of ferric to ferrous iron and the over-estimation of FeO contents. These reactions appear to be mineral specific. While it was possible to determine that pyrite does not affect ferrous iron determinations when present at up to 10 weight % in samples, the effect of other common sulphide minerals (e.g., pyrrhotite, pentlandite, and chalcopyrite) has yet to be investigated.

ACKNOWLEDGMENTS

The authors would like to thank Fareeda Amirault and Ricardo Martinez for their assistance with the acid digestions and recovery of residues for the spiking tests and Thomas Gore and Sandra Clarke for their assistance with the XRD and SEM analyses of original spiking material and residues.

REFERENCES

Abbey, S., McLeod, C.R. and Liang-Guo, W. 1983. FeR-1, FeR-2, FeR-3 and FeR-4. Four Canadian iron-formation samples prepared for use as reference materials; Geological Survey of Canada, Paper 83-19, 51p.

Gladney, E.S. and Roelandts, I. 1990. 1988 compilation of elemental concentration data for CCRMP reference rock samples SY-2, SY-3, and MRG-1; Geostandards Newsletter, v.14, p.373-358.

Hargreaves, J.C. 2019. Summary of quality-control data for the Geoscience Laboratories methods FEO-ION, IAW-200, ICW-100, IRC-100, IRW-H2O and TOC-100; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.25-1 to 25-6.

——— 2024. Summary of quality control data for the Geoscience Laboratories methods FEO-ION, IAW-200, IRC-100, IRW-H2O and TOC-100; *in* Summary of Field Work and Other Activities, 2024, Ontario Geological Survey, Open File Report 6413, p.28-1 to 28-7.

Reed, B.C. 1989. Linear least-squares fits with errors in both coordinates; American Journal of Physics, v.57, no.7, p.642-646.

Richardson, J.M. 1995. 1995 Update report on the composition of the Geoscience Laboratories in-house reference materials (MRB series); *in* Summary of Field Work and Other Activities, 1995, Ontario Geological Survey Miscellaneous Paper 164, p.198-203.

Tait, J. and Richardson, J.M. 1992. Determination of ferrous iron by automated potentiometric analysis; *in* Summary of Field Work and Other Activities, 1992, Ontario Geological Survey, Miscellaneous Paper 160, p.176-181.

Thompson, M. and Howarth, R.J. 1976. Duplicate analysis in geochemical practice. Part I. Theoretical approach and estimation of analytical reproducibility; Analyst, v.101, p.690-698.

Xue, D., Wang, H., Liu, Y., Xie, L. and Shen, P. 2017. An improved procedure for the determination of ferrous iron mass fraction in silicate rocks using a Schlenk line-based digestion apparatus to exclude oxygen; Geostandards and Geoanalytical Research, v.41, no.3, p.411-425.

27. Production and Characterization of an Alkali-Carbonate Reactive Reference Material: MTO RM ACR XRF

O.M. Burnham[1] and C.A. MacDonald[2]

[1]Geoscience Laboratories, Ontario Geological Survey, Sudbury, Ontario P3E 6B5
[2]Engineering Materials Office, Ministry of Transportation, Toronto, Ontario M9M 2L4

INTRODUCTION

Alkali-aggregate reactivity (AAR) is a chemical reaction that occurs in either mortar or concrete between the hydroxyl (OH^-) ions associated with sodium and potassium present in Portland cement (or other sources) and certain mineral phases that may be present in the coarse or fine aggregates. The reaction can lead to expansion and cracking of concrete, resulting in premature deterioration, increased maintenance costs and reduced service life of infrastructure.

The more common type of AAR, alkali-silica reactivity (ASR), is associated with the dissolution of silica (SiO_2) in aggregates and the formation of expansive alkali-silica gel in the aggregate and concrete. A second, more serious, type of AAR, alkali-carbonate reactivity (ACR), is associated with certain dolomitic limestone and argillaceous limestone rocks known to be present within the Ordovician Gull River Formation and possibly Bobcaygeon Formation of the Simcoe Group in southeastern Ontario. Although very rare, ACR associated with aggregates from these formations has been attributed to premature deterioration of concrete in Ontario in the past, particularly in the Cornwall and Lancaster areas.

Because several studies have shown that it is not possible to mitigate or cure ACR using additives or supplementary cementing materials (SCM) in concrete and the Gull River and Bobcaygeon formations are being increasingly utilized as sources of quarried concrete aggregates in Ontario, the most viable solution to their use is to identify and avoid the incorporation of the potentially reactive rock types and aggregates through screening of their relative CaO, MgO and Al_2O_3 contents (Rogers 1985, 1986: Figure 27.1). Before being listed on any Ontario Ministry of Transportation (MTO) Concrete Aggregate Sources List (CASL), sources that could potentially exhibit ACR must submit X-ray fluorescence (XRF) chemical analysis of the major element oxide compositions of their properly prepared products to MTO for approval (following method LS-615: Ontario Ministry of Transportation 2020). This requirement helps identify and avoid potentially reactive rock types and aggregates. However, an MTO survey in the fall of 2020 found that, of the National Institute of Standards and Technology (NIST) certified reference materials (CRMs) required for quality testing according to the LS-615 R33 method (Ontario Ministry of Transportation 2020) (NIST 1c, NIST 1d, and NIST 88a), only NIST 1d (Argillaceous Limestone) was still available for purchase. The survey also found that most commercial laboratories commonly used by aggregate producers were unaware of and/or did not have a supply of the required NIST CRMs. Since this survey, even NIST 1d has become unavailable through the NIST organization's Website, with no indicated replacement, thereby removing the last commercial CRM available for use with the LS-615 method.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.27-1 to 27-10.

To address these and other concerns, in the spring 2021 update to the LS-615 method (R35):

- All references to the NIST CRMs, except the remaining available NIST 1d, were removed and MTO ACR FA1 (an aggregate from a quarry near Pittsburg, Ontario) was introduced as a cost-effective alternative reference material to NIST 1d, with acceptable ranges provided.
- The frequency of testing of the reference material was reduced from 2 times to only once per sample or series of samples to be evaluated.
- The method(s) of analysis was restricted to XRF analysis of fused glass beads, with the full suite of major elements and loss on ignition required to be reported.

However, the provision of MTO ACR FA1 was only intended to serve as a temporary alternative reference material (RM) for this test method until a suitable replacement RM could be developed as a permanent solution. As a result, limited quantities of the material were prepared, with an expected lifetime of 1 to 2 years at the estimated rate of use. To develop a long-term solution, in 2024, Ontario Geological Survey Geoscience Laboratories (Geo Labs) entered into a collaboration with MTO's Engineering Materials Office (EMO) to produce and characterize a larger mass of an argillaceous dolomitic limestone as RM for quality assurance on the LS-615 method, using material derived from the Pittsburg Quarry near Kingston, Ontario, obtained from the MTO's Pittsburg Aggregate or MTO RM ACR CA1 stockpile (MacDonald and Jiang 2023, 2024). The Pittsburg Aggregate (sometimes also referred to as the Kingston Quarry or Kingston aggregate) is recognized as one of the few sources of alkali-carbonate reactive reference material and is commonly used for AAR and ACR research (Rogers and MacDonald 2011).

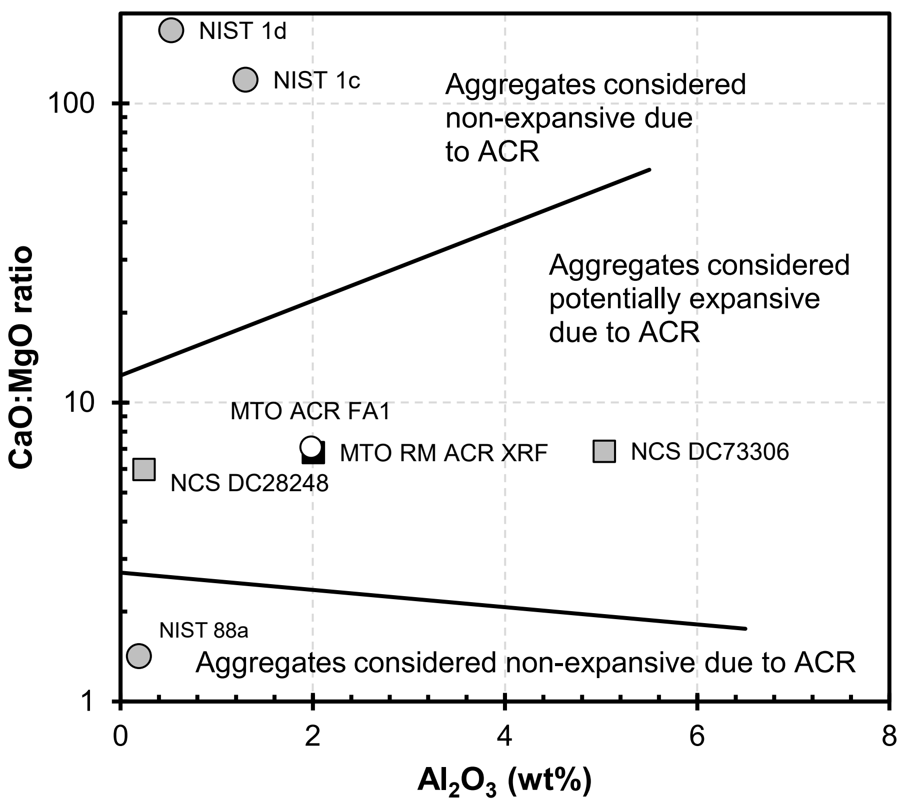


Figure 27.1. Illustration of the division between nonexpansive and potentially expansive aggregates on the basis of chemical composition *after* Rogers (1985). Grey circles: reference materials required as part of MTO Test Method LS-615 (rev. 16 and 35). Unfilled circle: composition of the interim MTO reference material MTO ACR FA1. Grey squares: composition of traceability materials used in the study. Black square: consensus composition of MTO reference material MTO RM ACR XRF.

This article outlines the production and characterization of the new reference material (MTO RM ACR XRF) and possible future collaborations between the Geo Labs and MTO with respect to quality assurance on analyses for MTO projects. Production of an XRF reference material from the Pittsburg reference aggregate, and other reference materials for use in quality control for other MTO projects represents a made-in-Ontario solution to ensure a readily available, fit-for-purpose and reliable supply of materials to support quality testing and MTO's CASL program for many years to come.

MATERIAL PREPARATION

Approximately 255 kg of ACR Pittsburg reference aggregate (MTO RM ACR CA1), crushed to under 0.25 inches, were supplied to the Geo Labs from the MTO's stockpile in its Aggregate Building at 95 Arrow Road, Toronto, Ontario. The material was dried for 14 days at 50°C and pulverized using chrome-steel mills (Geo Labs method SAM-SPA) to greater than 97.5% passing 170 mesh (90 µm). Chrome-steel was chosen as the pulverization medium because of its greater efficiency and least effect on the alumina and silica contents of the material. The bulk pulverized material was blended for 48 hours and transferred to 4 dedicated pails from which 1989 100 g glass jars were filled. The homogeneity of the jars was tested using 12 jars taken during the bottling process, representing material from the bottom, middle, and top of each pail, and triplicate analyses of each jar using the Geo Labs major and minor element analysis by wavelength-dispersive x-ray fluorescence (WD–XRF) on fused glass disks (method codes XRF-M01 and XRF-M02), three-step loss on ignition (method code LOI-3ST), and particle size analysis (method code PSA-100) test methods. With the exception of loss on drying and total loss on ignition (reflecting mild differences in the moisture contents in the pails), no statistically significant chemical differences were found within or between pails, but mild textural differences may be present, with the proportion of coarse (31.25–63 µm) material varying slightly between jars filled from each pail (Figure 27.2).

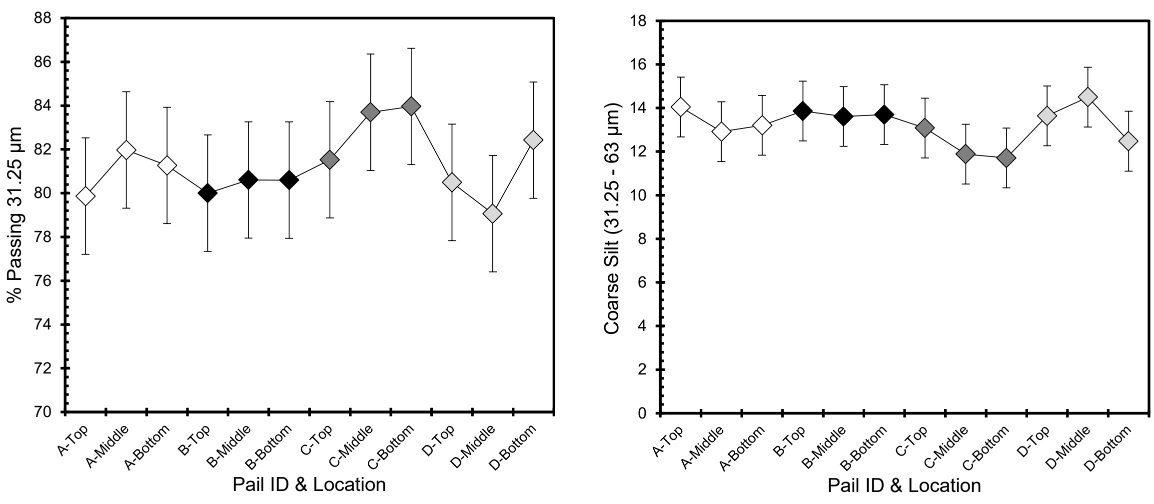


Figure 27.2. Particle-size distribution of MTO RM ACR XRF determined in jars taken for homogeneity testing. Jars selected from those filled from the top, middle and bottom of each of the 4 pails of blended material and analysed in triplicate. Plot on left shows percent passing at 31.25 µm and plot on right shows percent present in the coarse silt fraction.

DISTRIBUTION

To characterize the composition of MTO RM ACR XRF, the candidate material was circulated, along with 2 matrix-matched traceability materials (China National Analysis Centre for Iron and Steel, NCS, limestones NCS DC 28248 and NCS DC 73306[3]), to 12 commercial, government and university laboratories in Canada, Australia and Peru, each with expertise in the XRF analysis of limestones. Seven 100 g jars of MTO RM ACR XRF, set aside from different intervals during the bottling process, were split into ten 10 g aliquots and each laboratory was sent a set of 5 aliquots (extracted from the same original bottle) and a single 10 g aliquot of each of the traceability materials. Laboratories were requested to perform a single fused disk XRF analysis on each aliquot of the candidate material and duplicate preparations and provide results of analyses of each traceability material, characterizing the materials for the full suite of major element oxides (SiO_2, TiO_2, Al_2O_3, total Fe expressed as Fe_2O_3, MnO, MgO, CaO, Na_2O, K_2O, P_2O_5, and loss on ignition, LOI) on a dry-weight basis. Although laboratories were requested to report data unscreened for reporting limits and with more precision than usual so that the maximum amount of data could be gathered for each material, in many cases, their reporting capabilities were constrained by company policies and this request could only be honoured by 4 of the participating laboratories, limiting the number of laboratory means that could be used for analytes close to laboratories' reporting limits and/or the ability to estimate the within-laboratory precision for some analytes. As a result of instrument problems at 1 laboratory, only 11 laboratories were able to complete the analyses by the September 2024 project deadline.

