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Ontario 

**Ontario Geological Survey
Open File Report 6380**

**Summary of Field Work
and Other Activities,
2021**

2021

ONTARIO GEOLOGICAL SURVEY

Open File Report 6380

Summary of Field Work and Other Activities, 2021

by

Ontario Geological Survey

Edited by R.M. Easton, S. Préfontaine, S.M. Hamilton, O.M. Burnham, M. Duguet, A.K. Burt and E.H. Priebe

2021

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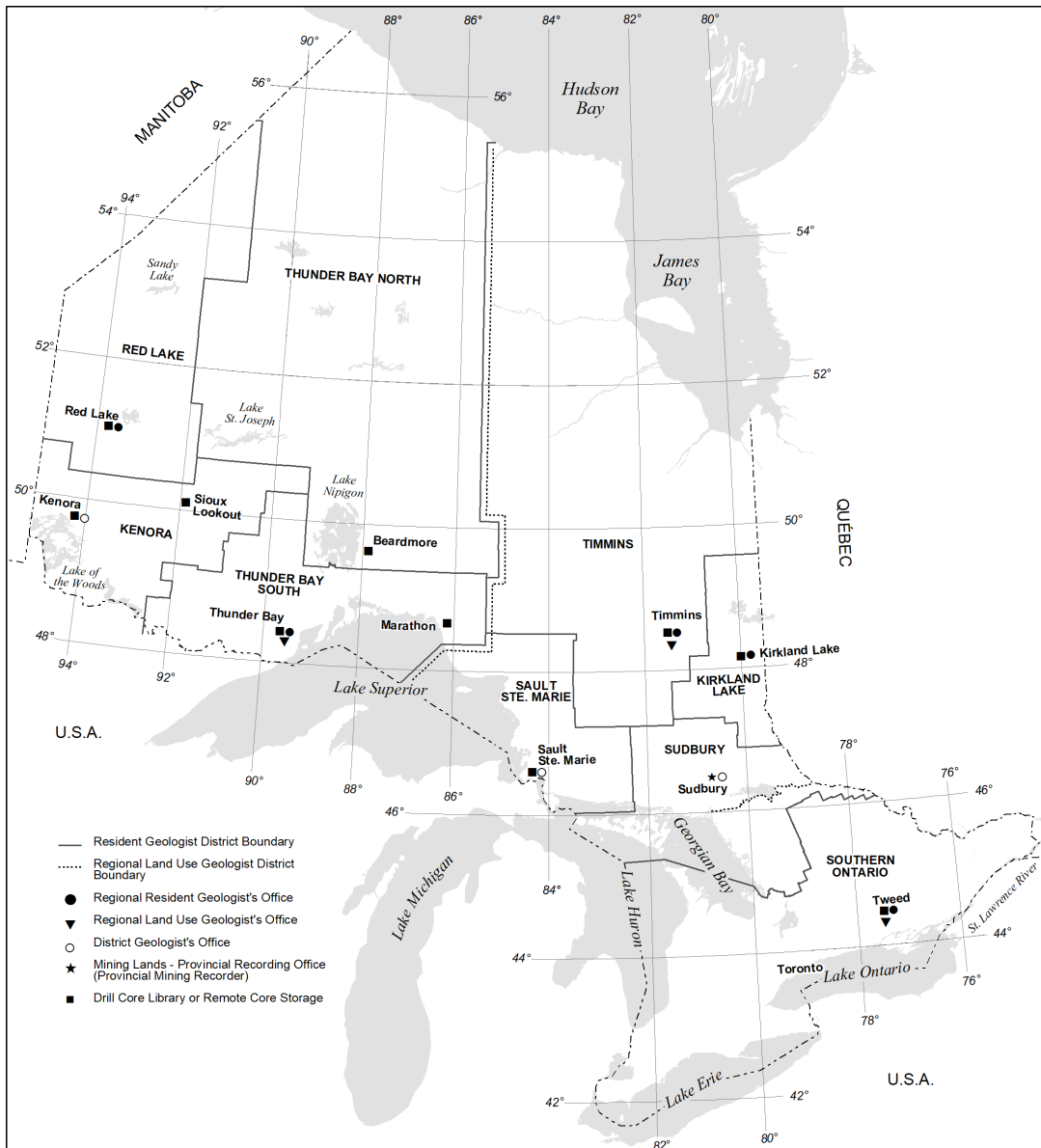
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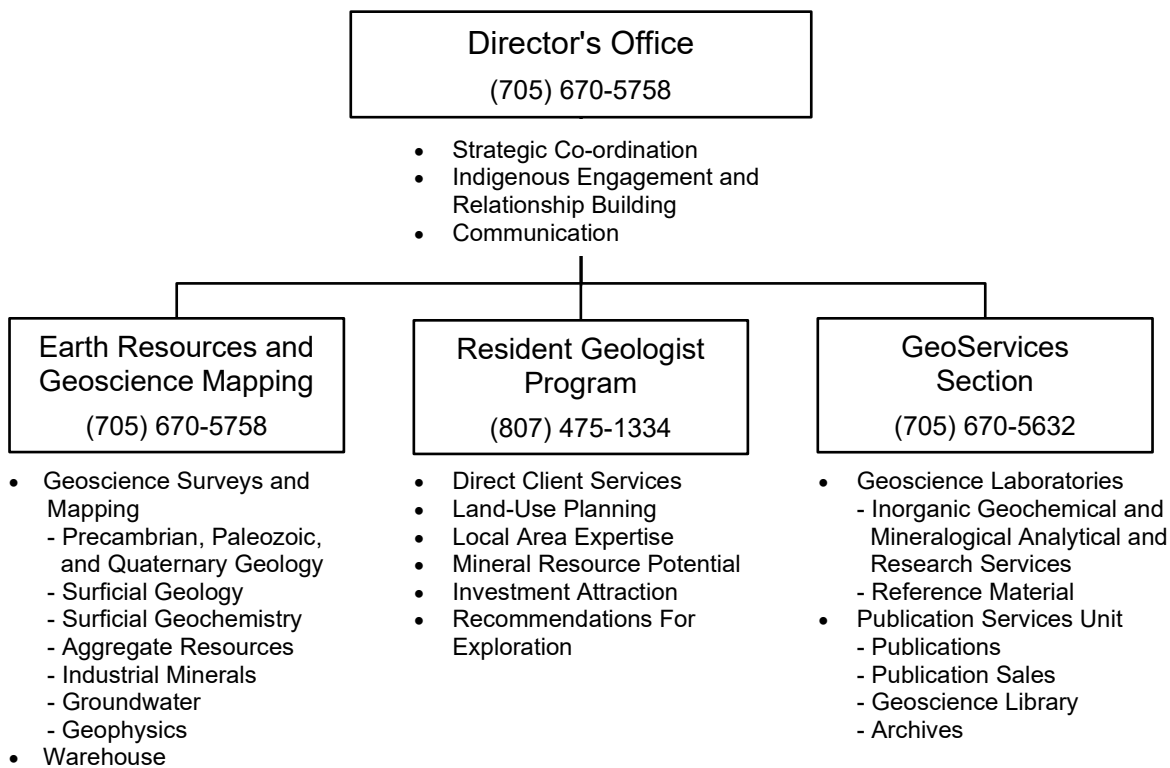


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Ministry of Northern Development, Mines, Natural Resources and Forestry

Ontario Geological Survey Branch



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Ontario Geological Survey**

1. Ontario Geological Survey: Update of Strategic Perspective for 2021–2022



S.B. Beneteau¹

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INTRODUCTION

This article provides an update on the strategic direction of the Ontario Geological Survey (OGS) based on activities during the 2021–2022 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, Indigenous and other stakeholders. 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, 2021,
Ontario Geological Survey, Open File Report 6380, p.1-1 to 1-11.*

The COVID-19 pandemic again created an unusually challenging year for the OGS. Although field activities were significantly reduced, a shortened field season was achieved. Despite a physical workplace shutdown for a large portion of the year, the OGS continued to generate world-class geoscience information, products and services, including the 21 articles included 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 2021–2022* in the coming months. The Geoscience Laboratories staff returned to the physical workplace in late September 2020 and continued to function throughout 2021, albeit at a reduced capacity because of COVID-19 safety protocols.

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 Ontario airborne geophysical surveys, magnetic and electromagnetic, grid, profile and vector data, Saganash Lake area, Nameigos Lake area and Mozhabong Lake area. The data for the latter 2 surveys were donated by the Nuclear Waste Management Organization (NWMO). In addition, a preliminary interpretation of the Saganash area aeromagnetic survey, northeastern Ontario is provided herein (this volume, Article 6);
- publication of geological, geochemical and petrographic data and isotopic data, western Schreiber–Hemlo greenstone belt, northwestern Ontario;
- publication of geological, geochemical and geophysical data in the Makokibatan Lake, Peninsular Lake and Wabassi River areas of the Fort Hope–Miminiska greenstone belt, northwestern Ontario;
- publication of geological, geochemical and geophysical data in Penhorwood and Kenogaming townships, Abitibi greenstone belt, northeastern Ontario;
- publication of Quaternary geology mapping in northeastern Ontario along the Highway 11 Corridor from Kapuskasing to Iroquois Falls;
- revised indicator mineral and geochemistry data for the till and alluvium sampling survey in the McFaulds Lake (“Ring of Fire”) area, northern Ontario;
- updates on drill-core logging in the southern James Bay Lowland area of Ontario’s Far North (this volume, Article 15);

- continuing groundwater aquifer mapping: three-dimensional (3-D) modelling of subsurface sediments and bedrock; and the karst map of southern Ontario: Clinton and Medina groups (this volume, Articles 17 and 18);
- publication of groundwater hydrochemistry, water isotope and manual water-level data for the early Silurian carbonates of the Niagara escarpment cuesta;
- updated compilations of the Ambient Groundwater Geochemical Database (this volume, Article 19)
- publication of, and update to, the Aggregate Resources of Ontario—2020 (ARO—2020) database compiled from mapping conducted by the OGS from 1980 to 2020;
- new geochronology from the Temagami greenstone belt, northeastern Ontario (this volume, Article 8);
- continuation of the Gold Fingerprinting project, with an analysis of gold fineness across Ontario (this volume, Article 13);
- ongoing delivery of the services of a world-class inorganic geochemical laboratory, which supports the OGS geochemical program; and
- 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 active OGS public geoscience information holdings include 10 352 maps, 3343 reports and 667 data releases. In the period November 1, 2020 to October 31, 2021, the OGS published 9 new reports, 73 new maps, and 18 new data releases.

From November 1, 2020 to October 31, 2021, numerous publications and data files were downloaded or accessed:

- downloaded from our [GeologyOntario](#) Web site:
 - ◆ in excess of 459 277 maps and reports in portable document format (.pdf) and image (.jpg) format
 - ◆ 16 623 compressed (.zip) files, representing 2062 different publications
- downloaded from our [OGS Earth](#) Web site:
 - ◆ 55 779 master .kml files
 - ◆ Resident Geologist Program databases and recommendations
 - ◆ Mineral Deposit Inventory (MDI) 839 .zip files
 - ◆ Ontario Assessment File Database (OAFD) 790 .zip files
 - ◆ Ontario Drill Hole Database (ODHD) 655 .zip files
 - ◆ *Recommendations for Exploration* 939 .pdf files
(50.7% represents the current *Recommendations for Exploration 2020–2021*, the remaining 49.3% represents recommendations from 2005 to 2019)
- accessed and downloaded from our OGS Earth RGP Activity Reports—Mineral Exploration (AR—ME) Web page, compiled by the district offices:
 - ◆ [AR—ME Web page](#) accessed 370 times
 - ◆ [AR—ME Web table page](#) accessed 546 times
 - ◆ AR—ME .kml file downloaded 502 times
 - ◆ individual pages for the district offices accessed 2278 times
(through either the OGS Earth Web page or the AR—ME Web table page)

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; that 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.
- Recently, 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 GEOLOGICAL SURVEY CLIENTS AND STAKEHOLDERS

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 Aboriginal Geoscience Liaison positions based in Sudbury and Thunder Bay. A summary of the activities of the Indigenous Geoscience Liaisons during the 2020–2021 fiscal year 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 2020–2021, 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 at expanding 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* Nadeau, 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* Nadeau, this volume, Article 2).

CURRENT STRATEGIC PRIORITIES

Four strategic priorities, with implementation plans, continue to be the focus of the OGS for fiscal years out to 2022.

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: water (groundwater), metal, mineral (including aggregate) 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* Hechler 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
- airborne geophysical survey flown in northeastern Ontario
- continuing updates to the Mineral Deposit Inventory (MDI) and its online database
- continuing updates to the Aggregate Resources of Ontario (ARO) database
- continuing updates to the Geochronology Inventory of Ontario (GeochrON) database

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

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

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

*Abbreviations: NDMNRF = Ministry of Northern Development, Mines, Natural Resources and Forestry; ERGMS = Earth Resources and Geoscience Mapping Section; GeoServices = GeoServices Section; OGS = Ontario Geological Survey; RGP = Resident Geologist Program.

Table 1.2. Strategic objectives for Indigenous relations.

Strategic Objectives – Indigenous Relations					
Outcomes	Divisional Mandate	Strategic Objectives	Activities	How?	Who? *
Strong and meaningful relationships between NDMNRF and Indigenous peoples and organizations	To support prosperous and sustainable economic growth, by collecting and disseminating geoscience information and regulating mineral exploration and mining in Ontario in a manner consistent with Indigenous reconciliation, protection of public health and safety and the environment	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: NDMNRF = Ministry of Northern Development, Mines, Natural Resources and Forestry; ERGMS = Earth Resources and Geoscience Mapping Section; OGS = Ontario Geological Survey; RGP = Resident Geologist Program.

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

Strategic Objectives – Mineral Development Investment and Opportunities					
Outcomes	Divisional Mandate	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	Research, development and promotion of strategic investment opportunities that influence policy issues and support Ontario's mineral competitiveness	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.

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 NDMNRF Mines and Minerals Division, the OGS contributes to the Divisional and Ministry goal to build and deliver on an Indigenous strategy (Table 1.2).