In addition to the 10 major oxides and total loss on ignition, several laboratories submitted data for BaO, CuO, Cr_2O_3, SrO, SO_3, V_2O_5, ZnO and/or ZrO_2. However, with the exception of SrO and SO_3, in many cases, the concentrations of these analytes were at or below the lower reporting limits for the methods and could not be used.

DATA REDUCTION

Data reduction was carried out in several stages:

- Calculation of laboratory means for the candidate reference material and 2 traceability materials using Equation 1:

$$\bar{y}_i = \frac{1}{n_i}\sum_{j=1}^{n_i} y_{ij} \qquad \textit{Eqn. 1}$$

where $\bar{y}_i$ is the mean and n_i is the number of repeat analyses y_{ij} performed by laboratory i.

- Conversion of the laboratory means for the traceability materials to z-scores using Equation 2:

$$z = \frac{(\bar{y}_i - y_a)}{\sigma_p} \qquad \textit{Eqn. 2}$$

Where y_a is the assigned mass concentration for the traceability material and σ_p is the target precision. Where mass concentrations were available from the traceability material certificates of analysis, these were used as the assigned values for the calculation of z-scores. When certificate values were unavailable (e.g., Na_2O and K_2O in NCS DC 28248), the mean of the laboratory means was used as y_a. Target precisions were taken from the greater of the between-laboratory standard deviations, stated on the traceability material certificates of analysis (when available) and a fit-for-purpose precision based on the Horwitz function (Equation 3: Horwitz, Kamps and Boyer 1980; Horwitz and Albert 1995):

$$H_a = 0.02 \cdot c^{0.8495} \qquad \textit{Eqn. 3}$$

[3] *Also known as GBW 07108 or GSR-6*

where H_a is the target between-laboratory reproducibility observed at analyte concentration c, with both c and H_a expressed as mass ratios. This function is an empirical observation that is considered to be applicable over a wide range of concentrations, test materials, analytes and analytical methods and depends solely on the assigned value rather than the observed spread in values. It allows the assessment of small data sets that may contain several outlying values. By taking the greater of the 2 values, it was possible to control for material heterogeneity (evidenced by elevated between-laboratory variability on the certificates of analysis) while maintaining reasonable acceptance windows.

- Screening of the laboratory traceability material z-scores using Youden ellipses (calculated as described in International Organization of Standardization 2005) to identify and reject laboratory means that potentially showed method biases (calculated within a 95% degree of confidence: Figure 27.3).
- Secondary screening of the laboratory means and standard deviations for MTO RM ACR XRF using Cochran and/or Grubbs tests to remove data sets that showed either elevated variability and/or biases not recognized from the traceability material analyses.
- Calculation of the compilation mean ($\bar{\bar{y}}$) from the mean of the p accepted laboratory means (weighted according to the number of analyses by each laboratory) according to Equation 4:

$$\bar{\bar{y}} = \frac{\sum_{i=1}^{p} n_i \bar{y}_i}{\sum_{i=1}^{p} n_i} \qquad \textit{Eqn. 4}$$

- Calculation of the standard deviation of repeatability (within-laboratory standard deviation, σ_r) from the weighted pooled standard deviations for each laboratory's measurements (s_{ij}) according to Equation 5:

$$\sigma_r = \sqrt{\frac{\sum_{i=1}^{p} (n_{ij}-1) s_{ij}}{\sum_{i=1}^{p} (n_{ij}-1)}} \qquad \textit{Eqn. 5}$$

- Calculation of the between-laboratory standard deviation (σ_l) according to Equations 6 to 8:

$$\sigma_l = \sqrt{\frac{\sigma_d^2 - \sigma_r^2}{\bar{\bar{n}}}} \qquad \textit{Eqn. 6.}$$

where

$$\sigma_d^2 = \frac{1}{1-p} \sum_{i=1}^{p} n_i (\bar{y} - \bar{\bar{y}})^2 \text{ and } \bar{\bar{n}} = \frac{1}{p-1} \left[\sum_{i=1}^{p} n_i - \frac{\sum_{i=1}^{p} n_i^2}{\sum_{i=1}^{p} n_i} \right] \qquad \textit{Eqn. 7 and 8}$$

- Calculation of the combined standard uncertainty (standard deviation of the mean of the contributing laboratory data, u) from the within- and between-laboratory standard deviations (σ_r and σ_l) according to Equation 9:

$$u = \sqrt{\frac{\sigma_l^2 + \sigma_r^2 / \bar{\bar{n}}}{p}} \qquad \textit{Eqn. 9}$$

- Finally, expansion of the standard uncertainty (Eqn. 10) to provide the reference material uncertainty (*U*) at a 95% confidence level, using an expansion factor given by Student's *t* factor at *p-1* degrees of freedom[4]:

$$U = t_{p-1,\,0.95} \cdot u \qquad \textit{Eqn. 10}$$

RESULTS

Data Screening

As described above, prior to their use in the determination of the compilation means for MTO RM ACR XRF, the individual laboratory means were screened using either the certified values obtained from the NCS certificates of analysis or the grand mean of the unscreened laboratory means. Despite selection of commercial and academic laboratories with a proven ability to obtain accurate WD–XRF data, approximately 18% (22) of the laboratory means for the 10 main oxides and LOI were rejected for not showing adequate agreement with the NCS reference material or initial grand means. Rejection rates varied, from 5 out of 11 data sets for Al_2O_3 to none for CaO, MgO and LOI (*see* Figure 27.3). Additionally, 9 laboratory data sets (7.5%) were rejected for showing poor reproducibility and 3 data sets were rejected as statistical outliers (Table 27.1).

Of the other analytes reported by the participating laboratories (BaO, Cr_2O_3, SO_3 and SrO), sufficient data for the assignment of consensus values were only received for SO_3 and SrO, with 9 or 10 of the 11 laboratories reporting values. Of these laboratory data sets, several either showed bias or poor reproducibility, such that only 6 data sets for each analyte were eventually used in the determination of the consensus concentrations.

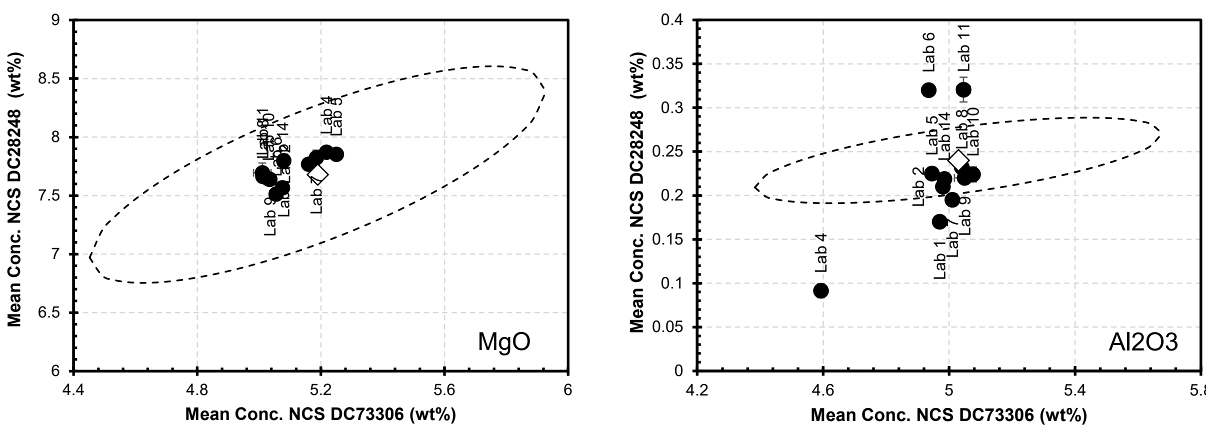


Figure 27.3. Youden plots summarizing the concentrations for laboratory means for MgO (left plot) and Al_2O_3 (right plot) in the traceability materials NCS DC73306 and NCS DC28248 used during the study. Open diamond: concentrations from certificate of analysis. Dashed ellipse: 95% confidence ellipse based on z-scores, calculated in accordance with ISO standard 13528 (International Organization of Standardization 2005). Data from laboratories whose traceability material means lay outside the confidence ellipse were excluded during the calculation of assigned values for MTO RM ACR XRF.

---

[4] *For an infinite number of analyses, p, the number of degrees of freedom, df = p-1, also approaches infinity, and t_{p-1} → 1.96 for 95% confidence, but as the number of analyses decreases, t_p increases to 2.36 for 8 analyses (df = 7) and 4.3 for 3 analyses (df = 2). Because t increases rapidly with decreasing number of analyses, the spread in data for analytes characterized by only a few laboratories must be considerably smaller than that for a widely analyzed analyte if the final uncertainty is to be within an acceptable range.*

Characterization of MTO RM ACR XRF

UNCERTAINTIES

Table 27.1 presents the assigned concentrations, expanded uncertainties (*U*) and within- and between-laboratory standard deviations (σ_{within} and $\sigma_{between}$) obtained by this study for the MTO RM ACR XRF reference material. Although ISO Guide 35 (International Organization of Standardization 2006) identifies several components of variance that should be included in the uncertainties of all reference values for compliance with the "Guide to the expression of uncertainty in measurement" (in particular, material instability, u_{stabil}, analytical bias, u_{bias}, material heterogeneity, u_{matl}, and random measurement variability, u_{mean}), not all were applicable or could be independently constrained during the current study. Provided the material is dried to remove moisture before use, no compositional changes may be expected during protracted periods of storage and so the uncertainty due to material instability, u_{stabil}, can be assumed to be small relative to other components of variance. Similarly, because the material was characterized and is intended to be used for quality control by a single technique, the inclusion of an analytical bias component of variance, u_{bias}, was also deemed unnecessary. Because the fused disk preparation requires destruction of the material, it is not possible to partition the material heterogeneity component of variance, u_{matl}, from the component that originates from random measurement variability, u_{mean}, both of which will be reflected in the between-laboratory standard deviation estimated from the round-robin study. In the absence of significant stability and bias components, the uncertainties in the final values were therefore calculated from the combined effects of u_{matl} and u_{mean} alone, using the standard errors of the laboratory averages and t-factors appropriate for the number of sets analyses used.

ASSIGNMENT OF DATA QUALITY

According to the guidelines set out by ISO Guide 35 (International Organization of Standardization 2006) or the IAG Certification Protocol (Kane et al. 2003; Kane and Potts 2007), certification for an analyte requires at least 15 individual laboratory measurements or 10 results that originate from at least 2 different methods of analysis that are in agreement and should have a target unexpanded uncertainty of 0.33 H_a or better. Because only 11 laboratories participated in the current study, as few as 5 or 6 laboratory means remained after screening for bias and the analyses were all by a single method, none of the final values presented in Table 27.1 can be considered to be certified. Despite the close agreement between laboratories for many analytes, these values must be designated a lower status. When it comes to noncertified values, there is less rigour in the definition of terms. Hence, for the purposes of this study, the following designations were used:

- "Preferred" values:
  $n \geq 7$, $u/H_a < 0.33$ and $\sigma_{within\text{-}lab}/H_a < 0.66$
  Low overall uncertainty and within-laboratory reproducibility, based on a reasonable number of data sets.
- "Provisional" values:
  $n \geq 7$, $u/H_a < 0.66$ and $\sigma_{within\text{-}lab}/H_a < 0.66$
  Reasonable overall uncertainty and low within-laboratory reproducibility, based on a reasonable number of data sets.
  $n \geq 4 - 6$, $u/H_a < 0.33$ and $\sigma_{within\text{-}lab}/H_a < 0.66$
  Low overall uncertainty and within-laboratory reproducibility, but based on a limited number of data sets.
  $n \geq 7$, $u/H_a < 0.33$ (low overall uncertainty) and $\sigma_{within\text{-}lab}/H_a < 1.5$
  Low overall uncertainty but poor within-laboratory reproducibility, based on a reasonable number of data sets.

Table 27.1. Summary of data sets and assigned concentrations for MTO RM ACR XRF.

Analyte	Unit	Received	Number of Laboratory Means: Flagged for Bias†	Flagged for Uncertainty‡	Flagged as Outliers*	Accepted	Assigned Value	Within-Lab Standard Deviation	Between-Lab Standard Deviation	95% Confidence Limit
Preferred Values										
CaO	wt %	11	0	1	1	9	42.53	0.11	0.09	0.08
$Fe_2O_3^{Total}$	wt %	11	2	1	0	8	0.774	0.006	0.013	0.011
K_2O	wt %	11	1	1	0	9	0.692	0.007	0.003	0.003
MgO	wt %	11	0	1	0	10	6.25	0.02	0.06	0.04
SiO_2	wt %	11	1	1	0	9	6.98	0.03	0.06	0.05
LOI	wt %	11	0	2	1	8	40.23	0.03	0.12	0.10
Provisional Values										
Al_2O_3	wt %	11	5	0	0	6	2.003	0.012	0.013	0.015
Information Values										
MnO	wt %	11	4	0	0	7	0.027	0.003	0.003	0.003
Na_2O	wt %	10	4	1	0	5	0.070	0.006	0.011	0.014
P_2O_5	wt %	11	2	1	1	7	0.0197	0.0013	0.0002	0.0006
TiO_2	wt %	11	3	0	0	8	0.091	0.005	0.006	0.006
SO_3	wt %	9	2	1	0	6	0.359	0.011	0.037	0.040
SrO	wt %	10	3	1	0	6	0.054	0.002	0.005	0.005

*†Flagged using Youden ellipse. ‡Cochran test (α = 5%) *Grubbs's test (α = 5%).*

- "Indicative" values:
  $n \geq 4 - 6$, $u/H_a < 0.66$ and $\sigma_{within\text{-}lab}/H_a < 0.66$
  Reasonable overall uncertainty and low within-laboratory reproducibility, but based on a limited number of data sets.
  $n \geq 4 - 6$, $u/H_a < 0.33$ and $\sigma_{within\text{-}lab}/H_a < 1.5$
  Low overall uncertainty, but poor within-laboratory reproducibility and based on a limited number of data sets.
  $n \geq 7$, $u/H_a < 0.66$ (low overall uncertainty) and $\sigma_{within\text{-}lab}/H_a < 1.5$
  Reasonable overall uncertainty, but poor within-laboratory reproducibility, based on a reasonable number of data sets.
- "Information" values:
  $n \leq 3$, $u/H_a \geq 0.66$ and/or $\sigma_{within\text{-}lab}/H_a \geq 1.5$
  Consensus values based on a low number of laboratory means that exhibit a higher degree of overall uncertainty and/or show poor within-laboratory reproducibility.

Based on these designations, it was possible to assign preferred values to CaO, Fe_2O_3Total, K_2O, MgO, SiO_2 and LOI; a provisional value to Al_2O_3; and information values to MnO, Na_2O, P2O_5, TiO_2, SO_3 and SrO (Table 27.1).

SUMMARY

Through a round-robin study using commercial, government and academic laboratories, a robust, externally-verified consensus composition has been obtained by fused disk XRF for a new quality control material, MTO RM ACR XRF. This reference material will be used during the screening of rocks and aggregates for alkali-carbonate reactivity (ACR) by the LS-615 method, prior to their listing in the MTO Concrete Aggregate Sources List.

Based on the submitted data sets, it has been possible to assign preferred values (with low overall uncertainties and good within-laboratory reproducibilities) to 6 of the major element oxides, including CaO and MgO; a provisional value (based on a lower number of laboratory data but also with low overall uncertainties and good within-laboratory reproducibilities) to Al_2O_3; and information values to another 6 oxides. This allows for the necessary quality control on analyses required for the screening of materials based on the Al_2O_3 contents and CaO:MgO values.