Results

Focus during the 2021–2022 fiscal year was to continue collaborations and relationship building with Temagami First Nation, Mississauga First Nation, Nookiiwin Tribal Council, Rocky Bay First Nation, Constance Lake First Nation, Red Rock Indian Band, Sand Point First Nation, Anishinabek Nation Northern Superior Regional Table, Anishinabek Nation Lake Huron Regional Table, Anishinabek Nation Southeast and Southwest Regional Table, and Anishinabek Nation Technical Table (*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 strategic 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 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 virtually at the Association for Mineral Exploration (AME) Annual Mineral Exploration Roundup 2021 and the Prospectors and Developers Association of Canada (PDAC) 2021 Annual Convention, and helped to co-host the 2021 Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House. Staff also participated virtually in the Ontario Stone, Sand and Gravel Association (OSSGA) Virtual Conference; 2021 Denver X-ray Conference; GeoConvention 2021 (joint meeting of the Canadian Society of Petroleum Geologists, Canadian Society of Exploration Geophysics and the Canadian Well Logging Society); Institute of Lake Superior Geology meeting; Mining the Abitibi Greenstone Belt Conference; the 2021 Inductively Coupled Plasma (ICP) Conference; Society of Economic Geologists Conference; the GeoNiagara Conference (joint meeting of the Canadian Geotechnical Society and Canadian International Association of Hydrogeologists); Geological Society of America Connects 2021 Annual Conference; the Geological Association of Canada–Mineralogical Association of Canada 2021 Joint Annual Meeting; Critical Minerals Workshop 2021 (organized by British Columbia Geological Survey, Geological Survey of Canada, Geoscience Australia, and Geological Association of Canada–Pacific Section); and the Québec Mines + Énergie 2021 conference.

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 online data warehouse (www.mndm.gov.on.ca/en/mines-and-minerals/applications/geologyontario). Some key data sets are also available through OGS Earth (www.geologyontario.mndm.gov.on.ca/ogsearth.html), which uses the Google Earth™ mapping service to view public geoscience data and information in a geographic context. The Resident Geologist Program (RGP) has also enhanced access to data using OGS Earth 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 Twitter, Facebook and LinkedIn and internal communication channels;
- formal public presentations that describe the value, relevance and application of geoscience;
- development of a “geoscience lens” to facilitate and guide the application of public geoscience in government decision making;

- 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
- launch of a new GIS-based geological and geospatial data product (OGS Focus) to assist mineral sector clients with exploration targeting.

THE FUTURE

Building on the work initiated in 2018–2019, the OGS management team has been implementing the OGS strategic plan. The 5-year strategic plan is integrated with the 2018–2023 Mines and Minerals Division Strategic Plan, which includes the following 5 priorities: 1) a dynamic and fully engaged workforce; 2) global leadership in geoscience, exploration and mining investment; 3) streamlined regulatory processes; 4) partnerships with Indigenous communities; and 5) fully integrated online service delivery and access to information.

The OGS continues 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;
- 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;
- continue the utilization of 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 January 2021, Annie McLeod joined the Director's Office as an Indigenous Geoscience Liaison for 6 months. In March 2021, Erin Rondeau took on a 9-month training and development assignment with the Financial Administration Unit, Strategic Services Branch, within the Mines and Minerals Division. Also, in March 2021, Chantel Desrochers joined the Director's Office as the Administrative Assistant for 4 months. In September 2021, Lesley McAdam joined the Director's Office on a 6-month contract, as the Administrative Assistant.

2. Ontario Geological Survey: Measuring Success



J.E. Nadeau¹

¹Director'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 investments 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).
6. Annual number of square kilometres mapped by OGS based on results of 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, 2021,
Ontario Geological Survey, Open File Report 6380, p.2-1 to 2-6.*

VALUE-ADDED PRODUCTS AND SERVICES

The Resident Geologist Program (RGP) and the GeoServices Section of the OGS conduct client surveys that are specific to their program areas. The RGP distribute hard-copy surveys at regional offices and at various tradeshow and conferences that they attend. However, because of the current COVID-19 pandemic throughout 2020 and 2021, the RGP has not had the opportunity to distribute these surveys and, therefore, did not collect any data for this year (Table 2.1).

The GeoServices Section uses SurveyMonkey® software to distribute client surveys and collect results (*see* Table 2.1).

The OGS, in collaboration with the Geological Survey of Canada and Conservation Ontario, conducts an annual Regional-Scale Groundwater Geoscience Open House in southern Ontario. Participants are surveyed on their overall satisfaction with the event, using SurveyMonkey®, and results are recorded (*see* Table 2.1). It should be noted that in 2021 the Groundwater Geoscience Open House was hosted virtually for the first time.

Table 2.1. Client survey results from the Resident Geologist Program, GeoServices Section and the Groundwater Open House.

Survey Question	Program Area	2015– 2016	2016– 2017	2017– 2018	2018– 2019	2019– 2020	2020– 2021
How satisfied are you with the RGP products and services	Resident Geologist Program	n/a	79%	94%	96%	100%*	n/a
How satisfied are you with the analyses and services provided by the Geoscience Laboratories	GeoServices Section	84%	n/a	83%	97%	99%	100%*
Please rate your overall satisfaction with the Groundwater Open House	Groundwater Open House	n/a	94%	93%	99%	100%	93%

n/a = no data available.

**Please note that there were less than 40 respondents.*

ANNUAL CLIENT SURVEY

Method

The 2020–2021 OGS Client Survey was conducted from April 1 to 30, 2021. A database of 676 clients was compiled by OGS staff, with 608 of these clients having valid contact information. The survey was conducted using SurveyMonkey®, which is an online survey platform that is used to create and distribute surveys and collect and analyze results. This approach involved sending electronic invitations through the software to respondents who had e-mail addresses provided for them to complete the survey online. A total of 4 follow-up reminders were then sent to those who did not complete the survey.

A total of 261 responses were captured, a 43% response rate. This response was a 3% decrease from the 2020 results. This lower response rate may be attributed to the COVID-19 pandemic during the survey period. Another factor to consider is the 2021 sample size is the largest of all years, also resulting in the number of responses (N=261) being the highest received within the 8 years the survey has been completed.

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, however, that this was the third year clients were divided into these categories; therefore, the results may be skewed in the representation to years previous 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. The results of each category are noted below in Table 2.2 for questions asked of all clients, Table 2.3 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 2019–2020 client survey questions and summary of results for OGS clients.

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

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

Table 2.3. Ontario Geological Survey 2019–2020 client survey questions and summary of results for OGS product users.

Survey Questions	Mineral / Resource / Exploration						
	2014– 2015	2015– 2016	2016– 2017	2017– 2018	2018– 2019	2019– 2020	2020– 2021
Percentage of clients who used OGS products within the past 12 months?	90%	94%	90%	89%	94%	92%	84%
Overall satisfaction with the quality of OGS products	n/a	n/a	88%	79%	80%	85%	86%
Percentage of clients who used OGS products to make a decision ¹	69%	80%	68%	54%	57%	50%	62% 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% 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% ²
Did the use of OGS products improve clients' exploration models or strategies?	80%	76%	55%	46%	40%	46%	51% ³
Did the use of OGS products reduce clients' decision risks?	74%	65%	60%	39%	28%	34%	36% 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% ³

Table 2.3, continued.

Survey Questions	Land Use Planning / Groundwater / Environmental						
	2014– 2015	2015– 2016	2016– 2017	2017– 2018	2018– 2019	2019– 2020	2020– 2021
Percentage of clients who used OGS products within the past 12 months?	85%	94%	91%	89%	90%	89%	86%
Overall satisfaction with the quality of OGS products	n/a	n/a	91%	97%	89%	95%	94%
Percentage of clients who used OGS products to make a decision ¹	90%	91%	78%	77%	77%	71%	74% 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% 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% ²
Did the use of OGS products improve clients' exploration models or strategies?	80%	58%	50%	69%	64%	86%	77% ³
Did the use of OGS products reduce clients' decision risks?	78%	36%	50%	60%	34%	36%	42% 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% ³

¹ An open-ended question asking respondents if there was a specific reason why they did not use OGS products to make a decision. Mineral/resource/exploration clients: 36% had no specific reason why and 10% the COVID-19 pandemic was a factor. Land-use/groundwater/environmental clients: 35% had no specific reason why and 30% said that the COVID-19 pandemic was a factor.

² New option added to these questions of "Other" where respondents were able to provide how products increased the efficiency of their decision-making: 20% of mineral/resource/exploration clients gave a response here and 13% of land-use clients responded.

³ New option added to these questions of "Other" where respondents were able to provide how products increased the effectiveness of their decision-making: 19% of mineral/resource/exploration clients gave a response here and 6% of land-use clients responded. n/a = no data available.

Table 2.4. Ontario Geological Survey 2019–2020 client survey questions and summary of results for OGS service users.

Survey Questions	Mineral / Resource / Exploration						
	2014– 2015	2015– 2016	2016– 2017	2017– 2018	2018– 2019	2019– 2020	2020– 2021
Percentage of clients who used OGS services within the past 12 months?	n/a	n/a	96%	85%	53%	54%	42%
Overall satisfaction with the quality of OGS products	n/a	n/a	91%	82%	84%	81%	80%
Percentage of clients who used OGS services to make a decision	69%	80%	68%	54%	48%	32%	35% ⁴
Did OGS services allow clients to focus their efforts on areas of potential and/or interest?	74%	76%	73%	50%	50%	75%	76% 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% ⁵
Did the use of OGS services improve clients' exploration models or strategies?	80%	76%	55%	46%	46%	56%	53% ⁶
Did the use of OGS services reduce clients' decision risks?	74%	65%	60%	39%	25%	32%	32% ⁶
Did the use of OGS services provide evidence of the presence or absence of critical features, target deposit type or topic of interest?	72%	57%	59%	41%	37%	50%	41% ⁶

Table 2.4, continued.

Survey Questions	Land Use Planning / Groundwater / Environmental						
	2014– 2015	2015– 2016	2016– 2017	2017– 2018	2018– 2019	2019– 2020	2020– 2021
Percentage of clients who used OGS services within the past 12 months?	n/a	n/a	100%	97%	75%	68%	48%
Overall satisfaction with the quality of OGS products	n/a	n/a	91%	97%	87%	100%	89%
Percentage of clients who used OGS services to make a decision	90%	91%	78%	77%	77%	74%	47% ⁴
Did OGS services allow clients to focus their efforts on areas of potential and/or interest?	83%	58%	83%	57%	67%	90%	58% 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% ⁵
Did the use of OGS services improve clients' exploration models or strategies?	80%	58%	50%	69%	59%	83%	75% ⁶
Did the use of OGS services reduce clients' decision risks?	78%	36%	50%	60%	23%	40%	44% ⁶
Did the use of OGS services provide evidence of the presence or absence of critical features, target deposit type or topic of interest?	83%	53%	64%	74%	44%	50%	56% ⁶

⁴ An open-ended question asking respondents if there was a specific reason why they did not use OGS services to make a decision. Mineral/resource/exploration clients: 40% had no specific reason why and 20% said the COVID-19 pandemic was a factor. Land-use/groundwater/environmental clients: 50% had no specific reason why and 25% said exploration was not their core business or that was not the purpose of usage.

⁵ New option added to these questions of "Other" where respondents were able to provide how services increased the efficiency of their decision-making: 20% of mineral/resource/exploration clients gave a response here and 25% of land-use clients responded.

⁶ New option added to these questions of "Other" where respondents were able to provide how services increased the effectiveness of their decision-making: 19% of mineral/resource/exploration clients gave a response here and 0% of land-use clients responded.

n/a = no data available.

SUCCESSSES WITH PRODUCTS AND SERVICES

The OGS measures its products and services success by monitoring exploration companies working in Ontario who reference OGS data to make an informed decision. The 3 most recent successes are described below.

1. In December 2020, Palladium One Mining Inc. acquired a large claim block, 65 kilometres northeast of Marathon, Ontario, to add to the already established Tyko Ni-Cu-PGE project. This acquisition was the result of a significant new nickel showing on the original Tyko claim block. The company utilized OGS geophysical data and received assistance from an OGS staff in the identification of drill targets for the program that resulted in the new discovery. (Palladium One Mining Inc., written communication, 2021; Palladium One Mining Inc., news release, December 7, 2020).
2. In April 2021, Solstice Gold Corporation acquired through staking 9467 ha comprising 3 new projects, Taillon, Moreau and Berens, which have been mapped as greenstone and extensions of the Red Lake greenstone belt by the OGS. It was noted in the news release that the *Recommendations for Exploration 2020–2021*, published by the OGS, triggered the company's major staking in the area (Solstice Gold Corp., news release, April 13, 2021).

3. In 2016, Pavey Arc Minerals Inc. completed a resampling program of the core from the Hawkins Gold project located south of Hearst, Ontario, with assistance from the RGP. The core was previously logged by Falconbridge Ltd. and stored at the OGS's Sault Ste. Marie core library. The resampling program has resulted in a significant investment in follow-up exploration work by E2Gold Inc. in December 2020 (E2 Gold Inc., written communication, 2021; E2Gold Inc., news release, December 30, 2020).

SUCCESSSES WITH INDIGENOUS COMMUNITIES

The OGS measures its success with Indigenous communities through qualitative data collection (e.g., collaborations, blessings, testimonials). Unfortunately, during 2020–2021 and the current pandemic, the OGS did not visit communities in person. However, the OGS was able to have meaningful virtual engagement with communities. The following successes were documented (*see also* Levesque, this volume).

1. On October 8, 2020, staff from the OGS facilitated online training between Temagami First Nation's lands and resources staff and the Mining Lands Administration System (MLAS) staff. The staff from Temagami learned how to extract MLAS data to identify mining claims in their traditional land use area.
2. In March and December of 2020, staff from OGS presented "Geology 101" and "Minerals in Our Lives" during 2 separate training weeks for the Nokiiwin Tribal Council, providing further education for the lands and resource staff.
3. In May 2021 and June 2021, OGS staff from the Resident Geologist Program and the Earth Resources and Geoscience Mapping Section connected virtually with Anishinabek Nation Technicians Table and Grand Council Treaty #3, respectively, to present OGS online tools and provide a live demonstration on using these tools.

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;
- build strong and successful collaborations and relationships with Indigenous communities.

3. Activities of the Indigenous Geoscience Liaisons in 2020–2021



M.D. Levesque¹

¹Director’s Office, Ontario Geological Survey

INTRODUCTION

The Ontario Geological Survey (OGS) is committed to building meaningful relationships with Indigenous communities in anticipated and planned geoscience project areas. Since 2016, the OGS Indigenous Geoscience Liaisons (IGL) have been focussed on engaging, building and maintaining strong treaty relationships with First Nation, as well as Métis, communities across Ontario. A responsibility 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. Because of the COVID-19 pandemic, several projects were delayed, and many Indigenous communities were closed, leading to reduced engagement and travel. As a result, this article will also focus on internal and external products developed by the IGL to assist the OGS with Indigenous engagement and staff competencies.