Compared to the NIST reference materials previously used for quality control on aggregate analyses, MTO RM ACR XRF is not only more readily available but also a compositionally closer match to those of carbonate-rich rocks considered potentially expansive due to ACR. This makes MTO RM ACR XRF a more suitable and reliable reference material for the quality testing required for CASL listing.

Once characterization is complete, it is anticipated that MTO RM ACR XRF will be incorporated into future revisions of test method LS-615, as well as into MTO's CASL program requirements, possibly using MTO PH-CC forms, a series of documents used by the MTO for construction and contract administration purposes, to officially capture the submission of test results. Other future anticipated deliverables related to this project include a Miscellaneous Release of Data (MRD) that will include all raw data with statistical analysis, as well as the official established ranges for the new reference material for each of the major elements and LOI. It is intended that the stock of MTO RM ACR XRF finished product (series of 100 g bottles of the established reference standard) will be curated by and distributed to analytical laboratories by MTO free of charge to support quality testing.

ACKNOWLEDGMENTS

The authors would like to thank Matt Eles and Nathan Guitard at the Geoscience Laboratories for their work on the preparation and subsampling of MTO RM ACR XRF and the staff and analysts at Activation Laboratories Ltd. (Ancaster), AGAT Laboratories (Calgary), ALS Canada (Sudbury and North Vancouver), ALS Peru (Lima, Peru), Bureau Veritas Commodities Canada (Vancouver), Bureau Veritas Minerals Pty (Perth, WA), Geoscience Laboratories, Memorial University and the University of Ottawa for their work on sample analyses. The authors would also like to thank Eashwaar Mahibal, Sam Nichols, Ge Tao and Agamdeep Singh who assisted with sampling of the MTO RM ACR CA1 stockpile and the initial preparation stages in the MTO labs.

REFERENCES

Horwitz, W. and Albert, R. 1995. Precision in analytical measurements: Expected values and consequences in geochemical analyses; Fresenius' Journal of Analytical Chemistry, v.351, p.507-511.

Horwitz, W., Kamps, L.R. and Boyer, K.W. 1980. Quality assurance in the analysis of foods for trace constituents; Journal of the Association of Official Analytical Chemists, v.63, p.1344-1354.

International Organization of Standardization 2005 Statistical methods for use in proficiency testing by interlaboratory studies; International Organization of Standardization, Geneva, Switzerland, ISO Standard 13528, 66p.

——— 2006. Reference materials – General and statistical principles for certification, 3rd ed.; International Organization for Standardization, Geneva, Switzerland, ISO Guide 35, 64p.

Kane, J.S. and Potts, P.J. 2007. ISO best practices in reference material certification and use in geoanalysis; Geostandards and Geoanalytical Research, v.31, p.361-378.

Kane, J.S., Potts, P.J., Wiedenbeck, M., Carignan, J. and Wilson, S. 2003. International Association of Geoanalysts' protocol for the certification of geological and environmental reference materials; Geostandards Newsletter: The Journal of Geostandards and Geoanalysis, v.27, p.227-244.

MacDonald, C.A. and Jiang, Z. 2023. MTO reference materials for control, calibration and development of soil and aggregate test methods; paper and presentation *in* the Green Technology in Roadway/Embankment Materials and Geotechnical Engineering Session of the 2023 Conference of the Transportation Association of Canada, September 24–27, 2023, Ottawa, Ontario, 20p.

—— 2024. MTO AAR reference materials for control, calibration, test method development and research; Abstract, paper and presentation *in* 17th International Conference on Akali-Aggregate Reaction in Concrete, ICAAR 2024, Proceedings, v.1, , p.291-299.

Ontario Ministry of Transportation 2020. Laboratory testing manual; Materials Engineering and Research Office, Ontario Ministry of Transportation, Toronto, Ontario, Canada.

Rogers, C.A. 1985. Evaluation of the potential for expansion and cracking due to the alkali-carbonate reaction; Ontario Ministry of Transportation and Communications Engineering Materials Office, Report EM-75, 38p.

——— 1986. Evaluation of the potential for expansion and cracking due to the alkali-carbonate reaction; Cement Concrete and Aggregates, CCAGDP, v.8, no.1, , p.13-23.

Rogers, C. and MacDonald, C.A. 2011. The properties of Spratt, Sudbury and Pittsburg aggregate held by the Ontario Ministry of Transportation for calibration of tests for alkali-aggregate reactivity; abstract, paper and presentation *in* 14th International Conference on Alkali-Aggregate Reactions in Concrete (ICAAR), May 20–25, 2012, Austin, Texas, USA, 10p.

28. Summary of Quality Control Data for the Geoscience Laboratories Methods FEO-ION, IAW-200, IRC-100, IRW-H2O and TOC-100

J.C. Hargreaves[1]

[1]Geoscience Laboratories, Ontario Geological Survey

INTRODUCTION

This article summarizes the results of analyses for quality control samples for the Geoscience Laboratories' FEO-ION, IAW-200, IRC-100, IRW-H2O and TOC-100 test methods. The FEO-ION test method is the determination of ferrous iron by potentiometric titration after dissolution in a non-oxidizing acid mixture. The IAW-200 test method is the determination of major and trace element concentrations in fresh water samples by inductively coupled plasma atomic emission spectrometry (ICP–AES). The IRC--100 test method is the determination of total carbon (C, expressed as CO_2) and total sulphur (S) by infrared absorption after combustion in rocks, soils and sediments. The IRW-H2O test method is the determination of moisture and crystalline water in rocks and materials; moisture (H_2O^-) is driven off at 105°C and crystalline water (H_2O^+) at 1000°C, and each is measured by infrared absorption. The total organic carbon (TOC-100) test method determines non-purgeable organic carbon (NPOC) and total carbon (TC) in water samples by non-dispersive infrared detection following direct injection oxidative-combustion. The TOC-100 test method also provides an estimate of inorganic carbon (TIC) by subtraction of NPOC from TC.

The quality control data for the IAW-200, IRC-100, IRW-H2O and TOC-100 methods were summarized from September 13, 2019, to August 6, 2024, and capture results obtained since the last *Summary of Field Work and Other Activities* QC summary published in 2019 (Hargreaves 2019). Quality control results for the FEO-ION test method were summarized from January 20, 2022, to August 6, 2024, and capture results obtained by a new analyst and using new instrumentation.

ACKNOWLEDGMENTS

The author would like to thank Fareeda Amirault, Marcus Burnham, Brent Handford, Lizane Pamer and Tanya Rainville for their help in preparing this article.

REFERENCES

Burnham, O.M., Pallot, J., Priebe, E.H., Dell, K.M. and Hamilton, S.M. 2019. Characterization of new in-house groundwater quality-control materials: Results of a round-robin study; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.24-1 to 24-20.

Hargreaves, J.C. 2019. Summary of quality-control data for the Geoscience Laboratories methods FEO-ION, IAW-200, ICW-100, IRC-100, IRW-H2O and TOC-100; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.25-1 to 25-6.

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.28-1 to 28-7.

Table 28.1. Summary of results obtained by the FEO-ION test method for routine in-house and certified reference materials from January 20, 2022 to August 6, 2024.

Material	Provider	Description	FeO (wt %)
In-house Reference Materials			
LK-NIP-1	In-house	Diabase	10.09 ± 0.19 (12)
MRB-17	In-house	Nb-bearing Pegmatite	0.21 ± 0.04 (24)
MRB-29	In-house	Basalt	5.74 ± 0.13 (114)
ORCA-1	In-house	Rhyolite	2.11 ± 0.18 (23)
Certified Reference Materials			
FER-1	CANMET	Iron Formation	22.6 ± 0.9 (19)
Certificate			*23.34*
FER-3	CANMET	Iron Formation	13.5 ± 0.3 (50)
Certificate			*13.63*
MA-N	GIT-IWG	Granite	0.33 ± 0.06 (51)
*Certificate*ƚ			*0.31 ± 0.09*
MRG-1	CANMET	Augite-Olivine Gabbro	9.02 ± 0.06 (8)
Certificate			*8.63*
OKUM-1	IAG	Ultramafic Komatiite	8.74 ± 0.08 (7)
Certificate			*NA*
SY-3	CANMET	Syenite	3.68 ± 0.13 (28)
Certificate			*3.58*
SY-4	CANMET	Diorite Gneiss	2.83 ± 0.07 (20)
Certificate‡			*2.86 ± 0.09*
SY-5	CANMET	Syenite	5.643 ± 0.031 (3)
Certificate			*NA*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
ƚ Certificate value is average ± 1 standard deviation of the mean.
‡ Certificate value is average ± 95% confidence interval on the population mean.
Abbreviations: *CANMET = Canada Centre for Mineral and Energy Technology; GIT-IWG = Group International de Travail – International Working Group; IAG = International Association of Geoanalysts; NA = not available.*

Table 28.2. Summary of results obtained by the IAW-200 test method for routine in-house and certified reference materials from September 13, 2019 to August 6, 2024.

Material	Provider	Description	Al (ppb)	B (ppb)	Ba (ppb)	Be (ppb)	Ca (ppm)
In-house Reference Materials							
BLK-1-17	In-house	Groundwater	161 ± 10 (19)	1,936 ± 143 (19)	41.0 ± 2.3 (19)	<0.2 (19)	14.7 ± 0.6 (19)
Characterization			*169 ± 10***	*1,736 ± 92***	*40.7 ± 2.3***	*~0.023*	*15.79 ± 0.32***
BLK-2-17	In-house	Groundwater	204 ± 11 (16)	62 ± 6 (16)	46.7 ± 2.9 (16)	<0.2 (16)	171 ± 10 (16)
Characterization			*218 ± 12***	*55.2 ± 4.3***	*50.7 ± 3.0***	*~0.028*	*171.8 ± 3.8****
Certified Reference Materials							
HAMIL-20.2	ECCC	Lake Water	<3 (26)	53 ± 5 (26)	30.0 ± 2.3 (26)	<0.2 (26)	47.6 ± 1.7 (26)
Certificate‡			*NA*	*NA*	*NA*	*NA*	*46.2 ± 3.5*
MISSIPPI-14	ECCC	River Water	<3 (9)	19.9 ± 1.8 (9)	50.0 ± 0.7 (9)	<0.2 (9)	40.4 ± 1.3 (9)
Certificate‡			*NA*	*20 ± 2*	*NA*	*NA*	*39.1 ± 3.3*
TMDA-51.5	ECCC	Lake Water	103 ± 6 (35)	47 ± 4 (35)	75 ± 4 (35)	10.5 ± 0.4 (35)	21.5 ± 0.8 (35)
Certificate‡			*104 ± 10*	*47.2 ± 5.1*	*72.4 ± 4.4*	*10.0 ± 0.9*	*NA*

Material	Provider	Description	Cd (ppb)	Cl (ppm)	Co (ppb)	Cr (ppb)	Cu (ppb)
In-house Reference Materials							
BLK-1-17	In-house	Groundwater	<1 (12)	226 ± 17 (19)	<3 (19)	<3 (19)	26.2 ± 2.5 (19)
Characterization			*0.181 ± 0.015**	*227.5 ± 2.9***	*0.439 ± 0.016**	*~0.24*	*25.75 ± 0.78**
BLK-2-17	In-house	Groundwater	<1 (9)	6.8 ± 1.8 (16)	<3 (16)	<3 (16)	<3 (16)
Characterization			*0.0211 ± 0.0042****	*~5.78*	*~0.05*	*~0.148*	*2.95 ± 0.53***
Certified Reference Materials							
HAMIL-20.2	ECCC	Lake Water	<1 (12)	74 ± 6 (26)	<3 (16)	<3 (26)	<3 (26)
Certificate‡			*NA*	*71.7 ± 3.3*	*NA*	*NA*	*NA*
MISSIPPI-14	ECCC	River Water	<1 (9)	15.8 ± 0.5 (9)	<3 (9)	<3 (9)	<3 (9)
Certificate‡			*NA*	*15.9 ± 0.8*	*NA*	*NA*	*NA*
TMDA-51.5	ECCC	Lake Water	25.9 ± 1.6 (21)	18.2 ± 1.9 (35)	70 ± 3 (35)	68 ± 4 (35)	80 ± 7 (35)
Certificate‡			*25.7 ± 1.7*	*NA*	*68.6 ± 4.8*	*65.1 ± 4.5*	*77.6 ± 5.5*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
Characterization values for BLK-1-17 and BLK-2-17 given as mean ± expanded standard uncertainty (Burnham et al. 2019).
**Provisional; **Indicative; ***Information.*
‡Certificate value is average ± 95% confidence interval on the population mean.
Abbreviations: *ECCC = Environment and Climate Change Canada; NA = not available.*

Table 28.2, *continued.*

Material	Provider	Description	Fe (ppb)	K (ppm)	Li (ppb)	Mg (ppm)	Mn (ppb)
In-house Reference Materials							
BLK-1-17	In-house	Groundwater	89 ± 5 (19)	2.39 ± 0.12 (19)	56 ± 5 (19)	6.20 ± 0.19 (19)	239 ± 13 (19)
Characterization			*94.2 ± 6.2***	*2.56 ± 0.11***	*55.3 ± 1.7**	*5.89 ± 0.31***	*227.5 ± 6.3**
BLK-2-17	In-house	Groundwater	153 ± 6 (16)	0.91 ± 0.08 (16)	6 ± 4 (16)	50 ± 4 (16)	4.6 ± 0.6 (16)
Characterization			*164.8 ± 9.6****	*0.919 ± 0.047***	*5.03 ± 0.22**	*~53.4*	*4.99 ± 0.23**
Certified Reference Materials							
HAMIL-20.2	ECCC	Lake Water	<2 (26)	4.10 ± 0.26 (26)	<6 (26)	12.6 ± 0.7 (26)	<0.4 (26)
*Certificate*ǂ			*NA*	*3.98 ± 0.33*	*NA*	*12.7 ± 1.0*	*NA*
MISSIPPI-14	ECCC	River Water	17 ± 4 (9)	2.49 ± 0.06 (9)	<6 (9)	12.39 ± 0.30 (9)	<0.4 (9)
*Certificate*ǂ			*NA*	*2.49 ± 0.20*	*NA*	*12.6 ± 1.0*	*NA*
TMDA-51.5	ECCC	Lake Water	108 ± 5 (35)	1.08 ± 0.11 (35)	19 ± 4 (35)	5.59 ± 0.16 (35)	80 ± 4 (35)
*Certificate*ǂ			*108 ± 11*	*NA*	*19.3 ± 2.1*	*NA*	*78.7 ± 4.5*

Material	Provider	Description	Mo (ppb)	Na (ppm)	Ni (ppb)	P (ppb)	Pb (ppb)
In-house Reference Materials							
BLK-1-17	In-house	Groundwater	5.4 ± 0.8 (12)	229 ± 8 (19)	<8.4 (19)	13 ± 7 (19)	<20 (19)
Characterization			*5.67 ± 0.36***	*224.5 ± 5.0***	*1.064 ± 0.096***	*NA*	*0.45 ± 0.11****
BLK-2-17	In-house	Groundwater	4.3 ± 1.5 (9)	8.7 ± 0.4 (16)	<8.4 (16)	<13 (16)	<20 (16)
Characterization			*3.569 ± 0.066**	*8.56 ± 0.39***	*1.12 ± 0.12****	*NA*	*0.237 ± 0.058****
Certified Reference Materials							
HAMIL-20.2	ECCC	Lake Water	<4 (12)	44.1 ± 2.0 (26)	<8.4 (26)	21 ± 5 (26)	<20 (26)
Certificate			*NA*	*42.3 ± 3.4*	*NA*	*NA*	*NA*
MISSIPPI-14	ECCC	River Water	<4 (9)	7.67 ± 0.15 (9)	<8.4 (9)	49 ± 7 (9)	<20 (9)
Certificate			*NA*	*7.79 ± 0.64*	*NA*	*NA*	*NA*
TMDA-51.5	ECCC	Lake Water	54.3 ± 2.9 (21)	9.9 ± 0.5 (35)	70 ± 5 (35)	<13	64 ± 6 (35)
Certificate			*55.0 ± 4.5*	*NA*	*65.5 ± 4.3*	*NA*	*63.7 ± 5.7*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
Characterization values for BLK-1-17 and BLK-2-17 given as mean ± expanded standard uncertainty (Burnham et al. 2019).
**Provisional; **Indicative; ***Information.*
ǂCertificate value is average ± 95% confidence interval on the population mean.
Abbreviations: *ECCC = Environment and Climate Change Canada; NA = not available.*

Table 28.2, *continued.*

Material	Provider	Description	S (ppm)	Si (ppm)	Sr (ppb)	Ti (ppb)	V (ppb)
In-house Reference Materials							
BLK-1-17	In-house	Groundwater	21.7 ± 1.0 (19)	3.83 ± 0.22 (19)	580 ± 22 (19)	4.3 ± 0.4 (19)	<4 (19)
Characterization			*NA*	*~3680*	*605 ± 13**	*5.27 ± 0.86****	*~0.4*
BLK-2-17	In-house	Groundwater	124 ± 5 (16)	4.54 ± 0.29 (16)	12,210 ± 650 (16)	14.9 ± 1.1 (16)	<4 (16)
Characterization			*NA*	*~4.346*	*12,986 ± 282***	*16.05 ± 0.74**	*0.367 ± 0.025**
Certified Reference Materials							
HAMIL-20.2	ECCC	Lake Water	15.3 ± 0.7 (26)	0.90 ± 0.07 (26)	404 ± 19 (26)	<1 (26)	<4 (26)
*Certificate*ǂ			*NA*	*0.883 ± 0.080*	*NA*	*NA*	*NA*
MISSIPPI-14	ECCC	River Water	6.52 ± 0.07 (9)	2.87 ± 0.04 (9)	82.8 ± 1.7 (9)	<1 (9)	<4 (9)
*Certificate*ǂ			*NA*	*NA*	*NA*	*NA*	*NA*
TMDA-51.5	ECCC	Lake Water	5.65 ± 0.26 (35)	0.265 ± 0.024 (35)	121 ± 6 (35)	14.0 ± 0.6 (35)	46.5 ± 2.9 (35)
*Certificate*ǂ			*NA*	*NA*	*118 ± 7*	*14.0 ± 0.9*	*46.4 ± 3.4*

Material	Provider	Description	Zn (ppb)
In-house Reference Materials			
BLK-1-17	In-house	Groundwater	6.8 ± 1.2 (19)
Characterization			*8.10 ± 0.44**
BLK-2-17	In-house	Groundwater	50.7 ± 2.8 (16)
Characterization			*49.2 ± 2.2***
Certified Reference Materials			
HAMIL-20.2	ECCC	Lake Water	5.6 ± 0.9 (26)
*Certificate*ǂ			*NA*
MISSIPPI-14	ECCC	River Water	5.7 ± 1.8 (9)
*Certificate*ǂ			*NA*
TMDA-51.5	ECCC	Lake Water	146 ± 8 (35)
*Certificate*ǂ			*140 ± 13*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
Characterization values for BLK-1-17 and BLK-2-17 given as mean ± expanded standard uncertainty (Burnham et al. 2019).
**Provisional; **Indicative; ***Information; ~Approximate value.*
ǂCertificate value is average ± 95% confidence interval on the population mean.
Abbreviations: *ECCC = Environment and Climate Change Canada; NA = not available.*

Table 28.3. Summary of results obtained by the IRC-100 test method for routine in-house and certified reference materials from September 13, 2019 to August 6, 2024. Values in weight %, total C expressed as CO_2. Where necessary, CO_2 values have been converted from certificate C_{TOT} values.

Material	Provider	Description	CO_2 (wt %)	S (wt %)
In-house Reference Materials				
LK-NIP-1	In-house	Diabase	0.080 ± 0.021 (37)	0.0242 ± 0.0031 (37)
MRB-11	In-house	Carbonated Ultramafic	20.0 ± 0.5 (302)	0.092 ± 0.012 (302)
MRB-29	In-house	Basalt	0.592 ± 0.016 (335)	0.0120 ± 0.0028 (335)
MRB-32	In-house	Peridotite	1.47 ± 0.06 (10)	1.48 ± 0.06 (10)
NPD-1	In-house	Diabase	0.196 ± 0.013 (6)	0.123 ± 0.021 (6)
ODL-1	In-house	Dolomitic Limestone	38 ± 4 (62)	0.2 ± 0.6 (62)
QS-1	In-house	Calcareous Shale	6.71 ± 0.17 (4)	0.012 ± 0.014 (4)
Certified Reference Materials				
CCU-1b	CANMET	Cu Flotation Concentrate	0.262 ± 0.016 (24)	35.0 ± 0.6 (24)
*Certificate*ǂ			*0.12 ± 0.014**	*34.8 ± 0.2*
CCU-1e	CANMET	Cu Concentrate	0.364 ± 0.014 (4)	38.5 ± 2.0 (4)
*Certificate*ǂ			*0.367 ± 0.029*	*35.28 ± 0.20*
FER-4	CANMET	Iron Formation	4.93 ± 0.11 (93)	0.2 ± 0.7 (93)
Certificate			*4.86*	*0.11*
JDo-1	GSJ	Dolomite	45.9 ± 0.6 (27)	<0.0012 (27)
Certificate			*46.75*	*0.009*
KC-1a	CANMET	Zn-Pb-Sn-Ag Ore	0.247 ± 0.020 (9)	26.4 ± 0.6 (9)
Certificate			*0.02**	*27.5**
MP-1b	CANMET	Zn-Sn-Cu-Pb Ore	0.114 ± 0.028 (32)	14.3 ± 0.4 (32)
*Certificate*ǂ			*0.028**	*13.79 ±0.25*
OKUM-1	IAG	Ultramafic Komatiite	0.4 ± 1.2 (17)	0.3 ± 1.2 (17)
Certificate			*NA*	*NA*
OREAS 600	ORE	Ag-Cu-Au Ore	1.79 ± 0.04 (194)	1.69 ± 0.04 (194)
Certificate⸸			*0.488***	*1.67 ± 0.040*
PR-1	CANMET	Mo Ore	1.063 ± 0.015 (56)	0.779 ± 0.015 (56)
Certificate			*1.08**	*0.793**
SU-1a	CANMET	Ni-Cu-Co Ore	0.154 ± 0.025 (23)	9.73 ± 0.23 (23)
Certificate			*NA*	*10.0**
TLS-1	CANMET	Unoxidized Tailings	0.387 ± 0.013 (21)	1.92 ± 0.10 (21)
*Certificate*ǂ			*NA*	*1.81 ± 0.03*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
ǂ*Certificate value is average ± 95% confidence interval on the population mean.*
⸸*Certificate value is average ± 1 standard deviation of the mean.*
**Provisional value; **Indicative value.*
Abbreviations: *CANMET = Canada Centre for Mineral and Energy Technology; GSJ = Geological Survey of Japan; IAG = International Association of Geoanalysts; NA = not available; OREAS = Ore Research and Exploration Pty Ltd.*

Table 28.4. Summary of results obtained by the IRW-H2O test method for routine in-house and certified reference materials from September 13, 2019 to August 6, 2024. Values reported in weight % as free moisture (H_2O^-) and crystalline moisture (H_2O^+).

Material	Provider	Description	H_2O^- (wt %)	H_2O^+ (wt %)
In-house Reference Materials				
MRB-9	In-house	Felsic Volcanic	0.18 ± 0.07 (18)	0.79 ± 0.14 (18)
MRB-12	In-house	Altered Diabase	0.52 ± 0.21 (44)	4.9 ± 0.3 (44)
Certified Reference Materials				
BX-N	GIT-IWG	Bauxite	0.47 ± 0.16 (5)	11.2 ± 0.8 (5)
Certificateǂ			*0.44 ± 0.09*	*11.48 ± 0.22*
GL-O	GIT-IWG	Glauconite	1.8 ± 0.9 (12)	5.1 ± 0.5 (12)
Certificateǂ			*2.52 ± 0.21*	*5.58 ± 0.28*
JB-1b	GSJ	Basalt	0.97 ± 0.25 (34)	1.75 ± 0.21 (34)
Certificate			*1.06*	*1.53*
SARM-4	MINTEK	Norite	0.14 ± 0.08 (14)	0.32 ± 0.06 (14)
Certificate			*NA*	*0.33*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
ǂCertificate value is average ± 1 standard deviation of the mean.
Abbreviations: *GSJ = Geological Survey of Japan; GIT-IWG = Group International de Travail – International Working Group; MINTEK = Council for Mineral Technology, South Africa; NA = not available.*

Table 28.5. Summary of results obtained by the TOC-100 test method for routine in-house and certified reference materials from September 13, 2019 to August 6, 2024. Values reported in ppm as total organic carbon or non-purgeable organic carbon (NPOC), total carbon (TC) and total inorganic carbon (TIC).

Material	Provider	Description	NPOC (ppm)	TC (ppm)	TIC (ppm)
In-house Reference Materials					
BLK-1-17	In-house	Groundwater	0.9 ± 0.9 (53)	41.0 ± 1.8 (53)	40.1 ± 1.7 (53)
BLK-2-17	In-house	Groundwater	0.4 ± 0.5 (53)	32.1 ± 6.2 (53)	31.6 ± 5.9 (53)
Certified Reference Materials					
HAMIL-20.2	ECCC	Lake water	3.11 ± 0.20 (31)	28.6 ± 0.9 (31)	25.6 ± 1.0 (31)
Certificate			*3.00 ± 0.59*	*NA*	*25.9 ± 3.3*
ION-96.4	ECCC	River water	5.0 ± 0.6 (11)	60.6 ± 2.1 (11)	56.0 ± 2.8 (11)
Certificate			*4.67 ± 0.73*	*NA*	*57.3 ± 6.4*
MISSIPPI-14	ECCC	River water	7.2 ± 0.6 (9)	33.0 ± 1.7 (9)	26.6 ± 3.1 (9)
Certificate			*NA*	*NA*	*26.8 ± 3.9*

Notes: *Compiled data given as mean ± 1 standard deviation of results (number of measurements).*
Certificate values are average ± 2 standard deviation of the mean.
Abbreviations: *ECCC = Environment and Climate Change Canada; NA: data not available.*

This page left blank intentionally

Resident Geologist Program

29. Characterizing the Geochemistry and Nickel-Copper-Platinum Group Element Potential of Mafic and Ultramafic Intrusions in Northwestern Ontario: An Update

J.R.B. Jonsson[1], P.M. Malegus[1], S.V. Churchley[1] and R.L. Price[1]

[1]Resident Geologist Program, Ontario Geological Survey

INTRODUCTION

Mafic and ultramafic intrusive rocks are the characteristic host to magmatic sulphide deposits, which contain globally significant resources of nickel, copper, cobalt and platinum-group elements (PGE). An important component of exploring for these deposits is to understand the chemistry and magmatic history of mafic-ultramafic intrusions in a target area. Many mafic-ultramafic intrusions in Ontario have characteristics that make them good magmatic sulphide exploration targets (e.g., geophysical anomalies, overburden geochemical anomalies), but have seen little to no exploration for this deposit type. For many of these intrusions, publicly available geochemical data is either nonexistent or exists only in the form of assays for economically significant metals.

This project was initiated in 2023 by staff of the Resident Geologist Program offices in the Thunder Bay South, Thunder Bay North and Red Lake districts to provide a publicly available data set to aid in evaluation of the mineral exploration prospectivity of mafic-ultramafic intrusions in these 3 Resident Geologist districts (Jonsson et al. 2023). This article provides a project update and partial preliminary interpretations from field work done to date.

SAMPLED AREAS

Locations of samples collected to date are shown in Figure 29.1. Areas sampled include the Red Lake, Birch–Uchi, McInnes Lake and Ponask greenstone belts (Red Lake District; 94 samples taken to date); granitoid- and/or paragneiss-dominated areas near the Saganagons, Garden Lake and Graham greenstone belts (Thunder Bay South District; 46 samples taken to date); and the Onaman–Tashota greenstone belt (Thunder Bay North District; 23 samples taken to date). Sampling of the Onaman–Tashota and Red Lake greenstone belts was described in Jonsson et al. (2023). Laboratory results are pending for many of these samples; of the 163 samples, full geochemical results have been received for 66.

Red Lake Greenstone Belt – Trout Bay Assemblage

Sampling in the Trout Bay assemblage in the Red Lake area focussed on mineralized intrusions that lack systematic historical exploration (Jonsson et al. 2023). These intrusions are hosted in metavolcanic and metasedimentary rocks of the Lower Sequence of the Trout Bay assemblage yet are geochemically

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.29-1 to 29-9.