INDIGENOUS ENGAGEMENT BY THE INDIGENOUS GEOSCIENCE LIAISONS

Table 3.1. Indigenous Community engagements by the Aboriginal Geoscience Liaisons.

Community	Visit	Purpose and Outcome
Temagami First Nation	October 8, 2020	<i>Purpose:</i> Facilitated online training between Temagami First Nation lands and resource staff and Mining Lands Administration System (MLAS) group. <i>Outcome:</i> Educated Temagami staff how to extract MLAS data to calculate mining claims in their traditional land use area.
Mississauga First Nation	October 22, 2020	<i>Purpose:</i> Provide mapping update and introduce new managers and Resident Geologist Program (RGP) staff to Mississauga lands and resource manager. <i>Outcome:</i> Continued relationship building with the community by providing updates and keeping the community engaged as project partners.
Temagami First Nation	October 22, 2020	<i>Purpose:</i> OGS technical staff provided a report-back to community on completed Sturgeon River area airborne geophysical survey via a virtual presentation. Hard-copy maps and DVDs were provided to the community beforehand. <i>Outcome:</i> Community satisfied with the data presented and continued relationship building.
Nokiiwin Tribal Council	December 9, 2020 March 23, 2021	<i>Purpose:</i> “Geology 101” and “Minerals in our lives” presentations were given during 2 separate Nokiiwin training weeks. <i>Outcome:</i> Attending members enjoyed the presentation. Good introduction and refresher for lands and resource staff.

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.3-1 to 3-3.*

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Community	Visit	Purpose and Outcome
Anishinabek Nation Northern Superior Regional Table	February 1, 2021 May 4, 2021	<i>Purpose:</i> Meetings focussed on environmental assessments, rehabilitation, and critical minerals. <i>Outcome:</i> Attended to answer any OGS related questions. Continued relationship building and engagement.
Anishinabek Nation Lake Huron Regional Table	February 2, 2021 May 5, 2021	<i>Purpose:</i> Meeting focussed on environmental assessments, rehabilitation, and critical minerals. <i>Outcome:</i> Attended to answer any OGS related questions. Continued relationship building and engagement.
Anishinabek Nation Southeast and Southwest Regional Table	February 3, 2021 May 6, 2021 July 20, 2021	<i>Purpose:</i> Meeting focussed on environmental assessments, rehabilitation, and critical minerals. <i>Outcome:</i> Attended to answer any OGS related questions. Continued relationship building and engagement.
Bingwi Neyaashi Anishinaabek (Sand Point First Nation)	February 26, 2021	<i>Purpose:</i> Provided an update on the Georgia Lake area bedrock geology mapping project. <i>Outcome:</i> Sand Point appreciated being engaged and is supportive of the project. Lands and resource staff introduced to OGS. Community members may join mapping crew for a day to learn more about the project.
Biinjitiwaabik Zaaging Anishnaabek (Rocky Bay First Nation)	February 26, 2021	<i>Purpose:</i> Provided an update on the Georgia Lake area bedrock geology mapping project. <i>Outcomes:</i> Rocky Bay continues to be supportive of the project. Community members may join mapping crew for a day to learn more about the project.
Constance Lake First Nation	April 7, 2021	<i>Purpose:</i> Engage with the lands and resources staff for future work and collaboration. <i>Outcome:</i> Once community reopens, OGS will start by offering a presentation by the RGP and continue to build the relationship with the community.
Red Rock Indian Band	April 26, 2021	<i>Purpose:</i> Provided an update on the Georgia Lake area bedrock geology mapping project. <i>Outcomes:</i> Red Rock continues to be supportive of the project. Community members may join mapping crew for a day to learn more about the project.
Anishinabek Nation Technician Table	May 19, 2021	<i>Purpose:</i> Presented OGS online tools and live demonstration with RGP and Earth Resources and Geoscience Mapping Section (ERGMS) staff. <i>Outcome:</i> Technicians were engaged and appreciated learning how the tools and data can be used for land use planning, future development and other applications.
Mineral Development Advisor and Community Communication Liaison Officer Training	June 16, 2021	<i>Purpose:</i> "Minerals in our lives" presentation was given by the RGP. <i>Outcome:</i> Trainees enjoyed the presentation and generated good discussion.
Grand Council Treaty #3	June 25, 2021	<i>Purpose:</i> Presented OGS online tools and live demonstration with RGP and ERGMS staff. <i>Outcome:</i> Presentation provided to lead technician. Likely to have follow up session with other GCT#3 technicians.
Red Rock Indian Band	August 23, 2021	<i>Purpose:</i> Provided an update on the Georgia Lake area bedrock geology mapping project to new lands and resource director. <i>Outcomes:</i> Red Rock still supportive of the project and appreciate being updated. May have community members attend a day of mapping with the crew.
Red Rock Indian Band	August 31, 2021	<i>Purpose:</i> Follow-up presentation to explain OGS services and products. <i>Outcomes:</i> Community will likely be much more engaged with OGS once community reopens.

FIRST NATION BEST PRACTICES DOCUMENT

The IGLs have prepared a First Nations Best Practices Guide that can be shared internally with staff and be provided to new OGS staff during onboarding. The Indigenous Consultation and Partnership Branch (ICPB) assisted in the review of this guide to ensure it is accurate. The intent of this introductory guide is to provide staff with the base knowledge of best practices when interacting or visiting a First Nation community and guide them to resources for self-learning, while directing them to the IGLs for any specific questions or guidance not covered throughout the document. The guide contains 8 pages, accompanied by an appendix. Sections within the document include quick facts, tips on working, staying, and presenting to First Nation communities, working with Elders, attending Indigenous ceremonies and common terminology. The appendixes contain a treaty map of Ontario and a list of Ontario's Tribal Councils and associated First Nation communities.

MONTHLY INDIGENOUS LEARNING ACTIVITIES

During monthly OGS section staff meetings, the IGLs have been presenting Indigenous learning activities. Presentations have covered topics such as land acknowledgments, traditional uses of rocks and smudging. These short activities help introduce staff to various Indigenous topics, where staff are then encouraged to do their own follow-up research or contact IGL for more information and resources.

WOODLAND ART PRESENTATIONS

Throughout the year, the IGL has given presentations on Indigenous woodland art. The presentation has been given both internally to staff and externally to the Rainbow District School Board (Sudbury). The presentation is focussed on introducing woodland art and demonstrating the multiple ways of interpreting the art using paintings from the IGLs personal collection. Woodland art is used as an avenue to share Indigenous history and customs and explain why the IGL role is important to the organization.

TRANSLATED OGS PROMOTIONAL PLACEMAT

In 2021, the OGS developed a promotional placemat explaining the OGS organization. The IGL has had the placemat translated into Cree Syllabic, in both N and L dialects. As the language revitalization is currently happening in Indigenous communities, this translated document will be an effective way to support engagement with the communities. The OGS plans to further translate the document into other Indigenous languages that can be found across Ontario, such as Oji-Cree and Ojibway.

These new products developed by the IGLs will make Indigenous engagement by OGS staff more meaningful and effective, as the materials are improving the knowledge and competencies of OGS staff as it relates to Indigenous engagement.

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Earth Resources and Geoscience Mapping Section

4. Earth Resources and Geoscience Mapping Section: 2021–2022 Program and Projects Overview



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GOAL AND RESPONSIBILITY OF THE SECTION

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

The ERGMS is responsible for

- mapping Ontario’s Precambrian and Phanerozoic bedrock geology and assessing its inherent resources at a regional scale;
- mapping and sampling of Quaternary sediments for the purpose of mineral resource assessment, land-use planning, aggregate delineation, geotechnical applications, etc.;
- three-dimensional (3-D) mapping of Quaternary and Phanerozoic hydrostratigraphic units and their contained groundwater resources at a regional scale; 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 better understand the effect of hydrocarbon interaction on groundwater resources.

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 Northern Development, Mines, Natural Resources and Forestry (NDMNR). Ministry and Government priorities are achieved through specific ERGMS strategies and initiatives that consist of one or more projects. Staff of the OGS conducts an annual, project planning

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.4-1 to 4-24.*

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 COVID-19 pandemic has had widespread impacts in these past 2 years. In Ontario, the provincial government implemented a work from home directive shortly after March 17, 2020. The ongoing impacts of the pandemic necessitated the cancellation of the Ontario Geological Survey's 2020 summer field season, and significantly restricted the 2021 summer field season. The transition from office work to remote work for many occurred relatively smoothly in 2020, and continued during 2021, with most staff being able to continue with work on their projects despite the physical workplace shutdown. This is reflected in the 17 articles included in this volume, as well as the list of publications released by ERGMS staff in 2021, as summarized in this article. Furthermore, staff have still been able to connect with clients via email and other electronic methods. As of this writing, planning is underway for a gradual return to the workplace at the Willet Green Miller Centre in Sudbury.

The ERGMS supported 70 active projects during the 2021–2022 fiscal year, which includes 53 active core projects and 17 active collaborative projects (Table 4.1). The collaborative projects include 2 projects with other provincial ministries; 5 projects with the Geological Survey of Canada (GSC); 2 projects with the City of Ottawa; 1 project in collaboration with the Mineral Exploration Resource Centre (MERC) at Laurentian University, Metal Earth and the Royal Ontario Museum (ROM); and 12 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 2020 to November 2021, inclusive, the ERGMS produced 3 Open File Reports, 9 Preliminary Maps, 11 Miscellaneous Releases—Data (MRD), 3 Geophysical Data Sets (GDS), 64 airborne geophysical survey maps and 1 database update (*see* “List of Publications” in this article for a complete listing of these publications; the geophysical maps are grouped by theme for the survey area). The ERGMS provincial-scale compilation databases consist of the Aggregate Resources of Ontario, the Lake Geochemistry of Ontario, and the Geochronology Inventory of Ontario, which are available for download through GeologyOntario (www.mndm.gov.on.ca/en/mines-and-minerals/applications/geologyontario) and for viewing in the Google Earth™ mapping service by downloading the appropriate .kml file through the OGSEarth Web site (www.geologyontario.mndm.gov.on.ca/ogsearth.html). 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.

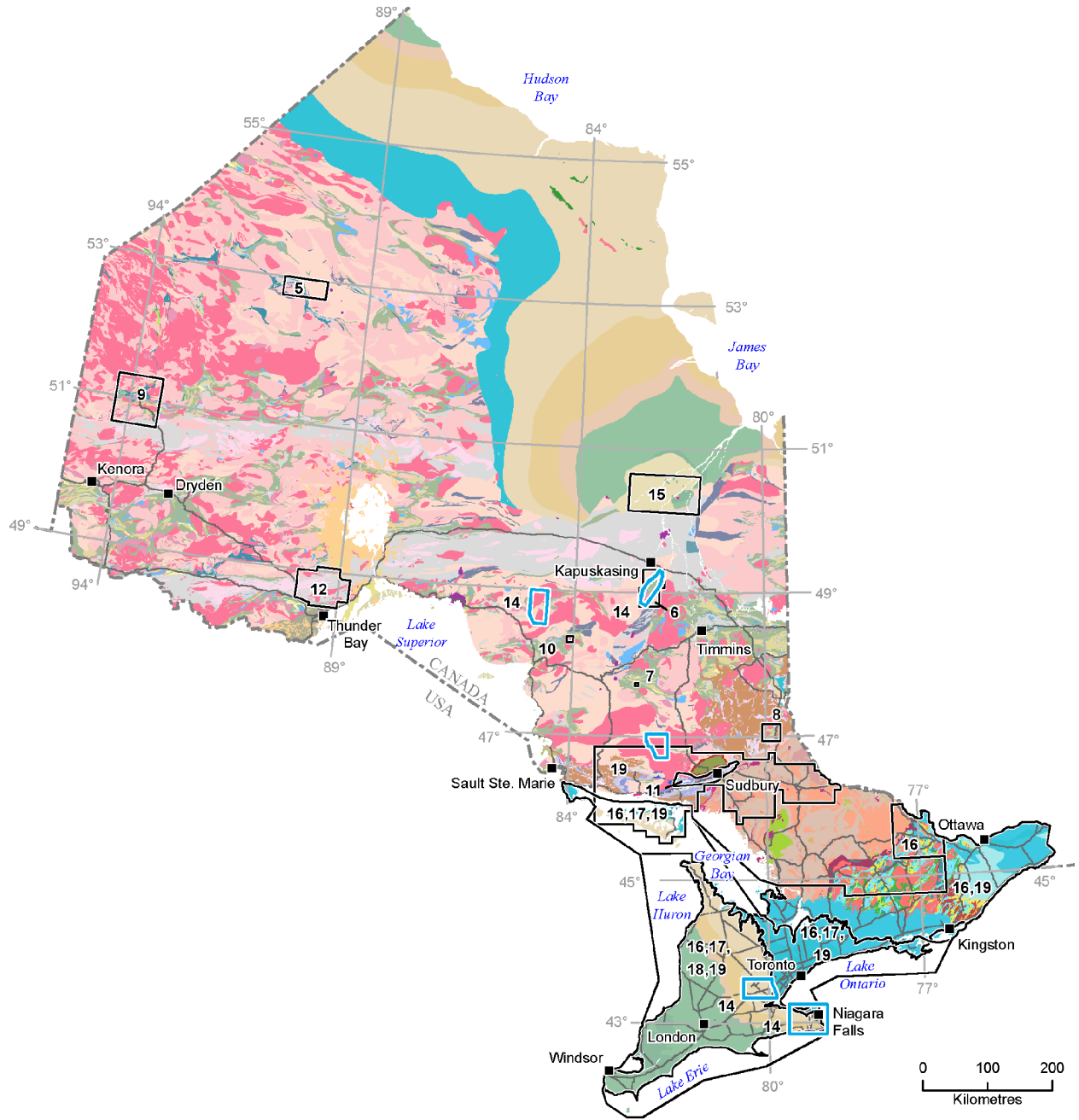


Figure 4.1. Location of the Earth Resources and Geoscience Mapping Section projects in Ontario as described in *Summary of Field Work and Other Activities, 2021*. Numbers correspond to article numbers; note: articles 1-4, 13, 20 and 21 are provincial in scope and are not indicated on the figure. Blue polygons represent geophysical survey areas. Bedrock geology from Ontario Geological Survey (2011).

Table 4.1. Earth Resources and Geoscience Mapping Section collaborative initiatives and projects, 2021–2022.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Geophysical Techniques in Support of Bedrock Geology Mapping Initiative	Airborne time-domain electromagnetic and magnetic survey over the Saganash area, west-central Ontario <ul style="list-style-type: none"> ▶ project management and QA/QC of airborne geophysical surveys 	ERGMS Core Program	Completed – Airborne survey in the Saganash Lake area western central Ontario: survey flown in winter 2021. Geophysical Data Set and maps published in October 2021 <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> (this volume, Article 6)
	Airborne gravity and magnetic surveys over the Mozhabong Lake and Nameigos Lake areas, north-central Ontario <ul style="list-style-type: none"> ▶ Reprocessing and/or reformatting of donated survey data 	ERGMS Core Program (data sets donated by Nuclear Waste Management Organization)	Completed – Geophysical Data Sets and maps published in October 2021.
	Airborne geophysical surveys, request for data <ul style="list-style-type: none"> ▶ Purchase of geophysical data from exploration companies for public release 	ERGMS Core Program	Request issued in March 2021. Request period ended in May 2021.
“Ring of Fire” Initiative	Bedrock geology and compilation of the Fort Hope–Miminiska greenstone belt <ul style="list-style-type: none"> ▶ multi-year bedrock geology mapping and compilation 	ERGMS Core Program	Ongoing – Field work completed. Preliminary Map and MRD for Peninsular Lake area mapped in 2017 published in June 2021. Preliminary Maps and MRDs for Makokibatan Lake area mapped in 2016 and Wabassi area mapped in 2017 published in June 2021. Compilation map and OFR in progress.
Far North Land Use Planning Initiative	Bedrock geological compilation of the North Caribou–Wachuska Lakes area, North Caribou greenstone belt	ERGMS Core Program	New project – Compilation in progress. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> (this volume, Article 5)
	Far North terrain mapping project <ul style="list-style-type: none"> ▶ remote predictive mapping, field checking; Quaternary mapping ▶ Sandy Lake area ▶ Pickle Lake–Cat Lake area 	ERGMS Core Program	Ongoing – Predictive Quaternary geology mapping in the Sandy Lake area in 2018, preliminary maps in progress. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> articles published in 2017, 2018 Ongoing – Predictive Quaternary geology mapping in the Pickle Lake–Cat Lake area in 2019. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> article published in 2019, 2020

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	Geochemistry of detrital chromites: investigating their use as a vector to nickel-copper-PGE, chromium and iron-titanium-vanadium deposits	ERGMS Core Program	Completed – MRD published in March 2021.
	Marathon region sediment and water sampling project ▶ high-density lake sediment and water geochemistry survey	ERGMS Core Program	Ongoing. ▶ MRD in progress
	Biogeochemical and electrical investigations in soils over a forest ring ▶ Thorn North forest ring	ERGMS Core Program University of Alberta University of Toronto	Ongoing – Field work completed, analyses in progress. ▶ <i>Summary of Field Work</i> articles published in 2018, 2019 ▶ Journal Paper: von Gunten et al. (2018)
	Surficial geochemistry sampling over the Borden Lake area and Kapuskasing Structural Zone	ERGMS Core Program (internship project: L.M. Colgrove)	Ongoing – OFRs and MRDs in preparation. ▶ <i>Summary of Field Work</i> article published in 2016
	Surficial mapping and geochemical and mineralogical characterization of Ni-Cu-PGE mineralization in Denison and Drury townships	PhD Thesis (S. Hashmi) Laurentian University– Queen’s University	Ongoing – Field work completed, analyses in progress, OFR and MRD published in 2018. ▶ <i>Summary of Field Work</i> article published in 2016
Surficial Mapping of Northern Ontario Initiative	Highway 17 Mapping and Sampling Initiative	ERGMS Core Program	New project – Mapping and sampling begun in September 2021.
	Quaternary geological mapping along the Highway 11 corridor ▶ 1:50 000 scale surficial mapping and sampling	ERGMS Core Program	Completed – Iroquois Falls to Smooth Rock Falls area mapped in 2016; Kapuskasing and Opatatika areas mapped in 2017: Preliminary Maps for Cochrane, Abitibi and Iroquois Falls areas published in 2019; Preliminary Maps for Kapuskasing and Smooth Rock Falls published in 2020. OFR and MRD released in October 2021. ▶ <i>Summary of Field Work</i> articles published in 2016, 2017, 2018, 2020

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

Table 4.1, continued.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Proterozoic Initiative	Southwest Sudbury Structure bedrock geology mapping project ▶ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – Bedrock mapping in Denison Township in 2018: Preliminary Map, OFR and MRD published in 2018 for Drury Township mapped in 2015–2016. ▶ <i>Summary of Field Work</i> articles published in 2016, 2017, 2018
	Structural, metamorphic and lithologic controls on low-sulphide PGE mineralization, Denison and Drury townships	PhD Thesis (C-A. Généreux) Laurentian University	Ongoing – Field work completed, analyses in progress. ▶ <i>Summary of Field Work</i> articles published in 2016, 2017
	Proterozoic mafic intrusions of the Sudbury area: Compilation and characterization project	ERGMS Core Program	New project – Compilation and database construction begun. ▶ <i>Summary of Field Work</i> (this volume, Article 11)
	Geology and mineral potential of Scarfe, Cobden, Thomson and Patton townships, Blind River area, Southern Province ▶ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – No mapping in 2020, bedrock mapping in Scarfe and part of Cobden townships in 2019. ▶ <i>Summary of Field Work</i> article published in 2019
	Geology of the Brudenell area, Grenville Province ▶ multi-year 1:50 000 bedrock geology and compilation mapping project to improve understanding of the geology and mineral deposits	ERGMS Core Program	Ongoing – Field work completed: Preliminary Map, MRD and OFR in progress.
	Geology of the Cobden area, Grenville Province ▶ multi-year 1:50 000 scale bedrock geology and compilation mapping project to improve understanding of the geology and mineral deposits	ERGMS Core Program	Ongoing – Field work completed: OFR and MRD published in 2017. ▶ Preliminary Map and OFR in progress
	Geology of the Perth area, Grenville Province ▶ multi-year 1:50 000 scale bedrock geology and compilation mapping project to improve understanding of the geology and mineral deposits	ERGMS Core Program	Ongoing – Field work completed: OFR published in 2017, MRD published in 2019. ▶ Preliminary Map and OFR in progress
	Geology of Carleton Place area, Grenville Province ▶ multi-year 1:50 000 scale bedrock geology and compilation mapping project to improve understanding of the geology and mineral deposits	ERGMS Core Program	Ongoing – Bedrock mapping of part of Carleton Place map area in 2019. ▶ <i>Summary of Field Work</i> articles published in 2017, 2018, 2019
	Geology of the Renfrew area, Grenville Province ▶ 1:50 000 scale bedrock geology and compilation mapping	ERGMS Core Program	Ongoing – Field work completed, analyses in progress, Preliminary Map and MRD in progress. ▶ <i>Summary of Field Work</i> article published in 2018

Abbreviations: 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	Southern Swayze area (Abitibi greenstone belt) bedrock geology mapping project <ul style="list-style-type: none"> ▶ 1:20 000 scale bedrock geology mapping 	ERGMS Core Program	Ongoing – No mapping in 2020, bedrock mapping in Heenan and Benton townships and part of Esther Township in 2019; Preliminary Map and MRD published in 2019 and 2020 for Mallard and Marion townships and part of Genoa Township mapped in 2018; Preliminary Map and MRD for Yeo and Chester townships area published in 2017 and 2018; Preliminary Map and MRD published in 2018 for Osway and Huffman townships and parts of Eric, Fingal and Arbutus townships mapped in 2017. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> articles published in 2016, 2017, 2018, 2019
	Swayze area (Abitibi greenstone belt) metavolcanic evolution study <ul style="list-style-type: none"> ▶ 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. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> article in 2017 and this volume (Article 7)
	Gold metallogeny in the Swayze area of the Abitibi greenstone belt	PhD thesis (E.C.G. Hastie) Laurentian University	Ongoing – Field trip guidebook published in 2017, MRD in progress. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> articles published in 2015, 2016 ▶ PhD completed in 2021
	Structural and tectonic study of the Swayze area of the Abitibi greenstone belt	PhD thesis (Q. Wu) University of Waterloo	Ongoing – Field work completed. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> articles published in 2015, 2016
	Northern Swayze area (Abitibi greenstone belt) bedrock geology mapping project <ul style="list-style-type: none"> ▶ 1:20 000 scale bedrock geology mapping 	ERGMS Core Program	Ongoing – Field work completed. Bedrock mapping of Reeves and Sewell townships in 2019. Preliminary Map and MRD published in January 2021. Bedrock mapping in Penhorwood Township in 2018, Preliminary Map and MRD published in December 2020. OFR and compilation map in progress. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> articles published in 2018, 2019
		ERGMS Core Program (internship project: L.E.D. Vice)	Completed – Bedrock mapping in Kenogaming Township completed: Preliminary Map published in December 2019; MRD published in December 2020. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> article published in 2018
	Northeast Michipicoten greenstone belt bedrock geology mapping <ul style="list-style-type: none"> ▶ 1:20 000 scale bedrock geology mapping 	ERGMS Core Program	Ongoing – No mapping in 2021. Preliminary Map for Stover Township published in 2019, Preliminary Maps and MRDs for Copenace and Bruyere townships published in 2018. <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> articles published in 2016, 2017, 2018, 2019 and this volume (Article 10)

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, <i>continued</i>	Temagami greenstone belt bedrock mapping project ▶ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – No mapping in 2021, reconnaissance bedrock mapping in 2019. ▶ <i>Summary of Field Work</i> articles published in 2019 and this volume (Article 8)
	Tectonometamorphic history of the Wawa–Abitibi terrane, northeastern Ontario: a deep crustal <i>P–T</i> transect from the Kapuskasing uplift to the Island Gold Mine	PhD thesis (J. Kendrick) University of Waterloo	Ongoing – Sampling transects in 2018 and 2019, analyses in progress. ▶ <i>Summary of Field Work</i> articles published in 2018, 2019 ▶ Journal paper: Kendrick, Duguet and Yakymchuk (2021)
	The Rundle intrusive complex: investigating oxidation processes related to gold mineralization in an Archean alkalic intrusive setting	MSc thesis (C. Small) Laurentian University–MERC (Metal Earth)	Ongoing – Field work completed. ▶ <i>Summary of Field Work</i> article published in 2018
	Abitibi greenstone belt cross-border digital assemblage map	ERGMS Core Program Geological Survey of Canada (GSC) Bureau de la connaissance géoscientifique du Québec (BCGQ)	New project – Discussion of cross-border geological nomenclature.
	Bedrock geology and compilation of the Ramsey–Algoma intrusive complex and surrounding rocks ▶ multi-year bedrock geology mapping and compilation 1:100 000	ERGMS Core Program	Ongoing - No mapping in 2021, reconnaissance bedrock mapping in 2019. ▶ <i>Summary of Field Work</i> articles published in 2019, 2020
Geology of Northwestern Ontario Initiative	Bedrock geology mapping of Marks and Conmee townships ▶ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – No mapping in 2021. Preliminary Map and MRD for Marks Township published in 2019; Preliminary Map for Conmee Township and MRD in progress. ▶ <i>Summary of Field Work</i> articles published in 2017, 2018
	Rowan–Kakagi lakes area bedrock geology mapping project ▶ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – Field work completed, analyses in progress; Preliminary Maps and MRD in progress. ▶ <i>Summary of Field Work</i> articles published in 2016, 2017
	Bedrock geology mapping of the western Schreiber–Hemlo greenstone belt ▶ 1:20 000 scale bedrock geology mapping	ERGMS Core Program	Completed – Preliminary Map for Syine Township and OFR (guidebook) published in 2019; Preliminary Map and MRD for Walsh and Tuuri townships published in 2017 and 2018; Preliminary Map and MRDs for Priske, Strey and Syine townships published in April 2021. OFR waiting publication. ▶ <i>Summary of Field Work</i> articles published in 2016, 2017, 2018

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	Structural study of the Dogpaw and Dubenski gold deposits in the Rowan–Kakagi lakes area	MSc Thesis (A.D. Kraft-Jones) University of Waterloo	Ongoing – Field work completed. ▶ <i>Summary of Field Work</i> articles published in 2016, 2017
	Bedrock geology mapping and rare-mineral potential in the central Quetico Subprovince ▶ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – No mapping in 2021, bedrock mapping of the Georgia Lake area, Quetico Subprovince in 2019. ▶ <i>Summary of Field Work</i> articles published in 2019, 2020
	Bedrock geology mapping of the Quetico Subprovince and related Proterozoic rocks northwest of Thunder Bay ▶ 1:50 000 scale bedrock geology mapping	ERGMS Core Program	Ongoing – No mapping in 2021, bedrock mapping of western MacGregor Township and portions of the Hicks Lake, Greenwich Lake, Tartan Lake and Onion Lake areas in 2019. ▶ <i>Summary of Field Work</i> articles published in 2019, 2020, and this volume (Article 12)
	Geological compilation of the Red Lake, Red Lake greenstone belt, Uchi Subprovince	ERGMS Core Program	New project – Compilation in progress. ▶ <i>Summary of Field Work</i> (this volume, Article 9)
	Petrology and geochemistry of mafic to ultramafic rocks of the Nakina area, English River Subprovince, northwestern Ontario	MSc Thesis (S. Killins) Lakehead University	Ongoing – Geochemical study of drill core donated to the Resident Geologist Program in Thunder Bay, sampling in fall 2020.
2-D and 3-D Surficial Sediment Groundwater Mapping Initiative	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 – Quaternary 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. ▶ <i>Summary of Field Work</i> articles published in 2016, 2017, 2018, 2019 ▶ PhD completed in 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: MRD published in 2020, GRS in progress. ▶ <i>Summary of Field Work</i> articles published in 2015, 2016, 2017
	Regional groundwater systems mapping in the County of Simcoe, southern Ontario	ERGMS Core Program	Ongoing – Groundwater sampling in 2018 and 2019. ▶ <i>Summary of Field Work</i> in 2018, 2019
	Various groundwater geoscience projects (groundwater data mining, chemostratigraphic framework; 3-D model of surficial geology) in southern Ontario as part of the Federal groundwater program	Geological Survey of Canada (GSC)	Ongoing – OGS input into 3-D sediment model of southern Ontario. ▶ GSC Special Volume published in 2020 (Russell and Kjarsgaard 2020) summarizing projects
	Surficial and subsurface sediment mapping in the City of Ottawa, eastern Ontario	ERGMS Core Program	Ongoing – No field work in 2021. ▶ <i>Summary of Field Work</i> article published in 2019