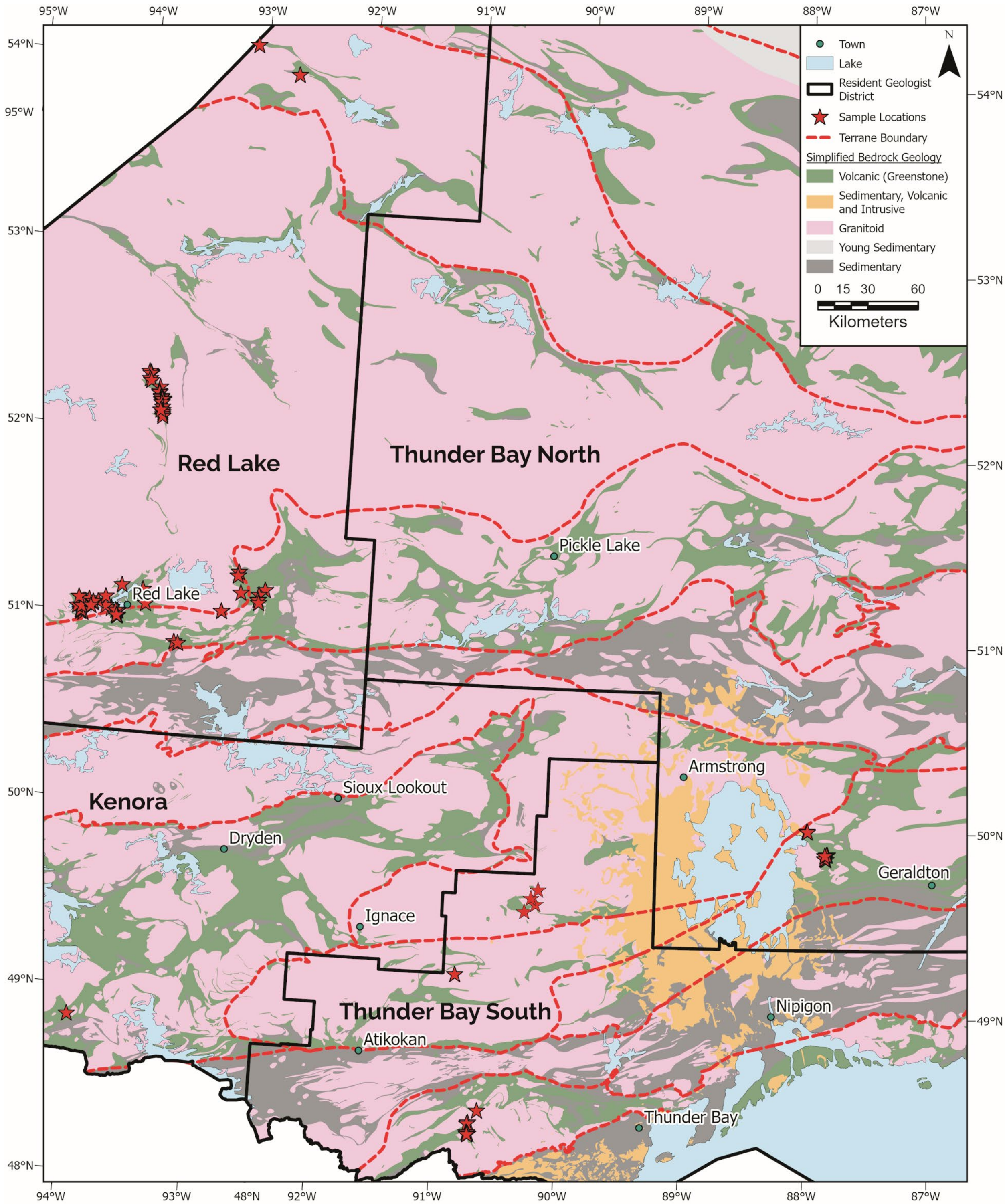


Figure 29.1. Generalized bedrock geology with 2023 and 2024 sample locations shown as red stars. Geology *modified from* Ontario Geological Survey (2011).

similar to the light rare earth element (LREE)-depleted metabasalts of the Upper Sequence of the Trout Bay assemblage (Sanborn-Barrie, Skulski and Parker 2001). Trace element profiles in samples taken for this study (flat to depleted LREE profiles, incompatible trace element abundances approximately 2 to 5 times primitive mantle values) are consistent with the interpretation that the intrusions hosted in the Trout Bay assemblage had a tholeiitic parent magma derived from a depleted mantle source (Sanborn-Barrie, Skulski and Parker 2001).

Significant results include sample 2023PM025 (1188 ppm Ni, 1317 ppm Cu, 90 ppm Co) and sample 2023PM024 (2833 ppm Ni, 3507 ppm Cu, 174 ppm Co, 515.29 ppb Pd, 110.74 ppb Pt, 49.5 ppb Au). Sample 2023PM024 is from the Trout Bay #1 Ni Zone (Ontario Mineral Inventory (OMI) file # MDI52L16NE00029; Ontario Geological Survey 2024). In general, our data show that platinum group element (PGE) enrichment in the Trout Bay assemblage correlates well with nickel content. Preliminary mineralogical work on sample 2023PM024 identified potential ore minerals including pyrrhotite, pentlandite, chalcopyrite, ilmenite and kotulskite (Pd(Te, Bi)) (Photo 29.1). Additional analytical work is planned to determine the chemistry of these minerals and the possible role of hydrothermal remobilization.

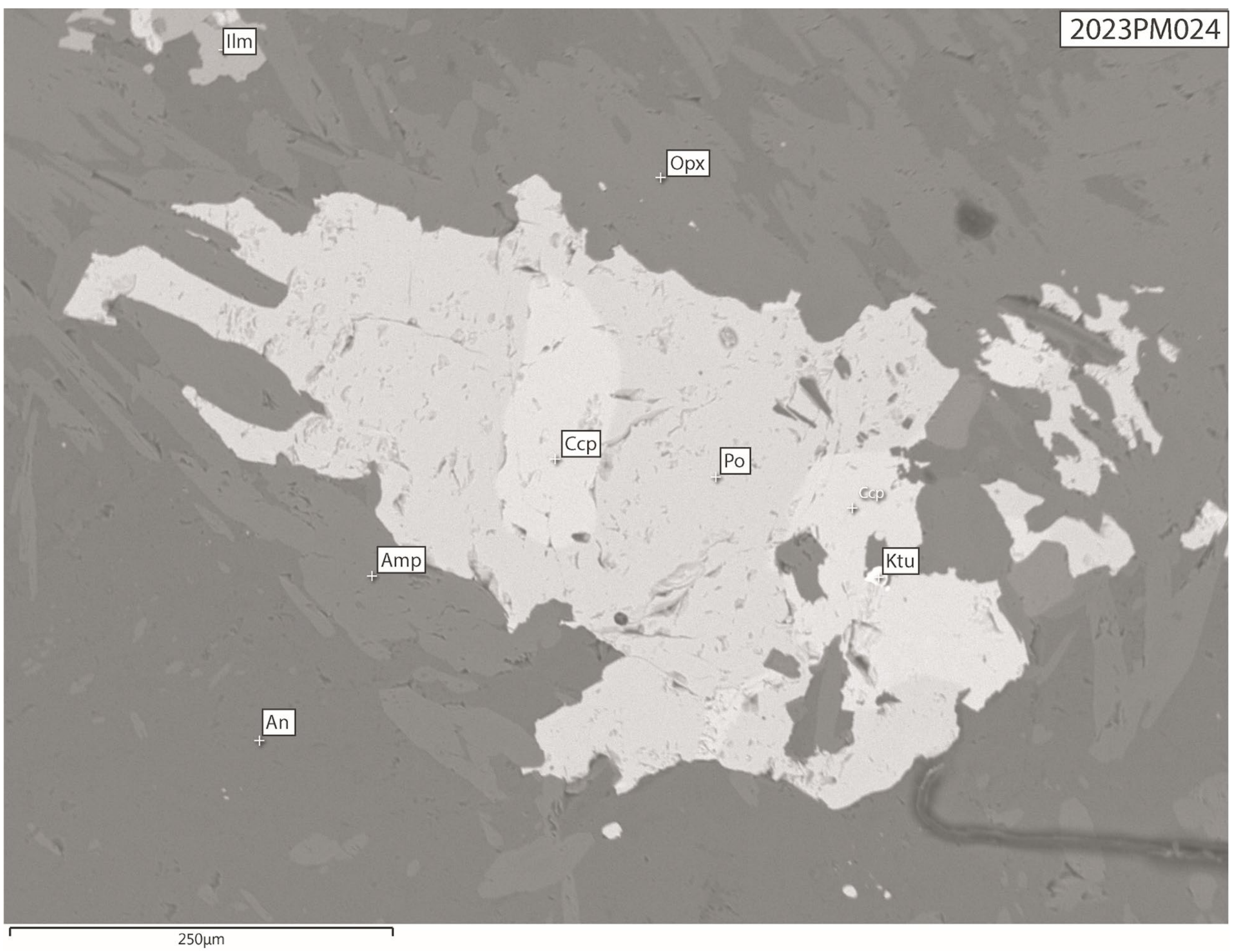


Photo 29.1. Backscattered electron image of polysulfide bleb and kotulskite crystal. Abbreviations: Ilm = ilmenite, Opx = orthopyroxene, An = anorthite, Amp = amphibole, Ccp = chalcopyrite, Po = pyrrhotite, Ktu = kotulskite. Image provided by T.E. Gore, Ontario Geological Survey, Geoscience Laboratories.

Birch–Uchi Greenstone Belt

Several mafic-ultramafic intrusions in the Birch–Uchi greenstone belt in the Red Lake District have mineral exploration potential but lack published whole-rock geochemistry. Intrusions sampled for this project in the Birch–Uchi greenstone belt included the Joyce River gabbro (OMI file # MDI000000001334, Ontario Geological Survey 2024), a pyroxene cumulate intrusion at the Bathurst Mine property (OMI file # MDI52N07SW00003, Ontario Geological Survey 2024), and unnamed intrusions adjacent to Confederation Lake.

The Joyce River gabbro is host to both disseminated and massive sulphide mineralization, with historically reported results of up to 10.58 weight % copper in grab samples (Frank 2008). The host rock to the intrusion is a magnetite-facies iron formation, which may have acted as a source of sulphur and/or silica contamination to trigger magmatic sulphide saturation. The massive sulphide zones are pyrite–pyrrhotite-dominated and contain trace chalcopyrite, whereas samples within the disseminated sulphide zones are comparatively chalcopyrite rich. Relatively sulphide-rich and sulphide-poor samples contain comparable cobalt, nickel and PGE tenors, with PGE content being consistently low in all samples. Economically interesting quantities of cobalt and nickel (up to 603 ppm Co and up to 950 ppm Ni) are reported from 1 massive sulphide sample taken as part of this project.

McInnes Lake Greenstone Belt

The McInnes Lake greenstone belt in the Red Lake District was selected for sampling because of the presence of relatively unexplored mineralized intrusions and recent detailed mapping in the area (Préfontaine and Mumford 2007a, 2007b). Sampling was completed throughout the greenstone belt, focussing on sites (Figure 29.2) not included in the geochemical compilation released in association with the mapping project (Préfontaine and Buse 2007).

There are several nickel occurrences associated with mafic intrusions throughout the greenstone belt that have had very little exploration work completed (for instance McInnes Lake Nickel 1, 2 and 3; OMI file # MDI53C04NE00005, MDI53C04NE00006 and MDI53C05SW00001, respectively, Ontario Geological Survey 2024). Geochemical results for samples from the McInnes Lake greenstone belt are pending.

Ponask Greenstone Belt

The planned target locations in the Ponask greenstone belt proved to be inaccessible; nonetheless, a few "opportunistic" samples of poorly exposed mafic intrusions were obtained from sites that had previously been mapped as tonalite and/or mafic metavolcanic rocks. Geochemical results were not available at the time of writing.

Saganagons Area

A series of posttectonic mafic to ultramafic intrusions in the area east of the Saganagons greenstone belt between Mowe and Northern Light lakes in the Thunder Bay South District were sampled (*see* Figure 29.1). Ubiquitous greenschist-facies alteration strongly suggests that the intrusions are Archean and are not related to the Proterozoic Midcontinent Rift. The host units to the intrusions are the Saganaga tonalite (*circa* 2689 Ma; Corfu and Stott 1988) and the Northern Light gneiss (*circa* 2690 Ma metamorphic age on titanite; Corfu and Stott 1998). Thus, the mafic to ultramafic intrusions are likely younger than 2692 Ma, accounting for analytical error. These age relationships allow for the possibility that the intrusions are coeval with the felsic Tower Lake stock (2690±3 Ma, Corfu and Stott 1998) that intruded the Shebandowan assemblage of the Shebandowan greenstone belt, which is thought to be a continuation of the Saganagons greenstone belt (Corfu and Stott 1998).

The largest of these mafic-ultramafic intrusions is the Big Ghee Lake intrusion (new name), which is approximately 1.5 by 2.5 km in size. The intrusion is a heterogenous mafic-ultramafic cumulate, intensely altered to a chlorite-amphibole assemblage but the intrusion itself is not strongly deformed (Photos 29.2A and 29.2B). Moderate enrichment in PGEs is present locally in the intrusion: 2 samples yielded values of 43.01 and 73.96 ppb Pt+Pd, respectively. Both samples contained less than 0.02 weight % sulphur, whereas more sulphur-rich samples (>0.02 wt %) (*see* Photo 29.2B) contained negligible PGE contents (below or near the detection limit of 0.22 ppb Pt+Pd). This may indicate that the PGEs have been hydrothermally mobilized, or alternatively, that the intrusion was formed by separate pulses of PGE-enriched and PGE-depleted magma. Incompatible element content in the Big Ghee Lake intrusion does not vary with PGE content and a consistent enrichment in large ion lithophile elements and depletion of high field strength elements suggest a crustal component to the magma.

Weaver Lake Area

Sampling was completed in the Weaver Lake area, on the north and south sides of the interpreted western extent of the Garden Lake greenstone belt. This area has not been subject to detailed geological mapping or exploration because of the wide extent of glacial till cover. The area contains unexplained

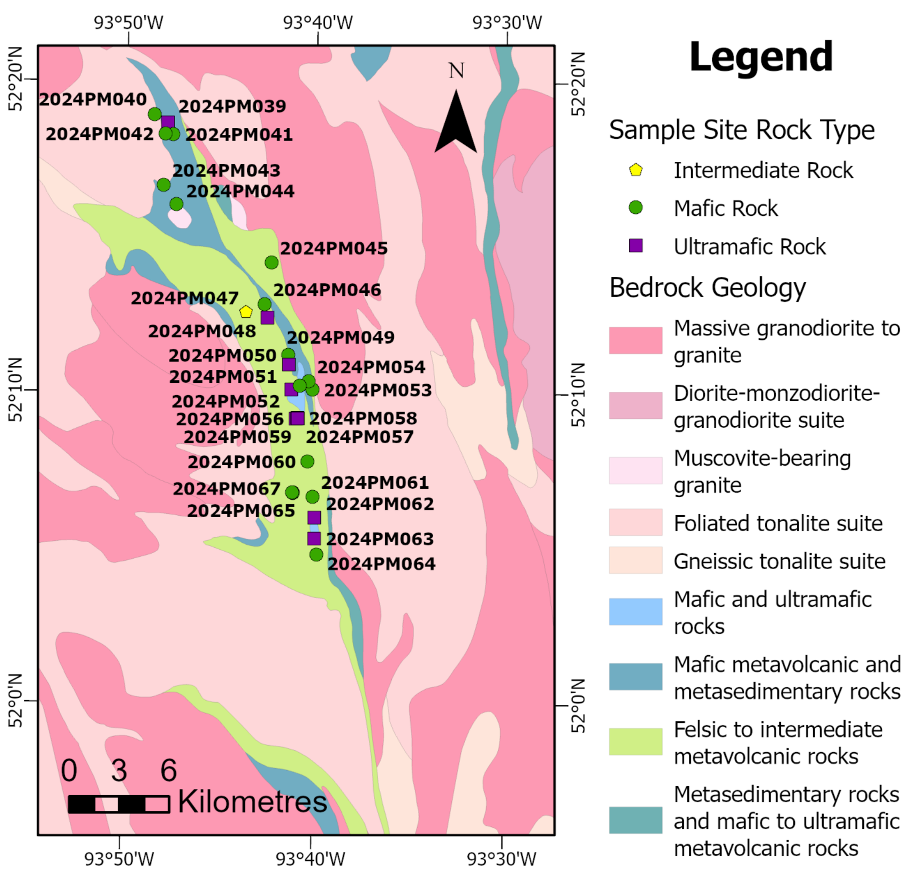


Figure 29.2. Sample locations in the McInnes Lake greenstone belt. Geology *from* Ontario Geological Survey (2011).

Photo 29.2. Photographs of the Big Ghee Lake intrusion, Saganagons area. **A)** Altered pyroxene cumulate that has brecciated the granitic host rock (UTM 670079E 5355735N). **B)** Pegmatitic gabbro patch (UTM 669786E 5356815N). UTM coordinates provided using NAD83 in Zone 15. Hammer in Photo 29.2A is 45 cm long. Marker in Photo 29.2B is 14 cm long.

airborne magnetic anomalies and 1 reported sample of an Archean mafic intrusion containing 188.85 ppb Pt+Pd (Stone 2010). Part of the area is interpreted to be underlain by mafic metavolcanic rocks (Ontario Geological Survey 2011), but the distribution of these rocks is equivocal because bedrock exposure is very poor.