Abbreviations: 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	Renfrew County Aggregate Resources Inventory	ERGMS Core Program	Ongoing – Sand and gravel and selected bedrock areas mapping have been published in the ARO 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. ▶ <i>Summary of Field Work</i> 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. ▶ <i>Summary of Field Work</i> article published in 2018 ▶ OFR in progress
	Identification of the distribution of pyrrhotite in Ontario, as related to its deleterious effects in concrete	ERGMS Core Program	Completed – desk-top study completed. ▶ MRD completed and <i>in press</i> as MRD 395
2-D and 3-D Paleozoic Bedrock Geology Groundwater Mapping Initiative	Bedrock aquifer, karst and Early Silurian sequence stratigraphic mapping project	ERGMS Core Program	Completed – Field work completed, GRS published in 2020.
	Characterization of groundwater flow systems of the Early Silurian carbonates, Niagara Escarpment cuesta	ERGMS Core Program City of Guelph PhD Thesis (E.H. Priebe) University of Waterloo	Ongoing – Field work completed. ▶ GRS published in 2017; MRDs published in 2016, 2021; 2 papers published, 1 paper in progress ▶ PhD completed in 2019
	Update karst map for southern Ontario	ERGMS Core Program	Ongoing – Mapping and sampling in 2019. ▶ <i>Summary of Field Work</i> article published in 2019
	Various groundwater geoscience projects (3-D geological model of Paleozoic bedrock) in southern Ontario as part of the Federal groundwater program	ERGMS Core Program Geological Survey of Canada (GSC)	3-D model published in 2019 as GRS 19 (Carter et al. 2019) ▶ <i>Summary of Field Work</i> articles published in 2017, 2018
Paleozoic Initiative	Paleozoic geology of eastern Ontario ▶ 1:50 000 bedrock geology mapping; establish stratigraphic framework for the area	ERGMS Core Program	Ongoing – No mapping in 2021, bedrock mapping and stratigraphic work in 2019. ▶ <i>Summary of Field Work</i> articles published in 2017, 2018, 2019 and in this volume (Article 16)
	South Niagara Peninsula bedrock geology mapping project	ERGMS Core Program	Ongoing – Field work completed. ▶ Preliminary Maps published in 2017 and 2018; 1 Preliminary Map in progress

Abbreviations: ARIP, *Aggregates Resources Inventory Paper*; ARO, *Aggregate Resources of Ontario [database]*; GRS, *Groundwater Resources Study*; MRD, *Miscellaneous Release—Data*; OFR, *Open File Report*

Table 4.1, continued.

Initiative	Project	ERGMS Core Program / Project Collaborator(s)	Project Progress
Ambient Groundwater Geochemistry Mapping Groundwater Initiative	Ambient Groundwater Geochemistry projects, southern Ontario ▶ data interpretation	ERGMS Core Program	Ongoing. ▶ update of MRD 283—Revised, completed and <i>in press</i> as MRD 283—Revision 2. ▶ <i>Summary of Field Work</i> (this volume, Article 19)
	Ambient Groundwater Geochemistry project, eastern Ontario (east Ottawa—Champlain Township)	ERGMS Core Program City of Ottawa	Field work completed. ▶ <i>Summary of Field Work</i> article published in 2017; update of MRD 283—Revised, completed and <i>in press</i> as MRD 283—Revision 2.
	Ambient Groundwater Geochemistry project, eastern Ontario (west Ottawa groundwater study)	ERGMS Core Program City of Ottawa	Ongoing – Field work completed. ▶ <i>Summary of Field Work</i> article published in 2019 ▶ data incorporated into update of MRD 283—Revised, completed and <i>in press</i> as MRD 283—Revision 2.
	Ambient Groundwater Geochemistry project, northeastern Ontario (North Bay)	ERGMS Core Program	Ongoing – Field work completed in 2018. ▶ <i>Summary of Field Work</i> article published in 2018 ▶ data to be incorporated into new northern ambient groundwater database MRD in 2022
	Ambient Groundwater Geochemistry project, northeastern Ontario (Manitoulin and North Shore)	ERGMS Core Program	Ongoing – Field work completed in 2017. ▶ <i>Summary of Field Work</i> article published in 2017 ▶ data to be incorporated into new northern ambient groundwater database MRD in 2022
	Ambient Groundwater Geochemistry project, northeastern Ontario (Sudbury)	ERGMS Core Program	Ongoing – Field work completed in 2016. ▶ <i>Summary of Field Work</i> article published in 2016 ▶ data to be incorporated into new northern ambient groundwater database MRD in 2022
	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, analyses in progress. ▶ OFR and northern Ontario ambient groundwater database MRD in progress for publication in 2022 ▶ <i>Summary of Field Work</i> article in 2020
	Characterization of groundwater chemistry, bedrock topography, marine sediment thickness and their inter-relationships along the south bank of the Ottawa River between Ottawa and Hawkesbury, eastern Ontario	MSc Thesis (S. Foubister) University of Ottawa	Ongoing – desk-top study in progress.

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)	ERGMS Core Program	Ongoing – beta version of provincial-scale compilation database released in 2019; update planned for 2022
	Aggregate Resources of Ontario (ARO)	ERGMS Core Program	Ongoing – Provincial-scale compilation database first published in 2015, with updates published in 2018, 2019, 2020 (second update of 2020 released in 2021)
	Lake Geochemistry of Ontario (LakeGeochemON)	ERGMS Core Program	Inaugural publication of beta version of provincial-scale compilation database in March 2020
	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 (ROM)	Ongoing – laboratory and desktop study, data acquisition and analysis in progress <ul style="list-style-type: none"> ▶ <i>Summary of Field Work</i> article in 2020 ▶ <i>Summary of Field Work</i> (this volume, Article 13)

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

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

The ERGMS main strategies consist of applying geoscience techniques

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

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

1. team initiatives (i.e., Geology of Northeastern Ontario Initiative) consisting of individual projects that are designed to meet an overall goal;
2. interjurisdictional collaborative team initiatives, such as the recently completed (March 2020) Targeted Geoscience Initiative 5 (TGI-5); and
3. 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:
 - 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.
- 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;
 - developing inventories of various tectonic settings relevant to mineral exploration;
 - 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. Metal Earth has conducted several major seismic and geological surveys in Ontario: the Larder Lake, Matheson and Swayze areas in the Abitibi Subprovince, the Kapuskasing area, the Cobalt area, the eastern Sudbury Basin, and the Beardmore–Geraldton, Sturgeon Lake, Dryden–Stormy River, Atikokan and Rainy River areas of the Wabigoon Subprovince. Metal Earth conducted a limited field season in the summer 2021 because of COVID-19 restrictions; details on these activities can be found on the Metal Earth Web site (<https://merc.laurentian.ca/research/metal-earth>) [accessed December 5, 2021].

As mentioned in articles in previous years (Simard 2017, 2018, Hechler et al. 2019, 2020), the OGS is a provincial partner of Metal Earth. Its participation in Metal Earth activities includes providing access to 1) zircons that were used in U/Pb geochronology studies conducted by the OGS, as well as the OGS geochronology database; 2) OGS geochemical data; 3) OGS geophysical data; and 4) OGS rock properties data.

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 are being led by GSC geoscientists in Ontario and some ERGMS geoscientists have shared information and knowledge to support these various projects over the last year (e.g., Hollings et al. 2021; Bleeker et al. 2020).

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. In addition, some residual activities in support of the OGS–GSC groundwater geoscience collaboration (formal agreement between 2014–2019) are ongoing, and plans are underway to host the annual OGS–GSC–Conservation Ontario workshop in a virtual format in 2022.

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. The ERGMS also supported and/or participated in several collaborative projects with academic partners in 2021 (*see* Table 4.1). Three of these projects were completed in 2021.

Following 3 groundwater mapping studies, completed with the South Nation Conservation Authority and local municipalities, in partnership with the OGS, to support the development of an Aquifer Capability Screening Tool (ACST) in eastern Ontario municipalities: the City of Clarence–Rockland (pilot study, 2013–2015) (Morton et al. 2013; Morton 2015; Geofirma Engineering Ltd. 2016), the Township of Alfred and Plantagenet (2015–2017) (Di Iorio, Lemieux and Hamilton 2015; Morrison Hershfield 2017) and the City of Ottawa (targeting eastern rural parts of the City) and Champlain Township. The program was continued in 2019–2020 within western rural parts of the City of Ottawa within western rural Ottawa (Di Iorio et al. 2019).

INTERJURISDICTIONAL AND COMMITTEE REPRESENTATION

Staff of the ERGMS represented the Ministry of Northern Development, Mines, Natural Resources and Forestry, the OGS and other geoscience organizations on several interjurisdictional committees, internal committees and associations during the 2020–2021 fiscal year, which are summarized below:

- North American Commission on Stratigraphic Nomenclature (representing the Geological Association of Canada and Commissioner at Large)
- Paleontology Division of the Geological Association of Canada
- Great Lakes Geologic Mapping Coalition
- CAMIRO Geochemical Expert Committee
- 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)
- NDM Information Technology–Information Management (IT/IM) Strategy Committee
- 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, Ohio State University, University of Western Ontario, University of Toronto, Chinese Academy of Sciences)

- organizing committee for the 68th annual meeting of the Institute on Lake Superior Geology (ILSG) in Sudbury in spring 2022
- 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

Robert Cormier accepted the Manager, Geoscience Mapping position within the Sedimentary and Environmental Geoscience Section of ERGMS. Desmond Rainsford, Senior Geoscience Leader, Geophysics, retired in the fall of 2021. Seamus Magnus, Precambrian Geoscientist, left the OGS in the summer of 2021. Sarah Ferguson accepted a temporary acting assignment as Precambrian Geoscientist. Jose Pallot accepted a permanent position in the Geoscience Laboratories. Jon Webb accepted a temporary acting assignment in the Information Lands Branch.

LIST OF PUBLICATIONS²

- Azar, B. 2021a. Geological, geochemical and geophysical data from the Makokibatan Lake area, Fort Hope–Miminiska greenstone belt, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 380.
- 2021b. Geological, geochemical and geophysical data from the Wabassi River area, Fort Hope–Miminiska greenstone belt, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 389.
- 2021c. Geological, geochemical and geophysical data from the Peninsular Lake area, Fort Hope–Miminiska greenstone belt, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 394.
- Azar, B. and Bellrose, J. 2021a. Precambrian geology of the Makokibatan Lake area, Fort Hope–Miminiska greenstone belt, west half, northwestern Ontario; Ontario Geological Survey, Preliminary Map P.3843, scale 1:50 000.
- 2021b. Precambrian geology of the Makokibatan Lake area, Fort Hope–Miminiska greenstone belt, east half, northwestern Ontario; Ontario Geological Survey, Preliminary Map P.3844, scale 1:50 000.
- Azar, B., Hakimian, M.N. and Zammit, K. 2021. Precambrian geology of the Wabassi River area, Fort Hope–Miminiska greenstone belt, northwestern Ontario; Ontario Geological Survey, Preliminary Map P.3829, scale 1:100 000.
- Azar, B., Zammit, K. and Hakimian, M.N. 2021. Precambrian geology of the Peninsular Lake area, Fort Hope–Miminiska greenstone belt; Ontario Geological Survey, Preliminary Map P.3849, scale 1:50 000.
- Béland Otis, C. 2020. Application of subsurface mapping to the interpretation of Paleozoic structures from lineament analysis of high-resolution aeromagnetic data in the Chatham Sag, southwestern Ontario; Ontario Geological Survey, Open File Report 6362, 171p.
- Burt, A.K. 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.

² This list provides references for 91 publications produced by ERGMS, during the period from December 2020 to November 2021, inclusive, comprising 3 Open File Reports, 9 Preliminary Maps, 11 Miscellaneous Releases—Data (MRD), 1 database update, 3 Geophysical Data Sets (GDS) and 64 airborne geophysical survey maps (the geophysical maps are grouped by theme for the survey area).

- Gao, C., Crabtree, D.C., Dyer, R.D. and Clarke, S.A. 2021. Indicator mineral and geochemistry data for the till and alluvium sampling survey in the McFaulds Lake (“Ring of Fire”) area, northern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 322 – Revised.
- Hastie, E.C.G. and Magnus, S.J. 2021a. Precambrian geology, Strey township; Ontario Geological Survey, Preliminary Map P.3846, scale 1:20 000.
- 2021b. Geological, geochemical, and petrographic data from Strey Township, western Schreiber–Hemlo greenstone belt, Wawa–Abitibi terrane, Superior Province, northwestern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 382.
- Magnus, S.J. 2021a. Precambrian geology, Priske township; Ontario Geological Survey, Preliminary Map P.3845, scale 1:20 000.
- 2021b. Geological, geochemical, and petrographic data from Priske Township and Nd, Sm and Sr isotopic data from Priske, Strey, Syine, Tuuri and Walsh townships, western Schreiber–Hemlo greenstone belt, Wawa–Abitibi terrane, Superior Province; Ontario Geological Survey, Miscellaneous Release—Data 381.
- Marich, A.S. 2021a. Quaternary geology mapping in the Great Clay Belt of northeastern Ontario: A study of sediments and glacial landforms along the Highway 11 corridor from Kapuskasing to Iroquois Falls; Ontario Geological Survey, Open File Report 6369, 57p.
- 2021b. Results of till and esker sand sampling in the Great Clay Belt of northeastern Ontario: Ontario Geological Survey, Miscellaneous Release—Data 392.
- Ontario Geological Survey 2020. Summary of Field Work and Other Activities, 2020; Ontario Geological Survey, Open File Report 6370, 182p.
- 2021a. Aggregate Resources of Ontario—2020; Ontario Geological Survey, Aggregate Resources of Ontario, database (June 2021 update).
- 2021b. Ontario airborne geophysical surveys, magnetic and electromagnetic data, grid and profile data (ASCII and Geosoft® formats) and vector data, Saganash Lake area; Ontario Geological Survey, Geophysical Data Set 1089.
- 2021c. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 026, scale 1:20 000.
- 2021d. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 027, scale 1:20 000.
- 2021e. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 028, scale 1:20 000.
- 2021f. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 029, scale 1:20 000.
- 2021g. Airborne magnetic and electromagnetic surveys, colour-filled contours of the residual magnetic field and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 030, scale 1:50 000.
- 2021h. Airborne magnetic and electromagnetic surveys, colour-filled contours of the residual magnetic field and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 031, scale 1:50 000.

- 2021i. Airborne magnetic and electromagnetic surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 032, scale 1:50 000.
- 2021j. Airborne magnetic and electromagnetic surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 033, scale 1:50 000.
- 2021k. Airborne magnetic and electromagnetic surveys, colour-filled contours of the EM decay constant and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 034, scale 1:50 000.
- 2021l. Airborne magnetic and electromagnetic surveys, colour-filled contours of the EM decay constant and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 035, scale 1:50 000.
- 2021m. Airborne magnetic and electromagnetic surveys, colour-filled contours of the apparent conductivity and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 036, scale 1:50 000.
- 2021n. Airborne magnetic and electromagnetic surveys, colour-filled contours of the apparent conductivity and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 037, scale 1:50 000.
- 2021o. Ontario airborne geophysical surveys, magnetic and gravimetric data, grid and profile data (ASCII and Geosoft® formats) and vector data, Nameigos Lake area; Ontario Geological Survey, Geophysical Data Set 1250.
- 2021p. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 484, scale 1:20 000.
- 2021q. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 485, scale 1:20 000.
- 2021r. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 486, scale 1:20 000.
- 2021s. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 487, scale 1:20 000.
- 2021t. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 488, scale 1:20 000.
- 2021u. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 489, scale 1:20 000.
- 2021v. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 490, scale 1:20 000.
- 2021w. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Nameigos Lake area; Ontario Geological Survey, Map 60 491, scale 1:20 000.
- 2021x. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 492, scale 1:20 000.
- 2021y. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 493, scale 1:20 000.
- 2021z. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 494, scale 1:20 000.

- 2021aa. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 495, scale 1:20 000.
- 2021ab. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 496, scale 1:20 000.
- 2021ac. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 497, scale 1:20 000.
- 2021ad. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 498, scale 1:20 000.
- 2021ae. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Nameigos Lake area; Ontario Geological Survey, Map 60 499, scale 1:20 000.
- 2021af. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 500, scale 1:20 000.
- 2021ag. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 501, scale 1:20 000.
- 2021afh Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 502, scale 1:20 000.
- 2021ai. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 503, scale 1:20 000.
- 2021aj. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 504, scale 1:20 000.
- 2021ak. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 505, scale 1:20 000.
- 2021al. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 506, scale 1:20 000.
- 2021am. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 507, scale 1:20 000.
- 2021an. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 508, scale 1:20 000.
- 2021ao. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 509, scale 1:20 000.
- 2021ap. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 510, scale 1:20 000.

- 2021aq. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 511, scale 1:20 000.
- 2021ar. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 512, scale 1:20 000.
- 2021as. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 513, scale 1:20 000.
- 2021at. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 514, scale 1:20 000.
- 2021au. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Nameigos Lake area; Ontario Geological Survey, Map 60 515, scale 1:20 000.
- 2021av. Ontario airborne geophysical surveys, magnetic and gravimetric data, grid and profile data (ASCII and Geosoft® formats) and vector data, Mozhabong Lake area; Ontario Geological Survey, Geophysical Data Set 1251.
- 2021aw. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Mozhabong Lake area; Ontario Geological Survey, Map 60 516, scale 1:20 000.
- 2021ax. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Mozhabong Lake area; Ontario Geological Survey, Map 60 517, scale 1:20 000.
- 2021ay. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Mozhabong Lake area; Ontario Geological Survey, Map 60 518, scale 1:20 000.
- 2021az. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Mozhabong Lake area; Ontario Geological Survey, Map 60 519, scale 1:20 000.
- 2021ba. Airborne magnetic and gravimetric surveys, colour-filled contours of the residual magnetic field, Mozhabong Lake area; Ontario Geological Survey, Map 60 520, scale 1:20 000.
- 2021bb. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Mozhabong Lake area; Ontario Geological Survey, Map 60 521, scale 1:20 000.
- 2021bc. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Mozhabong Lake area; Ontario Geological Survey, Map 60 522, scale 1:20 000.
- 2021bd. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Mozhabong Lake area; Ontario Geological Survey, Map 60 523, scale 1:20 000.
- 2021be. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Mozhabong Lake area; Ontario Geological Survey, Map 60 524, scale 1:20 000.
- 2021bf. Airborne magnetic and gravimetric surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Mozhabong Lake area; Ontario Geological Survey, Map 60 525, scale 1:20 000.

- 2021bg. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 526, scale 1:20 000.
 - 2021bh. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 527, scale 1:20 000.
 - 2021bi. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 528, scale 1:20 000.
 - 2021bj. Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 529, scale 1:20 000.
 - 2021bk Airborne magnetic and gravimetric surveys, colour-filled contours of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 530, scale 1:20 000.
 - 2021bl. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 531, scale 1:20 000.
 - 2021bm. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 532, scale 1:20 000.
 - 2021bn. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 533, scale 1:20 000.
 - 2021bo. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 534, scale 1:20 000.
 - 2021bp. Airborne magnetic and gravimetric surveys, colour-filled contours of the first vertical derivative of the terrain-corrected Bouguer gravity, Mozhabong Lake area; Ontario Geological Survey, Map 60 535, scale 1:20 000.
- Priebe, E.H. 2021. Groundwater hydrochemistry, water isotope and manual water-level data for the Early Silurian carbonates of the Niagara Escarpment Cuesta; Ontario Geological Survey, Miscellaneous Release—Data 390.
- Vice, L.E.D. and MacDonald, P.J. 2020. Precambrian geology of Penhorwood Township, northern Swayze area, Abitibi greenstone belt, northeastern Ontario; Ontario Geological Survey, Preliminary Map P.3842, scale 1:20 000.
- 2021a. Precambrian geology of Reeves Township, northern Swayze area, Abitibi greenstone belt, northeastern Ontario; Ontario Geological Survey, Preliminary Map P.3847, scale 1:20 000.
 - 2021b. Precambrian geology of Sewell Township, northern Swayze area, Abitibi greenstone belt, northeastern Ontario; Ontario Geological Survey, Preliminary Map P.3848, scale 1:20 000.
 - 2021c. Geological, geochemical and geophysical data related to Reeves and Sewell townships, northern Swayze area, Abitibi greenstone belt, northeastern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 393 – Revised.
 - 2021d. Geological, geochemical and geophysical data related to Penhorwood and Kenogaming townships, northern Swayze area, Abitibi greenstone belt, northeastern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 378 – Revised.

REFERENCES

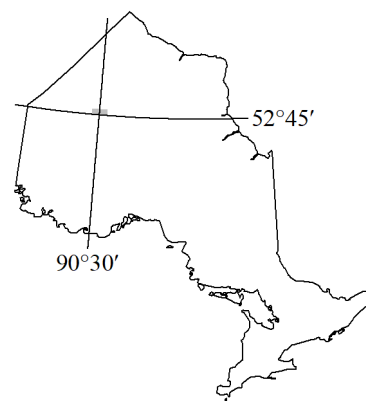
- Bleeker, W., Smith, J., Hamilton, M.[A.], Kamo, S.[L.], Liikane, D., Hollings, P., Cundari, R.[M.], Easton, [R.]M. and Davis, D.[W.] 2020. The Midcontinent Rift and its mineral systems: Overview and temporal constraints of Ni-Cu-PGE mineralized intrusions; *in* Advances in the understanding of Canadian Ni-Cu-PGE and Cr ore systems – Examples from the Midcontinent Rift, the Circum-Superior Belt, the Archean Superior Province, and Cordilleran Alaskan-type intrusions, Geological Survey of Canada, Open File 8722, p.7-35.
- Carter, T.R., Brunton, F.R., Clark, J.[K.], Fortner, L., Freckelton, C.N., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L. and Yeung, K.H. 2019. Three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Ontario Geological Survey, Groundwater Resources Study 19 / Geological Survey of Canada, Open File 8618, 45p.
- Di Iorio, T., Harrison, R.A., Al, T., Majury, A. and Hamilton, S.M. 2019. West Ottawa groundwater study; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6360, p.23-1 to 23-9.
- Di Iorio, T., Lemieux, A.J. and Hamilton, S.M. 2015. Township of Alfred and Plantagenet groundwater study; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.38-1 to 38-6.
- Geofirma Engineering Ltd. 2016. Clarence–Rockland Groundwater study: Development of an Aquifer Capability Screening Tool; unpublished report, Geofirma Engineering Ltd., 144p.
- Hechler, J.H., Easton, R.M., Rainsford, D.R.B., Bajc, A.F., Préfontaine, S. and Hamilton, S.M. 2019. Earth Resources and Geoscience Mapping Section: 2019–2020 Program and Projects Overview; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.4-1 to 4-22.
- Hechler, J.H., Easton, R.M., Rainsford, D.R.B., Préfontaine, S., Hamilton, S.M. and Dyer, R.D. 2020. Earth Resources and Geoscience Mapping Section: 2020–2021 Program and Projects Overview; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6370, p.4-1 to 4-21.
- Hollings, P., Smyk, M.[C.], Bleeker, W., Hamilton, M.A., Cundari, R.[M.] and Easton, R.M. 2021. Geology of the Mesoproterozoic Pillar Lake Volcanics and the Inspiration Sill, Armstrong, Ontario: Evidence of early Midcontinent Rift volcanism in the northwestern Nipigon Embayment; Canadian Journal of Earth Sciences, v.58, p.1116-1131. doi.org/10.1139/cjes-2021-0012
- Kendrick, J., Duguet, M. and Yakymchuk, C. 2021. Diversification of Archean tonalite-trondhjemite-granodiorite suites in a mushy middle crust; Geology, published online September 20, 2021. doi.org/10.1130/G49287.1
- Morrison Hershfield 2017. Development of an Aquifer Capability Screening Tool, Township of Alfred and Plantagenet; unpublished report, Morrison Hershfield, 53p.
- Morton, S.R. 2015. Development and evaluation of an aquifer capability screening tool. Pilot Study: Clarence–Rockland, Ontario; unpublished MSc thesis, University of Ottawa, Ottawa, Ontario, 113p.
- Morton, S.R., Di Iorio, T., Hamilton, S.M. and Robin, M.J.L. 2013. Development of an aquifer mapping tool, City of Clarence–Rockland, Ontario; *in* Summary of Field Work and Other Activities, 2013, Ontario Geological Survey, Open File Report 6290, p.40-1 to 40-7.
- Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.
- Russell, H.A.J. and Kjarsgaard, B.A., eds. 2020. Southern Ontario groundwater project 2014–2019: Summary report; Geological Survey of Canada, Open File 8536, 245p.

Simard, R-L. 2017. Earth Resources and Geoscience Mapping Section: 2017–2018 Program and Projects Overview; *in* Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p.4-1 to 4-29.

——— 2018. Earth Resources and Geoscience Mapping Section: 2018–2019 Program and Projects Overview; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.4-1 to 4-30.

von Gunten, K., Hamilton, S.M., Zhong, C., Nesbø, C., Li, J., Muehlenbachs, K., Konhauser, K.O. and Alessi, D.S. 2018. Electron donor-driven bacterial and archaeal community patterns along forest ring edges in Ontario, Canada; *Environmental Microbiology Reports*, v.10, p.663-672. doi.org/10.1111/1758-2229.12678

5. Project FN-21-002. Geological Compilation Map of the North Caribou–Wachusk Lakes Area, North Caribou Greenstone Belt, Northwestern Ontario



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INTRODUCTION

A six-month desktop geological compilation mapping project covering the north-central portion of the North Caribou greenstone belt (NCGB) was initiated by the Ontario Geological Survey (OGS) in 2021. The compilation mapping area is in the North Caribou–Wachusk Lake area, corresponding with the areas represented by National Topographic System (NTS) map sheets 53 B/15 and 53 B/16 (Figure 5.1). This project is proposed as the initial phase of a broader, multi-year NCGB mapping project. This article summarizes the rationale and objectives of this initial phase.

The NCGB is located approximately 500 km north of Thunder Bay and is host to the Musselwhite Mine in its southern extent (*see* Figure 5.1). Despite hosting this producing gold mine, the NCGB remains largely unexplored, although, in recent years, there has been an increase in the number of active mining claims in the NCGB.

The Musselwhite Mine has been in production since 1997 and continues to expand its resources and reserves with a measured and indicated resource of 340 000 ounces gold and proven and probable reserves of 1.79 million ounces gold (Newmont Corporation, news release, February 10, 2021). In addition to its potential for gold, the NCGB is also prospective for volcanogenic massive sulphide (VMS) deposits. Romios Gold Resources Inc. has been exploring for gold since 1996 on their Lundmark–Akow property, which is located within the compilation mapping area (*see* Figure 5.1). In 1999, a copper-(gold) zone was intersected during drilling, which was later interpreted to be a lower alteration zone associated with a larger VMS system (Biczok 2017). In 2019, the company conducted a small drilling program, in which a few VMS horizons were intersected, as well as an adjacent high-grade gold-quartz vein, assaying 8.64 g/t Au over 4.75 m. The company recently initiated a 2021 drilling program to test the VMS horizons intersected during their 2019 drilling program (Romios Gold Resources Inc., news release, September 7, 2021).

The continued success of projects such as those described above highlights the potential for more discoveries within this largely unexplored belt, and the need for an updated series of digital maps to help assist with exploration in the region.