Because these sampled intrusions are located adjacent to the Garden Lake greenstone belt, we compared these results to existing data for mafic-ultramafic intrusions in this belt. The chemistry of mafic intrusive rocks sampled in the Weaver Lake area differs from the 4 samples of Archean mafic-ultramafic intrusions from the eastern part the Garden Lake greenstone belt reported by Hart (2000). Samples from the Weaver Lake area have a more evolved signature, including higher iron content, lower magnesium content, and more fractionated rare earth element patterns (Figure 29.3) than the results from Hart (2000). At a location exposed along the Getz logging road (NAD83 15U 700353E 5498465N[2]), a contact between an intrusion and its host rock (paragneiss) is sulphide mineralized (Photos 29.3A and 29.3B). Copper content at this location is slightly elevated (up to 793 ppm), nickel and gold content are unenriched and PGE content is depleted. Follow-up sampling of intrusions in both the Garden Lake greenstone belt and the areas to the west and east are planned to better constrain the geochemical characteristics and mineral potential of these intrusions.

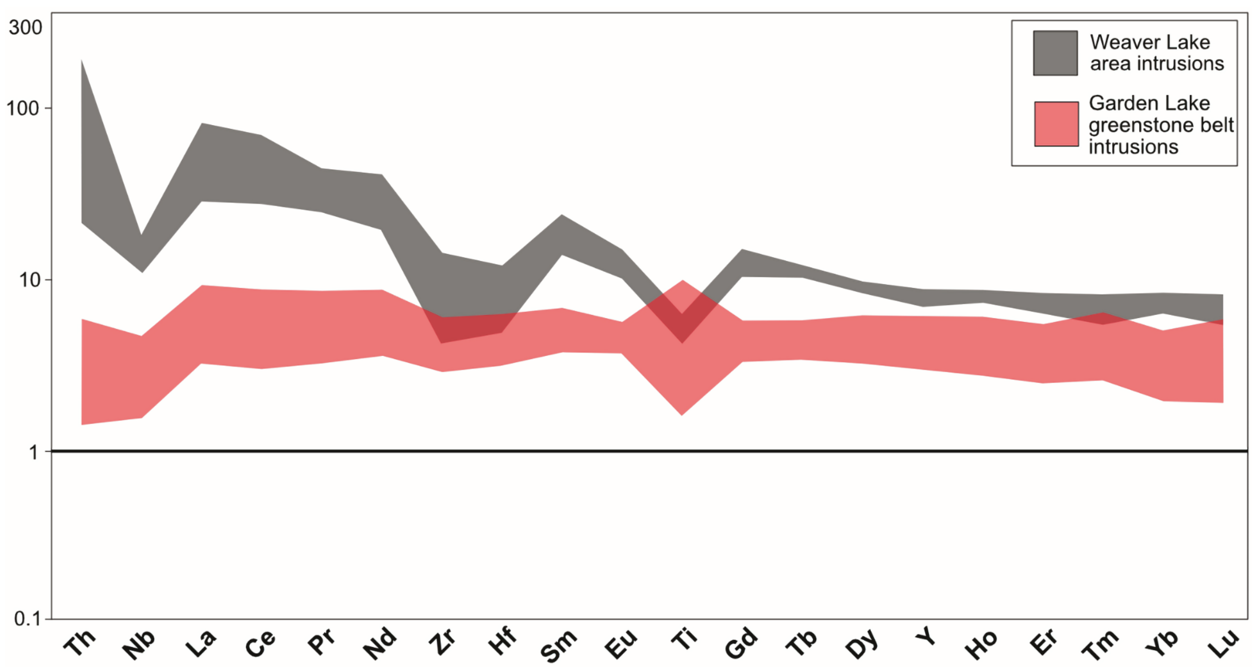


Figure 29.3. Primitive mantle-normalized element diagram for samples of mafic-ultramafic intrusions from the Weaver Lake area (new data) and the Garden Lake greenstone belt (Hart 2000). Normalizing values from Sun and McDonough (1989). Y-axis is logarithmic and shows normalized element contents in parts per million.

[2] *Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 15.*

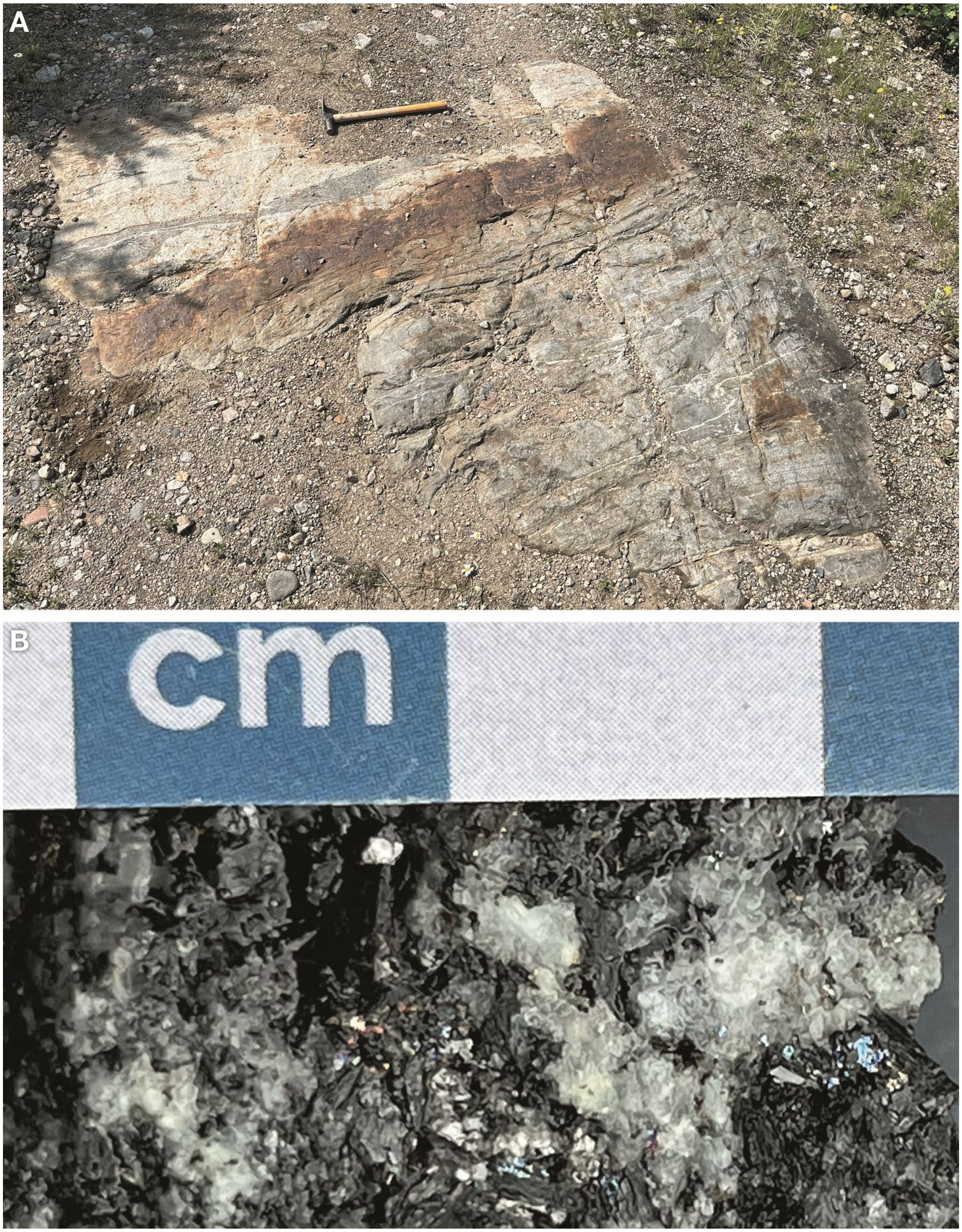


Photo 29.3. Photographs of an unnamed intrusion, near Weaver Lake, exposed on the Getz logging road. **A)** Oxidized sulphide mineralization (rusty area near hammer) in intrusive rock (upper left portion of outcrop) at the contact with a paragneiss host rock (bottom right portion of outcrop). **B)** Fresh surface of the rusty zone in Photo 29.3A showing disseminated copper sulphide mineralization (bornite or tarnished chalcopyrite). Both photos are from an outcrop located at 700353E 5498465N, NAD83 Zone 15. Hammer handle in Photo 29.3A is 64 cm long; scale card in Photo 29.3B is marked in centimetres.

ACKNOWLEDGMENTS

Robert Cundari and Mark Puumala are thanked for their support and assistance in conceptualizing this project. Marcus Burnham is acknowledged for his assistance in the selection of analytical methods, and Thomas Gore is thanked for his scanning electron microscopy work. Dorothy Campbell, Therese Pettigrew and Greg Paju are recognized for helpful geological discussions and advice in selecting targets. Colleen Kurcinka, Anthony Mitchell and Callie Kok are thanked for their support in the field. Michael Easton and Manuel Duguet are thanked for technical reviews that improved this article.

REFERENCES

Corfu, F. and Stott, G.M. 1998. Shebandowan greenstone belt, western Superior Province: U-Pb ages, tectonic implications, and correlations; Geological Society of America, Bulletin, v.110, no.11, p.1467-1484.

Frank, R.A. 2008. Prospecting report on the Raymond Frank prospect, Joyce River Township, Claim 3009732; unpublished report, Red Lake Resident Geologist's office, assessment file AFRI# 20000002938, 11p.

Hart, T.R. 2000. Precambrian geology, Garden Lake area; Ontario Geological Survey, Open File Report 6037, 81p.

Jonsson, J.R.B., Malegus, P.M., Churchley, S.V. and Price, R.L. 2023. Characterizing the geochemistry and Ni-Cu-PGE potential of mafic and ultramafic intrusions in northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023; Ontario Geological Survey, Open File Report 6405, p.38-1 to 38-6.

Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

——— 2024. Ontario Mineral Inventory; Ontario Geological Survey, online database, September 2024 update, www.hub.geologyontario.mines.gov.on.ca. [accessed October 13, 2024]

Préfontaine, S. and Buse, S. 2007. Geological, geochemical and geochronological data from the McInnes Lake greenstone belt, the Frame Lake pluton and the supracrustal remnants study area, Berens River Subprovince, Ontario; Ontario Geological Survey, Miscellaneous Release—Data 222.

Préfontaine, S. and Mumford, T. 2007a. Precambrian geology of the McInnes Lake greenstone belt, northwestern Ontario—north sheet; Ontario Geological Survey, Preliminary Map P.3589, scale 1:20 000.

——— 2007b. Precambrian geology of the McInnes Lake greenstone belt, northwestern Ontario—south sheet; Ontario Geological Survey, Preliminary Map P.3590, scale 1:20 000.

Sanborn-Barrie, M., Skulski, T. and Parker, J. 2001. Three hundred million years of tectonic history recorded by the Red Lake greenstone belt, Ontario; *in* Current Research 2001-C19, Geological Survey of Canada, 32p.

Stone, D. 2010. Geochemical analyses of rocks, minerals and soil in the central Wabigoon Subprovince area, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 242.

Sun, S. and McDonough, W.F. 1989. Chemical and isotopic systematics of ocean basalts: Implications for mantle composition and processes; Geological Society of London, Special Publications, v.42, p.313-345.

30. Identification of Fertile Parent Granitoid Units in the Superior Province of Ontario: Project Update

R.L. Price[1], J.R.B. Jonsson[1], S.V. Churchley[1], E.G. Amyotte[1], P.M. Malegus[1], G.F. Paju[1], P.J. Chadwick[1] and V. D'Angelo[1]

[1]Resident Geologist Program, Ontario Geological Survey

INTRODUCTION

After a one-year hiatus, this report follows up on the Fertile Parent Granitoid Project that was previously described by Cundari (2022). This project was initiated because of growing interest in lithium-cesium-tantalum (LCT)-group pegmatites and their potential to host economic amounts of lithium widely used in lithium-ion batteries. In this article, we summarize the initial results from analyses of samples collected in 2022, as well as the progress made from field work completed in 2023 and 2024 in multiple districts of the Resident Geologist Program (RGP) (Figure 30.1). The goal of the Fertile Parent Granitoid Project is to identify previously unrecognized granitoids that could be fertile and parental to LCT-group pegmatites. The intent of this work is to complement the initial work by Breaks, Selway and Tindle (2003), which aimed to identify fertile peraluminous granites as part of Operation Treasure Hunt (OFR 6099). S-type granites, peraluminous in composition, are commonly derived by the partial melting of a siliciclastic sedimentary source; for this reason, the study is primarily focussed on the metasedimentary terranes of the Superior Province.

The genetic relationship between S-type granites (i.e., fertile parent granites) and LCT-group pegmatites has long been recognized and studied (e.g., Černý 1989; Wise, Müller and Simmons 2022, and references therein). Granitoids are considered fertile if they are volatile-rich, evolved S-type granites that are capable of fractional crystallization that subsequently concentrates incompatible elements in a residual melt (Breaks and Tindle 1997; Breaks, Selway and Tindle 2003). Through further iterations, the residual melt will become increasingly enriched in these incompatible elements (i.e., beryllium, cesium, gallium, lithium, niobium, rubidium, tin and tantalum) that will be hosted in the ultimate product of the fractionation chain: the LCT-group pegmatites (Selway, Breaks and Tindle 2005). The identification of fertile granites is an exploration tool that greatly reduces the search area for a pegmatite (*see* Breaks and Tindle 1997). Fertile granites can be identified by their mineralogy as they vary considerably from those in barren (I-type) granites. Generally, S-type parent granites contain minor biotite and/or magmatic silver muscovite. More evolved, fertile granites contain green lithium muscovite, garnet, tourmaline, apatite, cordierite, andalusite and topaz (Breaks, Selway and Tindle 2003). Graphic textures are also common in fertile granites, primarily in potassium feldspar, as well as in muscovite, tourmaline and garnet (Breaks, Selway and Tindle 2003).

REGIONAL GEOLOGY

The Mesoarchean to Neoarchean Superior Province consists of several, generally east-trending, fault-bounded subprovinces. These subprovinces can generally be divided lithologically into 2 types: subprovinces that are dominated by supracrustal rocks and granitoids and those that are dominated by metasedimentary rocks, with each possessing its own characteristics (i.e., age, composition, metamorphic

Summary of Field Work and Other Activities, 2024,
Ontario Geological Survey, Open File Report 6413, p.30-1 to 30-9.