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.5-1 to 5-8.*

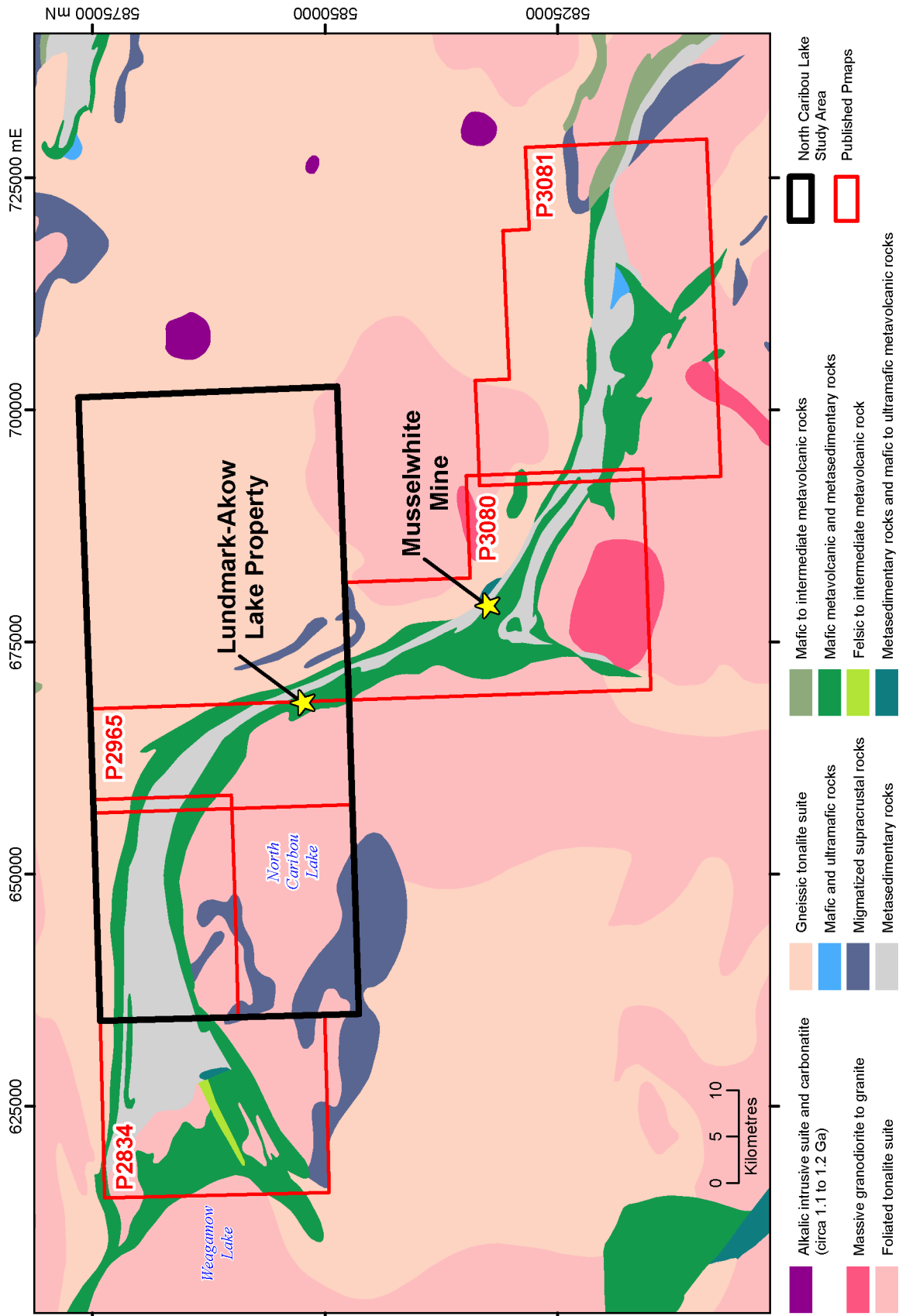


Figure 5.1. 1:250 000 scale geological map (Ontario Geological Survey 2011) showing the proposed North Caribou Lake–Wachusk Lakes geological compilation mapping area (black outline; NTS map sheets 53 B/15 and 53 B/16) and the Ontario Geological Survey Preliminary Map (“Pmaps”) coverage from the 1980s (red outlines). Important mineral deposits in the North Caribou greenstone belt are also noted by the yellow stars.

PREVIOUS WORK

The eastern portion of the NCGB was first mapped by Satterly (1941), followed by reconnaissance mapping by the Geological Survey of Canada (Emslie 1962) and the OGS (Thurston, Sage and Siragusa 1979). An airborne magnetometer survey was flown in 1960 and published at a scale of 1:63 000 by the Ontario Department of Mines and the Geological Survey of Canada (Ontario Department of Mines–Geological Survey of Canada 1960a, 1960b). A high-resolution airborne electromagnetic and total intensity magnetic survey was flown in 1985 by the OGS (Ontario Geological Survey 1985).

The NCGB was mapped in greater detail by the OGS over a three-year period from 1984 to 1986, resulting in 4 preliminary maps that covered the majority of the belt at a scale of 1:31 680 (*see* Figure 5.1; Bartlett et al. 1985; Breaks et al. 1986; Breaks, Osmani and deKemp 1987a, 1987b). An airborne geophysical survey conducted by the OGS in 2003 yielded high-resolution magnetic and electromagnetic data for the Opapimiskan Lake area (Ontario Geological Survey 2003a, 2003b). Apart from this 2003 survey, there has been no other field work completed by the OGS in the NCGB since the mapping in the 1980s. Furthermore, the granitoid rocks surrounding the NCGB have not been mapped or studied in nearly as much detail as the supracrustal rocks of the NCGB.

Geochronological studies have been conducted throughout the belt, most extensively within the vicinity of the Musselwhite Mine. High-precision U/Pb geochronological data were first obtained regionally within the belt by DeKemp 1987. Since then, additional regional sampling has been done by Davis and Moore (1991), Davis and Stott (2001), McNicoll et al. (2016) and Kelley and Schneider (2015). Geochronological studies around the Musselwhite Mine have been performed by Biczok et al. (2012), Van Lankvelt et al. (2016) and Oswald (2018). Published ages in the compilation area are shown in Figure 5.2 and summarized in Table 5.1.

GEOLOGICAL SETTING

The NCGB is a metavolcanic–metasedimentary belt surrounded mainly by younger granitic and gneissic rocks, forming a portion of the core of the North Caribou terrane (Thurston, Osmani and Stone 1991; Stott et al. 2010). The northern margin of the NCGB has been interpreted as the domain boundary between the North Caribou core and the Island Lake domain to the north (Stott et al. 2010). The NCGB has been subdivided into various supracrustal assemblages by different authors (deKemp 1987; Breaks and Bartlett 1991; Breaks et al. 1991; Breaks, Osmani and deKemp 2001; Thurston, Osmani and Stone 1991). Three of these occur in the compilation area (the South Rim assemblage, the North Rim assemblage and the Eyapamikama assemblage; *see* Figure 5.2).

The South Rim assemblage (*circa* 2980 Ma; Davis and Stott 2001; McNicoll et al. 2016; Biczok et al. 2012) occurs along the southern margin of the belt and is composed of variably metamorphosed massive to pillowed mafic volcanic rocks and minor felsic to intermediate volcanic rocks with rare banded iron formation (Breaks, Osmani and deKemp 2001).

The North Rim assemblage (2870±2 Ma; Davis and Stott 2001) occurs along the northern margin of the belt, and consists predominantly of variably metamorphosed massive to pillowed mafic volcanic rocks, with rare ultramafic volcanic, felsic to intermediate volcanic and sedimentary rocks (Breaks, Osmani and deKemp 2001). The North Rim assemblage is bounded to the north and east by a ductile cataclastic shear zone, separating it from the Schade Lake gneiss, and to the south by a brittle–ductile deformation zone along its contact with the Eyapamikama assemblage (Breaks et al. 1991; Breaks, Osmani and deKemp 2001).

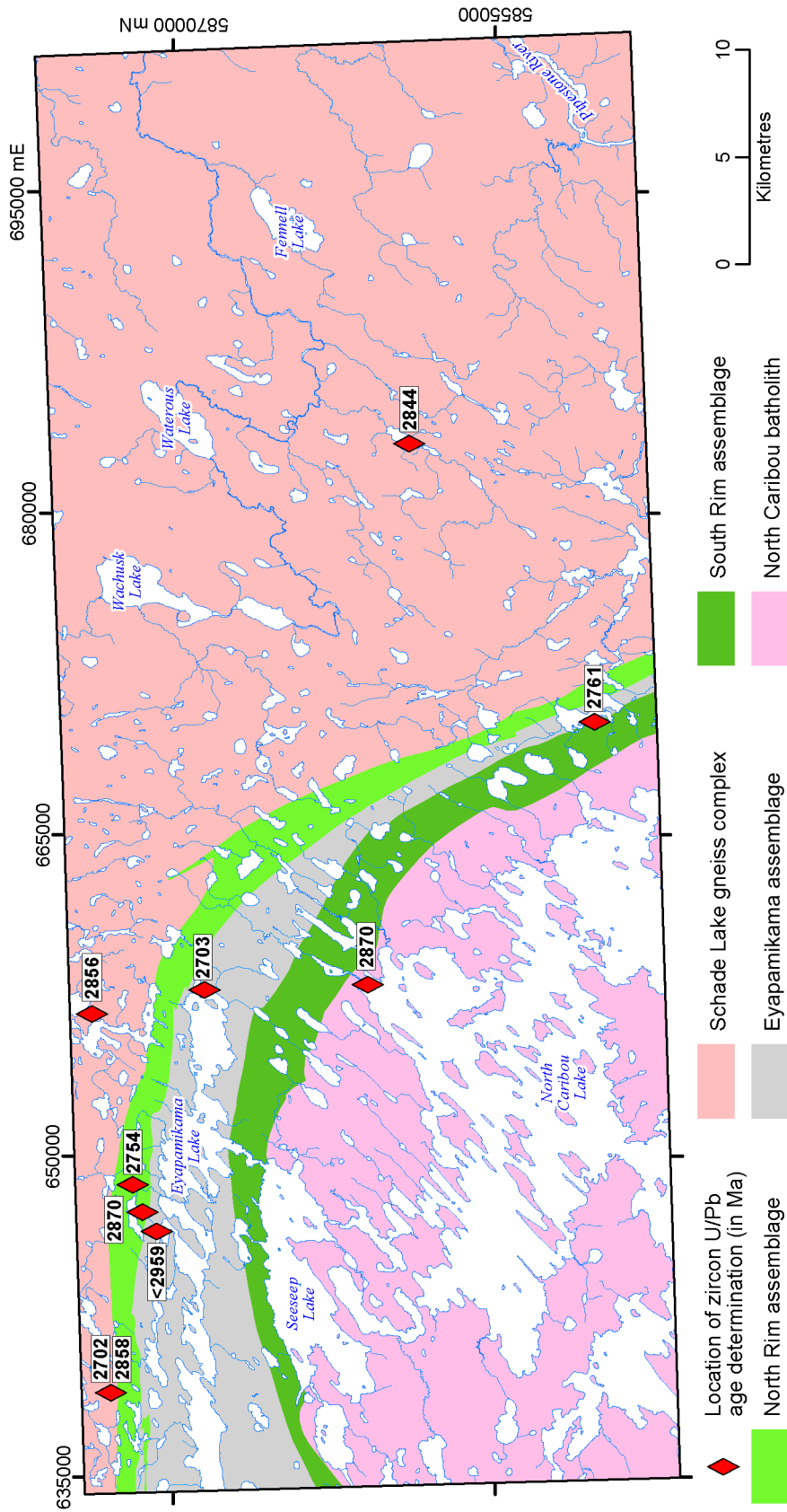


Figure 5.2. Tectonostratigraphic assemblages map for the compilation mapping area (*after* Breaks and Bartlett 1991). North Rim assemblage consists of mafic volcanic rocks with rare ultramafic volcanic, felsic to intermediate volcanic and sedimentary rocks; South Rim assemblage consists of mafic volcanic rocks with minor felsic to intermediate volcanic rocks and rare banded iron formation; Eyapamikama assemblage is a clastic sedimentary sequence; Schade Lake gneiss complex consists of massive to gneissic tonalite, trondhjemite, granite and quartz diorite; North Caribou batholith is a massive tonalite-trondhjemite-granodiorite complex. Also shown are all published U/Pb zircon ages for samples from the compilation mapping area with details provided in Table 5.1.

Table 5.1. Uranium–lead (U/Pb) zircon ages for samples in the compilation mapping area.

Age (Ma)	Method ^a	Easting (m) ^b	Northing (m) ^b	Sample Number	Rock Type and Assemblage	Interpretation	Source ^c
2870 ± 2	ID-TIMS	647250	5871500	DD87-9	Rhyolite, North Rim	Age of eruption	1
<2959 ± 2	ID-TIMS	646627	5870793	DD85-22	Conglomerate, Eyapamikama	Maximum age of deposition	2
2856 ± 1.8	ID-TIMS	656609	5873890	DD85-26	Trondhjemite, Schade Lake gneiss complex	Emplacement	2
2844 ± 15	LA-ICP-MS	683290	5858973	52	Not specified, Schade Lake gneiss complex	Emplacement	3
2702 ± 57	LA-ICP-MS	638939	5872856	71P	Highly evolved granite, Schade Lake gneiss complex	Emplacement	3
2858 ± 5	LA-ICP-MS	638939	5872856	71D	Not specified, Schade Lake gneiss complex	Emplacement	3
2870 ± 2	ID-TIMS	658002	5860947	DD85-21	Tonalite, North Caribou batholith	Emplacement	4
2761 ± 13	SIMS	670288	5850306	Akow Lake	Andalusite-sillimanite-staurolite schist, Eyapamikama	Metamorphism	5
2703 ± 17	SIMS	657715	5868570	East eyap	Cordierite schist, Eyapamikama	Metamorphism	5
2754 ± 16	SIMS	648708	5871865	NCGB13-01	Garnet schist, North Rim	Metamorphism	5

^a Abbreviations: ID-TIMS, isotope dilution thermal ionization mass spectrometry; LA-ICP-MS, laser ablation inductively coupled plasma mass spectrometry; SIMS, secondary ion mass spectrometry.

^b Locations provided as Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 15.

^c Sources: 1 = Davis and Stott (2001); 2 = deKemp (1987); 3 = Van Lankvelt et al. (2016); 4 = Davis and Moore (1991); 5 = Kelley and Schneider (2015).

The Eyapamikama assemblage (<2960 Ma: deKemp 1987; Davis and Stott 2001) separates the North Rim and South Rim assemblages and is the youngest supracrustal assemblage within the compilation area, apparently overlying both the North and South Rim volcanic rocks (Breaks, Osmani and deKemp 2001). The assemblage is a fining-upward sequence of metamorphosed alluvial fan conglomerate, feldspathic arenite and deep-water fine-grained turbidites (Breaks, Osmani and deKemp 2001).

There are 3 intrusive events documented surrounding the NCGB, occurring at *circa* 2990 Ma, 2850 to 2870 Ma and *circa* 2700 Ma (deKemp 1987; Davis and Moore 1991; Davis and Stott 2001; Biczok et al. 2012; Van Lankvelt et al. 2016). Within the compilation area, granitoid rocks of the North Caribou batholith and Schade Lake gneiss complex are present (*see* Figure 5.2).