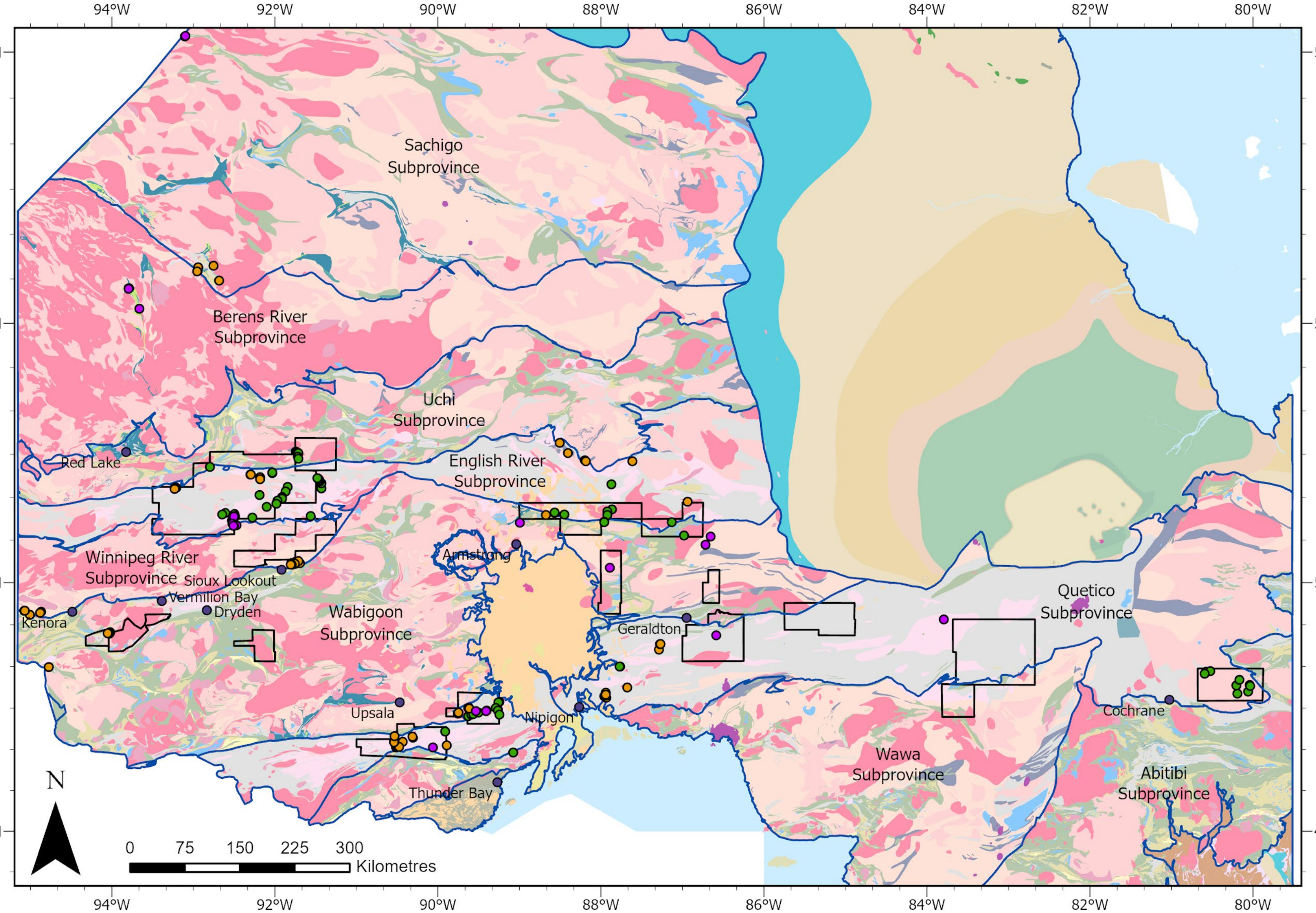


Figure 30.1. Locations of the target areas (outlined in black) and the sample locations for 2022 (green), 2023 (orange) and 2024 (purple). Subprovince boundaries are outlined with thick dark blue lines. Regional geology *from* Ontario Geological Survey (2011, *see* publication for a detailed geological legend).

and structural evolution). For reasons stated in the introduction, the majority of the project samples were collected from the 2 metasedimentary subprovinces of the Superior Province, the English River Subprovince to the north and the Quetico Subprovince to the south (*see* Figure 30.1).

English River Subprovince

The English River Subprovince occurs in the northwestern part of the Superior Province, extending, in Ontario, from the border with Manitoba in the west to where it is unconformably overlain by the Phanerozoic rocks of the James Bay Lowland in the east (*see* Figure 30.1). The subprovince consists predominantly of metamorphosed, locally migmatized, turbiditic sedimentary rocks that were deposited in a synorogenic flysch basin between 2720 and 2700 Ma (Corfu, Stott and Breaks 1995; Percival and Easton 2007). These turbiditic rocks are chemically immature greywackes interlayered with mudstones (some pelitic in composition) that were formed from the erosion of the adjacent greenstone–granite belts and volcanic detritus coming from synsedimentation volcanic rocks. Intrusive rocks intruded these metasedimentary rocks between 2698 and 2645 Ma and belong to 5 distinct groups: 1) gneissic tonalite suite, 2) tonalite–trondhjemite–granodiorite suite, 3) peraluminous granite–granodiorite suite, 4) biotite granite–granodiorite suite and 5) mafic–ultramafic plutonic suite (Breaks 1991). Between 2692 and 2660 Ma, these metasedimentary rocks also underwent a synorogenic low- to middle-pressure and medium- to high-temperature metamorphism that reached granulite-facies conditions coeval with partial melting (Breaks 1991; Corfu, Stott and Breaks 1995).

The peraluminous granite suite has an origin that is closely linked to these migmatite belts, as the granites can be derived from the anatexis of clastic metasedimentary rocks during high-temperature metamorphism (Breaks 1991). The peraluminous granites typically exhibit a white weathered surface and diverse assemblages of accessory minerals. They commonly contain both muscovite and biotite, and contain a combination of garnet, cordierite, sillimanite and tourmaline and the possible rare occurrence of beryl, topaz, dumortierite and andalusite (Breaks 1991). These rocks are widespread within the English River Subprovince; however, the most geochemically fractionated units seem to intrude at or near the subprovince boundary with either the Uchi Subprovince to the north or the Winnipeg River or Wabigoon subprovinces to the south (Breaks 1991). This may be the result of a sampling bias as a result of the lack of exploration away from these subprovince boundaries because of the belief that pegmatite emplacement is largely controlled by the large crustal-scale discontinuities commonly defining the subprovince boundaries. In this regard, the Georgia Lake pegmatite field in the Quetico Subprovince offers a perfect counter example. Although structurally controlled (*see* Duguet 2023; Duguet and Launay 2023), it is located away from any subprovince boundary.

Quetico Subprovince

The Quetico Subprovince occurs in the central part of Ontario, extending from the border with Minnesota in the west across the province to the border with Quebec in the east (*see* Figure 30.1). The metasedimentary units of this subprovince consist predominantly as metamorphosed turbiditic sequences that consist of interlayered siltstones, mudstones and greywackes, volcaniclastic rocks and rare iron formations (Williams 1991; Metsaranta 2015; Duguet 2019, 2020, 2023) that were deposited between 2702 and 2690 Ma. Williams (1991) interpreted the depositional environment as a fore-arc accretionary prism. The subprovince is metamorphosed to greenschist to amphibolite facies with areas that reached upper amphibolite to granulite facies synchronous with migmatite formation and granite intrusions that occurred between 2670 and 2650 Ma (Percival and Easton 2007). Early, calc-alkaline intrusions within the Quetico Subprovince consist of hornblendites, diorites, syenites and tonalites that are typically foliated and cut by leucogranite plutons (Williams 1991). Coeval with the metamorphism in the terrane are crust-derived granites and pegmatites, including peraluminous S-type granites at 2670 Ma and biotite granites at 2650 Ma (Percival and Easton 2007). The peraluminous S-type granites are muscovite-bearing, white to grey leucogranite that contain minor garnet, cordierite and sillimanite as well as accessory tourmaline, apatite and beryl (Williams 1991; Launay and Metsaranta 2023).

SAMPLE DESCRIPTION AND SAMPLING PROTOCOL

To date, 269 samples have been collected during the 2022, 2023 and 2024 field seasons across 6 RGP districts: Red Lake, Kenora, Thunder Bay North, Thunder Bay South, Timmins and Kirkland Lake (*see* Figure 30.1). The samples collected are predominantly granite to granodiorite that range from fine to coarse grained to pegmatitic (Photos 30.1A and 30.1B). The fresh surface ranges in colour from pink to white and typically has a weathered surface that is white in colour (Photos 30.1A to 30.1F). Although typically massive, several granitoids that were sampled have moderate, magmatic, preferred orientation or banding; locally, this banding forms anastomosed patterns. This magmatic fabric is defined primarily by the micaceous minerals, as well as variation in grain size and composition. The granites are leucocratic and consist predominantly of quartz and feldspar. Within the coarse-grained granites and pegmatites, the feldspar commonly exhibits a graphic intergrowth of quartz, typically proportionate with the size of the feldspar (Photos 30.1C and 30.1D). Pegmatites are problematic to sample because of their grain size. Pegmatite sampling was conducted according to the protocol outlined by Breaks, Selway and Tindle (2008). Granite samples with visible muscovite were preferentially sampled for this project because muscovite is indicative of S-type granites (Breaks and Tindle 1997). The samples variably contained biotite as a minor or accessory phase. With petrography alone, granites that contain biotite without muscovite cannot be distinguished between barren and fertile because biotite can occur in the primitive S-type granites as well as in barren I-type granites (Breaks, Selway and Tindle 2003). Therefore, sampling the biotite-bearing granites provides a more fulsome picture of the spatial distribution of the fertile parent granites and is useful in determining potential fractionation trends. The accessory minerals are more diagnostic of the category of granite (i.e., I-type or S-type, *see* Breaks, Selway and Tindle 2003) and varied considerably in the collected samples, which contain a combination of garnet, tourmaline, apatite, beryl, cordierite and sillimanite (Photos 30.1E and 30.1F).

LITHOGEOCHEMISTRY

The samples were submitted to the Ontario Geological Survey Geoscience Laboratories (Sudbury) for major and trace element analysis by X-ray fluorescence (XRF) on a fused disk and a pressed pellet, respectively. Trace element analysis by inductively coupled plasma mass spectrometry (ICP–MS) after closed vessel multi-acid digestion was also completed. To date, geochemical data have been returned for all the 2022 samples and the majority of the 2023 samples. While historically, the A/NCK value was used to assess granitoid compositions and their provenance, trace element composition has become indispensable in deciphering granitoid affinities and, for S-type granitoids, the degree of fractionation and subsequently the fertility of a given granite. In particular, the most useful indicators of fractionation are beryllium, cesium, lithium, niobium, rubidium, tin and tantalum (Breaks, Selway and Tindle 2003). Typically, the most fractionated samples will have elevated concentrations of some or all of these elements. Concentrations are considered elevated when they are greater than the average upper continental crust values (i.e., 3 ppm Be, 4.6 ppm Cs, 20 ppm Li, 12 ppm Nb, 112 ppm Rb, 5.5 ppm Sn, and 1.0 ppm Ta) (McLennan 2001). Table 30.1 displays a select number of samples collected from 2022 and 2023 that are representative of the study areas across the province. The pluton names provided in the table are historically used names or, if none were available, are based on township names.

Elemental ratios of major and/or trace elements such as Mg/Li or Nb/Ta values are even more appropriate to use to assess the level of fractionation and/or fertility of a given granite (Černý 1989; Selway, Breaks and Tindle 2005). Figure 30.2 displays the Mg/Li and Nb/Ta values of collected samples

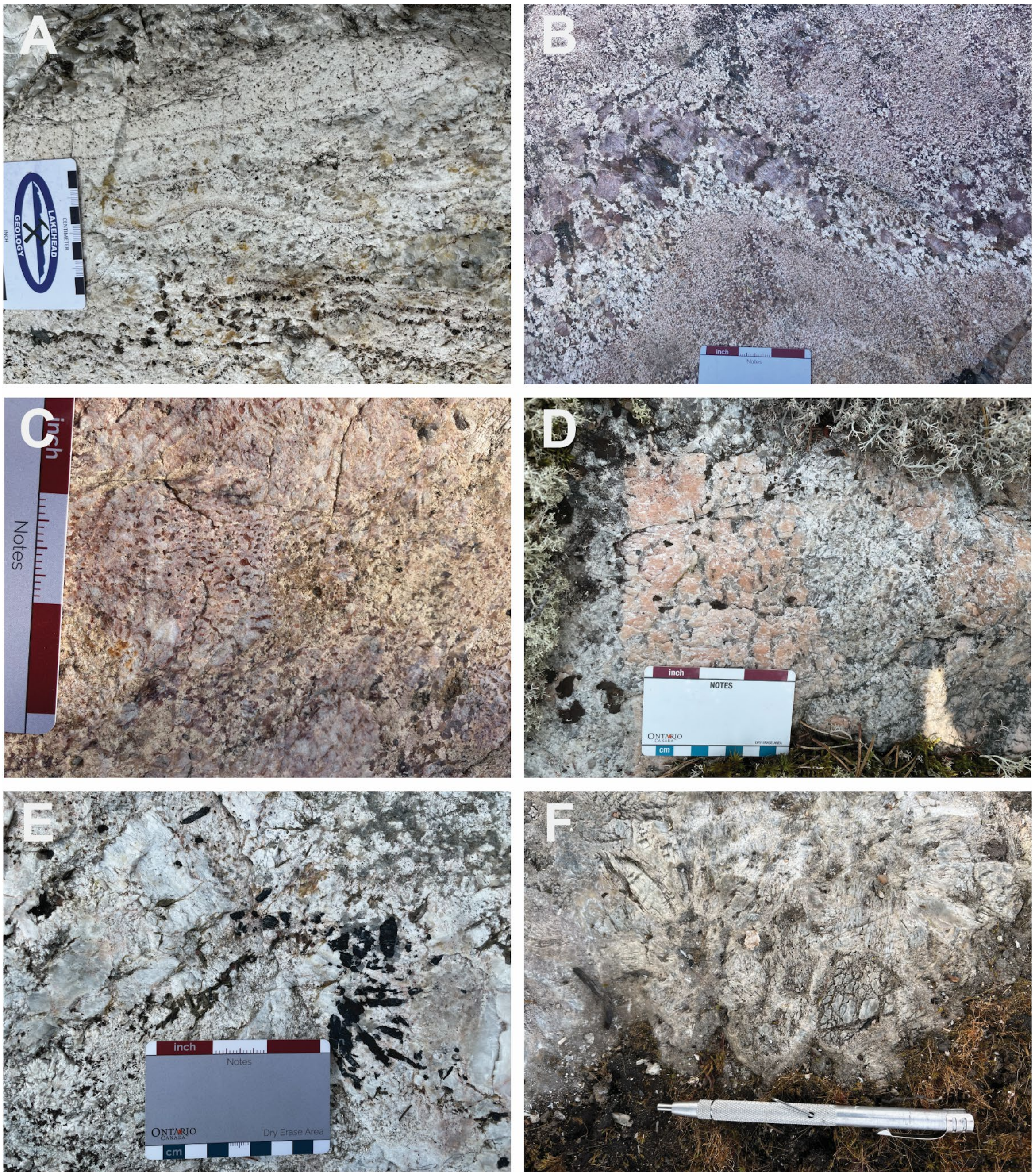


Photo 30.1. Representative photographs of some of the granites that were sampled as part of the Fertile Parent Granitoid Project. **A)** Medium-grained leucogranite that consists of feldspar, quartz, muscovite and garnet that is in contact with a pegmatitic unit of similar composition (697474 mE, 5405384 mN NAD83 Zone 15, Henderson Lake area, Kashabowie Lake pluton). **B)** Fine- to medium-grained leucocratic granite that contains sweats of pegmatite with gradational contacts, consisting predominantly of feldspar and quartz (499210 m E, 5599294 mN NAD83 Zone 16, Boston Lake area, Kapikotongwa pluton). **C)** Pale pink pegmatitic feldspar that contains fine-grained graphic texture (498139 mE, 5597838 mN NAD83 Zone 16, Boston Lake area, Kapikotongwa pluton). **D)** Pink and white pegmatitic feldspar with coarse-grained graphic intergrowth (503779 mE, 5807972 mN NAD83 Zone 15, Hewitt Lake area, North Spirit pluton). **E)** Leucocratic pegmatite with coarse-grained tourmaline, garnet and muscovite (454632 mE, 5773389 mN NAD83 Zone 15, South of McInnes Lake area, South McInnes pluton). **F)** Fibrous to blocky sillimanite grains within a predominantly feldspar and quartz pegmatite. Magnetic pen is 12 cm long. (430611 mE, 5438472 mN NAD83 Zone 16, Blair Lake area, Blair Lake pluton).

Table 30.1. Indicator element concentrations for fractionation in representative samples from the study area. The trace elements were determined from ICP–MS and are presented in ppm. Average upper continental crust values *from* McLennan 2001 and are presented in ppm. Sample indicator element concentrations greater than the average upper continental crust values are shown in bold.

Sample	Zone	Easting	Northing	Rock Type	Pluton	Be	Cs	Li	Nb	Rb	Sn	Ta
LoD						***0.024***	***0.018***	***0.24***	***0.05***	***0.15***	***0.17***	***0.015***
Average upper continental crust values						*3*	*4.6*	*20*	*12*	*112*	*5.5*	*1.0*
2022PM015	15	551295	5595443	Granite	Aerial[1]	0.445	1.203	11.32	3.01	**101.06**	0.84	0.175
22SK002	16	438717	5624489	Granite	French Lake[1]	0.302	0.992	**23.05**	7.82	**164.76**	1.15	0.322
2022PM011	15	571930	5607750	Granite	Bingo[1]	0.312	0.693	10.14	1.01	58.99	0.44	0.103
22SK006	16	434675	5600995	Granodiorite	Kapikotongwa[1]	0.637	1.89	14.25	8.06	**114.86**	0.53	0.603
22GP010	15	610468	5626487	Granodiorite	Kim[1]	0.82	2.241	18.68	6.76	80.82	0.76	0.512
23-OGR-002	16	416659	5644601	Granodiorite	Morden[1]	1.205	**5.31**	**32.5**	2.77	38.51	0.83	0.193
23-06-08-02	16	381167	5598937	Granite	Ratte Lake[1]	**4.522**	**8.175**	3.19	11.02	**185.72**	**12.61**	**2.413**
22GP007	15	590167	5648773	Granite	Root[1]	1.228	2.812	**30.36**	4.90	**115.76**	0.61	0.737
2023PM006	15	557658	5630730	Granodiorite	Sharp Lake[1]	1.26	**6.701**	**35.41**	10.22	**124.79**	1.28	0.974
2022PM013	15	557186	5614878	Granite	Wapesi[1]	0.689	2.474	**32.48**	7.47	**222.2**	2.01	0.549
2023PM030	15	485258	5621107	Granite	Wenesaga[1]	**82.46**	**89.974**	**55.07**	**25.10**	**359.20**	4.31	**38.734**
22TBS-020	16	444161	5464836	Granite	Barbara[2]	**5.191**	**15.195**	**73.88**	**21.18**	**373.00**	**7.26**	**4.903**
22-PC-17	17	568456	5442594	Granite	Case[2]	1.604	2.932	8.20	3.15	**156.39**	0.41	0.589
22TBS-011	16	298992	5427139	Granite	Eayrs[2]	**3.309**	**17.397**	**38.72**	**14.98**	**414.19**	3.79	**2.383**
23-GTL-04	16	479983	5484661	Granite	Gathering[2]	**3.946**	**7.123**	8.80	**14.80**	**295.51**	**9.88**	**1.498**
720202306	15	365244	5514353	Granite	Gidley[3]	1.06	0.831	15.16	6.30	66.79	0.65	0.252
2023PM074	15	585897	5556453	Granite	Sioux Lookout[3]	1.153	1.636	**32.37**	4.09	79.37	0.82	0.312
720202304	15	351130	5515922	Granodiorite	Gundy[3]	0.77	1.524	**20.42**	4.21	111.49	0.79	0.237
727202304	15	425870	5495184	Granite	Work[3]	0.995	3.754	**43.92**	1.62	34.04	0.38	0.222
2023RP009	15	521643	5796784	Granite	North Spirit[4]	2.974	1.829	**27.32**	**42.17**	**217.08**	2.11	**9.033**

Pluton names are those historically used; if none could be identified, names are taken from the township name.
UTM coordinates in NAD 83.
[1]English River Subprovince, [2]Quetico Subprovince, [3]Western Wabigoon Subprovince,[4]Sachigo Subprovince.
Abbreviations: LoD, limit of detection; ppm, parts per million.

on a gradational dot map; dot size represents the Mg/Li values, while colour indicates the various Nb/Ta values. The Mg/Li values range from 0 to 1000 and the Nb/Ta values range from 0 to 40. These elemental ratios are useful for characterizing the degree of fractionation in a sample and can indicate whether the pluton is an S-type granite. The Mg/Li values less than 30 indicate a high degree of fractionation whereas the most primitive S-type granites will have moderate Mg/Li values of approximately 100. Likewise, Nb/Ta values from samples of S-type granites are expected to be low, less than 30, with the most fractionated samples having ratios of less than 10. Identifying granites that are S-type is important because they are capable of producing economic pegmatites (Breaks, Selway and Tindle 2003).

Several of the plutons (e.g., Bingo, Gidley, Gundy and Kapikotongwa) are not fractionated, with indicator elements for fractionation at or below the average upper continental crust values. Other intrusions (Aerial, Case, French Lake, Gathering, Kim, Morden, Root, Sharp Lake, Sioux Lookout, Wapesi and Work) are weakly to moderately fractionated, with most of the element concentrations at or

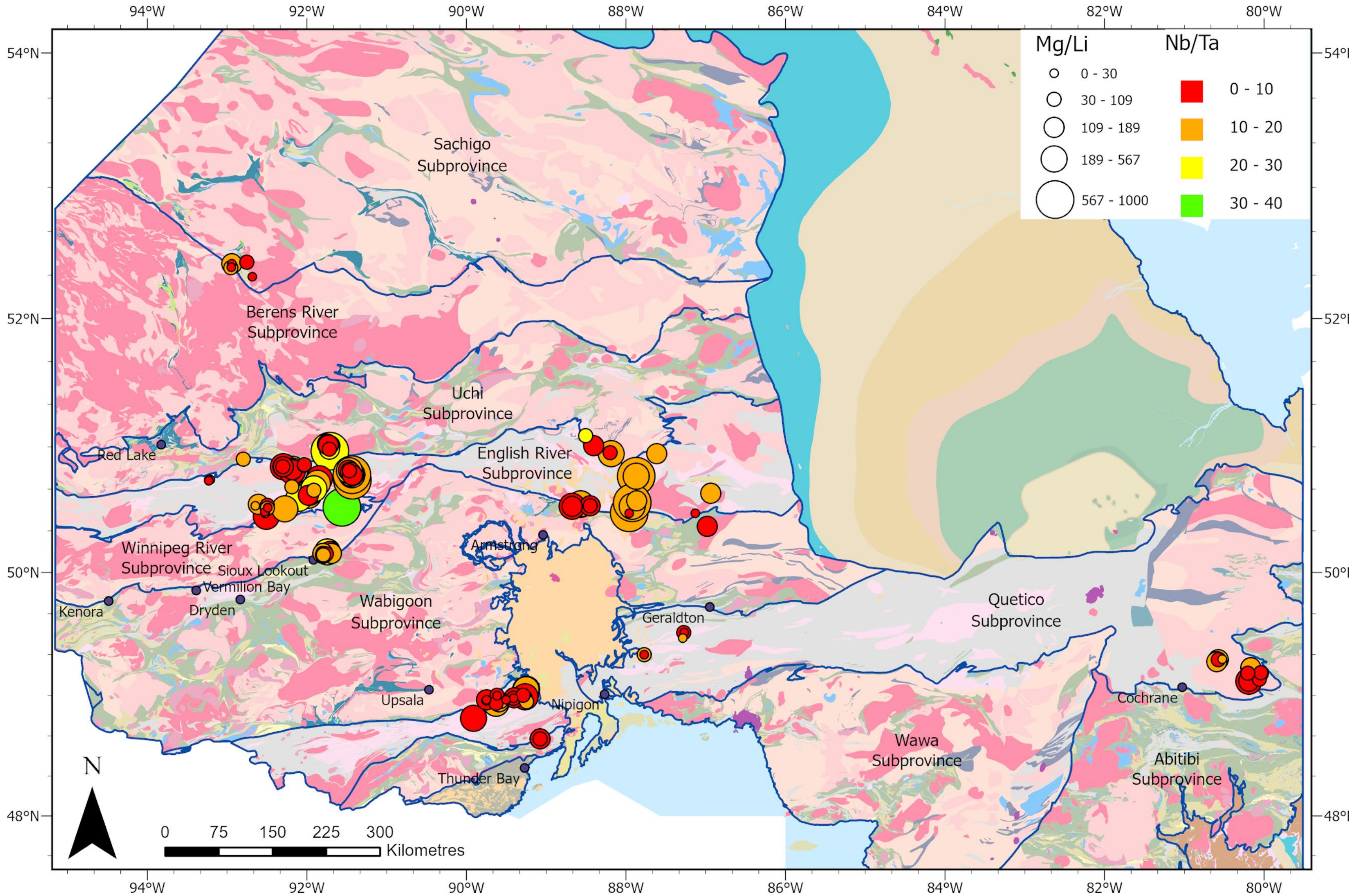


Figure 30.2. Gradational dot map showing the Mg/Li values for the samples as variably sized dots and the Nb/Ta values in distinct colours. Regional geology *after* Ontario Geological Survey (2011, *see* publication for a detailed geological legend).

below the average upper continental crust values, but with a few elements being elevated. The strongly fractionated plutons, with most of the indicator element concentrations above the average continental crust values, include Barbara, Eayrs, North Spirit, Ratte Lake and Wenesaga. There is considerable heterogeneity, particularly with respect to the trace elements, among samples from the same pluton. For example, according to the indicator elements, some samples are strongly fractionated, while others from the same intrusion are only weakly fractionated or not fractionated at all. This could indicate multiple intrusive phases within a single pluton that could be used to identify a fractionation trend.

FUTURE WORK

Further evaluation is needed to fully assess the most prospective granites, with the next steps being to continue to evaluate the whole-rock geochemical data and integrating the whole-rock geochemical data from the samples collected in 2023 and 2024 that have yet to be returned. Additional samples, particularly in the eastern Quetico Subprovince, will be collected in 2025 to provide a more complete representation of the two metasedimentary subprovinces. The principal deliverable will be a Miscellaneous Release—Data with an accompanying compendium or Open File Report.

ACKNOWLEDGEMENTS

The Fertile Parent Granitoid Project has spanned multiple years and has had significant contributions from a collective of people across the Ontario Geological Survey, particularly the RGP. Robert Cundari is acknowledged as the individual who initiated this project in 2022 and is thanked for his support in allowing this project to continue in his absence. The RGP staff from 6 districts collectively completed all the field work and sample collection for this project. Thérèse Pettigrew is thanked for her support of this project, as is Zeinab Azadbakht for her guidance with the whole-rock geochemistry. Manuel Duguet is thanked for his editorial advice and technical guidance. Mathieu Levesque and Darla Bennett contributed to the project by recognizing sensitivities related to Indigenous communities across the province. Alexandra Withers, Marcus Burnham and Victoria Hingst from Geoscience Laboratories are thanked for providing guidance and support related to analytical methods and results.

REFERENCES

Breaks, F.W. 1991. English River Subprovince; Chapter 7 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.239-277.

Breaks, F.W. and Tindle, A.G. 1997. Rare-metal exploration potential of the Separation Lake area: An emerging target for Bikita-type mineralization in the Superior Province of northwest Ontario; *in* Summary of Field Work and Other Activities, 1997, Ontario Geological Survey, Miscellaneous Paper 168, p.72-88.

Breaks, F.W., Selway, J.B. and Tindle, A.G. 2003. Fertile peraluminous granites and related rare-element mineralization in pegmatites, Superior Province, northwest and northeast Ontario: Operation Treasure Hunt; Ontario Geological Survey, Open File Report 6099, 179p.

——— 2008. The Georgia Lake rare-element pegmatite field and related S-type, peraluminous granites, Quetico Subprovince, north-central Ontario; Ontario Geological Survey, Open File Report 6199, 176p.

Černý, P. 1989. Exploration strategy and methods for pegmatite deposits of tantalum; *in* Lanthanides, tantalum and niobium, Springer-Verlag, New York, p.274-302.

Corfu, F., Stott, G.M. and Breaks, F.W. 1995. U-Pb geochronology and evolution of the English River Subprovince, an Archean low *P*-high *T* metasedimentary belt in the Superior Province; Tectonics, v.14, p.1220-1233.

Cundari, R.M. 2022. Identification of fertile parent granitoid units in the Superior Province of Ontario: Project description; *in* Summary of Field Work and Other Activities, 2022, Ontario Geological Survey, Open File Report 6390, p.30-1 to 30-5.

Duguet, M. 2019. Archean and Proterozoic geology of the Georgia Lake area, Quetico Subprovince, Ontario; *in* Summary of Field work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.12-1 to 12-9.

——— 2020. Geochemistry of Archean volcaniclastic and mafic intrusive rocks, Georgia Lake area, Quetico Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2020, Ontario Geological Survey, Open File Report 6370, p.8-1 to 8-10.

——— 2023. Archean geology of the Georgia Lake area, Quetico Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p. 12-1 to 12-11.

Duguet, M. and Launay, G. 2023. Structural control of the Georgia Lake lithium-cesium-tantalum-type pegmatite field, northwestern Ontario: Preliminary results of lineament analyses; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.13-1 to 13-10.

Launay G. and Metsaranta R.T. 2023. Precambrian bedrock geology mapping in the Onion Lake and Sunshine areas, Quetico and Wawa subprovinces, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2023, Ontario Geological Survey, Open File Report 6405, p.11-1 to 11-12.

McLennan, S.M. 2001. Relationship between the trace element composition of sedimentary rocks and upper continental crust; Geochemistry Geophysics Geosystems, v.2, issue 4, 24p.

Metsaranta, R.T. 2015. Preliminary results from geological mapping of the Quetico Subprovince, the Shebandowan greenstone belt and Proterozoic rocks north of Thunder Bay; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.15-1 to 15-20.

Ontario Geological Survey 2011. 1:250 000 scale bedrock of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.

Percival, J.A. and Easton R.M. 2007. Geology of the Canadian Shield in Ontario: An update; Ontario Geological Survey, Open File Report 6196 / Geological Survey of Canada, Open File 5511 / Ontario Power Generation, Report 06819-REP-0120010158-R00, 65p.

Selway, J.B., Breaks, F.W. and Tindle, A.G. 2005. A review of rare-element (Li-Cs-Ta) pegmatite exploration techniques for the Superior Province, Canada and large worldwide tantalum deposits; Exploration and Mining Geology, v.14, p.1-30.

Williams, H.R. 1991. Quetico Subprovince; Chapter 10 *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.383-403.

Wise, M.A., Müller, A. and Simmons, W.B. 2022. A proposed new mineralogical classification system for granitic pegmatites; The Canadian Mineralogist, v.60, p.229-248. doi.org/10.3749/canmin.1800006

This page left blank intentionally

Index of Authors (with corresponding article numbers)

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.*

ISSN 0826-9580 (print)
ISBN 978-1-4868-8544-2 (print)

ISSN 1916-6117 (online)
ISBN 978-1-4868-8545-9 (PDF)