The North Caribou batholith (*circa* 2870 Ma: deKemp 1987; Davis and Moore 1991; Davis and Stott 2001; Van Lankvelt et al. 2016) occurs south and west of the NCGB and is a predominantly massive tonalite–trondhjemite–granodiorite complex that becomes increasingly foliated toward its intrusive contact with the NCGB (Breaks, Osmani and deKemp 2001).

The Schade Lake gneiss complex (*circa* 2860 Ma: deKemp 1987; Biczok et al. 2012; Van Lankvelt et al. 2016) bounds the NCGB to the north and east. It is highly deformed, consisting of massive to gneissic tonalite, trondhjemite, granite and quartz diorite (Breaks, Osmani and deKemp 2001). The contact with the NCGB is tectonic in nature, with a ductile cataclastic zone evident along its length (Breaks, Osmani and deKemp 2001). In the compilation area, an alkali-feldspar-rich gneissic band, also part of the Schade Lake gneiss complex, yielded a younger age of 2702±57 Ma, which was interpreted to indicate a protracted history of intrusion and deformation within the gneiss complex (Van Lankvelt et al. 2016). Younger plutonism has also been identified south of the compilation area near the Musselwhite Mine, where several granites yielded U/Pb ages of *circa* 2700 Ma, coeval with the timing of the local gold mineralization (Biczok et al. 2012).

Metamorphic grade ranges throughout the belt from hornfels and greenschist to upper amphibolite facies, generally increasing in grade across the belt from the northwest toward the southeast, with the highest metamorphic conditions occurring in the North Rim assemblage (Breaks et al. 1991; Breaks, Osmani and deKemp 2001; Kelly and Schneider 2015). Timing of regional metamorphism and hydrothermal activity has been constrained to between 2700 and 2790 Ma (Kelly and Schneider 2015), coincident with other gold mineralizing and tectonic events within the western Superior Province. An earlier regional metamorphic event between 2981 and 2870 Ma, and subsequent contact metamorphism resulting from the emplacement of the North Caribou batholith at 2870 Ma also have been suggested based on overprinting metamorphic assemblages (Breaks, Osmani and deKemp 2001).

Three deformation events (D_1 , D_2 and D_3) have been documented throughout the NCGB (Breaks, Osmani and deKemp 2001). The D_2 deformation event (<2846 Ma: McNicoll et al. 2016) is the most dominant, resulting in a steeply dipping penetrative foliation present throughout most of the belt as well as variably developed lineations and folds. Syn- D_2 shear zones are also developed throughout the belt, typically along lithological contacts and the axial planes of F_2 folds (Breaks, Osmani and deKemp 2001). Syn- D_2 shearing has been correlated with anomalous gold mineralization at several locations in the NCGB, including at the Musselwhite Mine (Breaks, Osmani and deKemp 2001), although the timing of gold mineralization may be much younger (cf. Biczok et al. 2012).

OBJECTIVES

Although the OGS map products from the 1980s continue to demonstrate accuracy, the black and white, hand-drawn maps are difficult to read and interpret. Hence the need for a new series of colour, geographic information system (GIS)-compatible map products for the NCGB.

For this specific project, the main objective is to produce an improved, more user-friendly 1:50 000 scale digital map product for NTS map sheets 53 B/15 and 53 B/16 (*see* Figure 5.1). This digital compilation map will be based primarily on the OGS mapping from the 1980s (Bartlett et al. 1985; Breaks et al. 1986; Breaks, Osmani and deKemp 1987a, 1987b), geochronology data (*see* Table 5.1), and the most recent high-resolution geophysical survey data for the area (Ontario Geological Survey 2003a, 2003b). The geophysical data indicate complex folding in the Schade Lake area and several high-intensity magnetic anomalies in the Wachusk Lake area (Ontario Geological Survey 2003a, 2003b) that may indicate the presence of rock types other than the granitoid rocks currently displayed on the existing maps.

Objectives for the broader NCGB project that this initial phase may contribute to include

1. improved resolution of the northern margin of the NCGB and its contact with the Schade Lake gneiss complex, including assessing the continuity of the deformation zone along it and evaluating the proposed boundary between the North Caribou terrane and the Island Lake domain, and
2. gaining insight into the significance of the younger plutonism in the Musselwhite area and its potential relationship with the D_2 deformation event and local gold mineralization, as well as the potential for this type of plutonism to occur elsewhere in the region.

ACKNOWLEDGMENTS

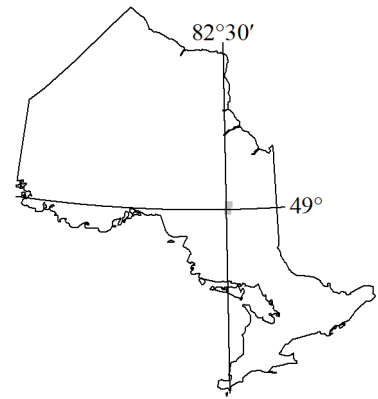
The author would like to thank Michael Easton for his geological advice and revisions to this article. Shannon Evers is thanked for her ongoing GIS support and her assistance drafting figures for this report. Saurav Biswas is acknowledged for the preparation of geophysical imagery for this project. Pat Gervais is acknowledged for drafting the figures for this report.

REFERENCES

- Biczok, J.L. 2017. Report on the 2017 diamond drilling program at the Lundmark–Akow Lake property of Romios Gold Resources Inc., Patricia Mining Division, northwestern Ontario, NTS 53 B/15 and 53 B/16, assessment file–technical report 20000015639, 92p.
- Biczok, J.[L.], Hollings, P., Klipfel, P., Heaman, L., Maas, R., Hamilton, M., Kamo, S. and Friedman, R. 2012. Geochronology of the North Caribou greenstone belt, Superior Province Canada: Implications for tectonic history and gold mineralization at the Musselwhite Mine; *Precambrian Research*, v.192, p.209-230.
- Bartlett, J.R., Breaks, F.W., deKemp, E.A. and Shields, H.N. 1985. Precambrian geology of Eyapamikama Lake area (Opapimiskan Lake project), Kenora District (Patricia Portion); Ontario Geological Survey, Preliminary Map P.2834, scale 1:31 680.
- Breaks, F.W. and Bartlett, J.R. 1991. Geology of the Eyapamikama Lake area; Ontario Geological Survey, Open File Report 5792, 132p.
- Breaks, F.W., Bartlett, J.R., deKemp, E.A. and Osmani, I.A. 1986. Precambrian geology of the Doubtful–Akow lakes area (Opapimiskan Lake project), Kenora District (Patricia Portion); Ontario Geological Survey, Preliminary Map P.2965, scale 1:31 680.
- 1991. Geology of the Doubtful–Akow lakes area, District of Kenora; Ontario Geological Survey, Open File Report 5795, 131p.
- Breaks, F.W., Osmani, I.A. and deKemp, E.A. 1987a. Precambrian geology of the Opapimiskan–Neawagank lakes area, western part (Opapimiskan Lake project), Kenora District (Patricia Portion); Ontario Geological Survey, Preliminary Map P.3080, scale 1:31 680.
- 1987b. Precambrian geology of the Opapimiskan–Neawagank lakes area, eastern part (Opapimiskan Lake project), Kenora District (Patricia Portion); Ontario Geological Survey, Preliminary Map P.3081, scale 1:31 680.
- 2001. Geology of the North Caribou Lake area, northwestern Ontario; Ontario Geological Survey, Open File Report 6023, 80p.
- Davis, D.W. and Moore, M. 1991. Geochronology in the western Superior Province, Summary Report – May, 1991; internal report for the Ontario Geological Survey, 7p.
- Davis, D.W. and Stott, G.M. 2001. Geochronology of several greenstone belts in the Sachigo Subprovince, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2001, Ontario Geological Survey, Open File Report 6070, p.18-1 to 18-13.
- deKemp, E.A. 1987. Stratigraphy, provenance and geochronology of Archean supracrustal rocks of western Eyapamikama Lake area, northwestern Ontario; unpublished MSc thesis, Carleton University, Ottawa, Ontario, 93p.
- Emslie, R.F. 1962. Wunnummin Lake (NTS 53A), Ontario; Geological Survey of Canada, Map 1-1962, scale 1:253 440.
- Kelley, C.J. and Schneider, D.A. 2015. Insights into the timing of mineralization and metamorphism in the North Caribou greenstone belt, western Superior Province; *in* Targeted Geoscience Initiative 4: Contributions to the understanding of Precambrian lode gold deposits and implications for exploration, Geological Survey of Canada, Open File 7852, p.245-253.
- McNicoll, V., Dubé, B., Castonguay, S., Oswald, W., Biczok, J., Mercier-Langevin, P., Skulski, T. and Malo, M. 2016. The world-class Musselwhite BIF-hosted gold deposit, Superior Province, Canada: New high-precision U-Pb geochronology and implications for the geological and structural setting of the deposit and gold exploration; *Precambrian Research*, v.272, p.133-149.

- Ontario Department of Mines–Geological Survey of Canada 1960a. North Caribou Lake, Kenora District, Ontario, airborne magnetic, total field; Ontario Department of Mines–Geological Survey of Canada, Geophysical Map 919G, scale 1:63 360.
- 1960b. Wachusk Lake, Kenora District, Ontario, airborne magnetic, total field; Ontario Department of Mines–Geological Survey of Canada, Geophysical Map 929G, scale 1:63 360.
- Ontario Geological Survey 1985. Geophysical/geochemical series, Opapimiskan Lake area, airborne electromagnetic survey, total intensity magnetic survey, District of Kenora, Patricia Portion; Ontario Geological Survey, Maps 80 716 to 80 753, scale 1:20 000.
- 2003a. Ontario airborne geophysical Surveys, magnetic and electromagnetic data, grid and profile data, ASCII format, Opapimiskan Lake area; Ontario Geological Survey, Geophysical Data Set 1011a.
- 2003b. Ontario airborne geophysical surveys, magnetic and electromagnetic data, grid and profile data, Geosoft® format, Opapimiskan Lake area; Ontario Geological Survey, Geophysical Data Set 1011b.
- 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.
- Oswald, W. 2018. Géologie du gisement aurifère encaissé dans des formations de fer Musselwhite, Province du Supérieur, Ontario, Canada; unpublished PhD thesis, Institut national de la recherche scientifique, Québec City, Québec, 463p.
- Satterly, J. 1941. Geology of the Windigo–North Caribou lakes area, Kenora District (Patricia Portion); Ontario Department of Mines, Annual Report, 1939, v.48, pt.9, p.1-32.
- 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.
- Thurston, P.C., Osmani, I.A. and Stone, D. 1991. Northwestern Superior Province: Review and terrane analysis; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 1, p.81-142.
- Thurston, P.C., Sage, R.P. and Siragusa, G.M. 1979. Geology of the Winisk Lake area, District of Kenora (Patricia Portion); Ontario Geological Survey, Report 193, 169p.
- Van Lankvelt, A., Schneider, D.A., Biczok, J., McFarlane, C.R.M. and Hattori, K. 2016. Decoding zircon geochronology of igneous and alteration events based on chemical and microstructural features: A study from the western Superior Province, Canada; *Journal of Petrology*, v.57, p.1309-1334.

6. Project AS-20-003. Preliminary Interpretation of the Saganash Lake Area Aeromagnetic Survey, Northeastern Ontario



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INTRODUCTION

An approximately 4747 line-kilometre, helicopter-borne, magnetic and time-domain electromagnetic (TDEM) survey was flown over the Saganash Lake area in north-central Ontario in early 2021 (Figure 6.1). The surveyed area, approximately 826 km² in size, covered a poorly studied, yet mineralized, greenstone belt located approximately 30 km south of Kapuskasing (*see* Figure 6.1). The Saganash Lake greenstone belt is accessible by a main logging road that connects Kapuskasing, Moonbeam and Foleyet. The Saganash Lake greenstone belt was last mapped at a scale of 1:63 360 in 1958 (McMurchy 1960a). The newly acquired geophysical data will be used to assist future bedrock geology mapping in the area, as well as aid in mineral exploration and land use planning.

The airborne magnetic and electromagnetic survey results were published as Geophysical Data Set (GDS) 1089 (Ontario Geological Survey 2021a) and as a set of hard-copy maps (Ontario Geological Survey 2021b-m), as shown in Figure 6.2. This article summarizes preliminary findings from the survey.

REGIONAL GEOLOGY

The Saganash Lake greenstone belt, located in the Kapuskasing Uplift of Leclair et al. (1994), is considered as part of the Wawa Subprovince. To the west, it is flanked by the Val Rita block, which consists predominantly of tonalitic gneisses, with metamorphic pressures and temperatures increasing from approximately 14 km paleodepth in the greenstone belt to 20 to 25 km paleodepth adjacent the Lepage fault on the west side of the Val Rita block (Leclair et al. 1994).

To the east, the greenstone belt is in fault contact, along the Saganash Lake fault, with the Groundhog River block of the Kapuskasing Structural Zone (*see* Figure 6.1). The Groundhog River block consists of a variety of mafic and intermediate migmatites and gneisses, which were subjected to peak metamorphic conditions at *circa* 2658 to 2648 Ma (Leclair and Sullivan 1991). These rocks formed at paleodepths of 25 to 35 km, indicating considerable structural relief along the Saganash Lake fault (Leclair et al. 1994). The eastern boundary of the Groundhog River block is the Ivanhoe Lake fault, with rocks of the Abitibi Subprovince present on the east side.

SAGANASH LAKE GREENSTONE BELT

Descriptions of the Saganash Lake greenstone belt are based mainly on the work of Hogg (1948) and McMurchy (1960a, 1960b), with some reconnaissance work by Leclair and Nagerl (1988) and Leclair and Poirier (1989). No geochemical or geochronological data are available for metavolcanic rocks from the

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Ontario Geological Survey, Open File Report 6380, p.6-1 to 6-11.

belt. The post-tectonic, Shack Lake quartz diorite pluton yielded a zircon age of $2691^{+2/-1}$ Ma (Leclair and Sullivan 1991), suggesting that the metavolcanic rocks are older than *circa* 2695 Ma, that regional deformation was completed by *circa* 2691 Ma, and that the Saganash Lake greenstone belt was relatively unaffected by the intense, high-grade metamorphic event that affected rocks of the adjacent Groundhog River block at *circa* 2658 Ma (Leclair and Sullivan 1991).

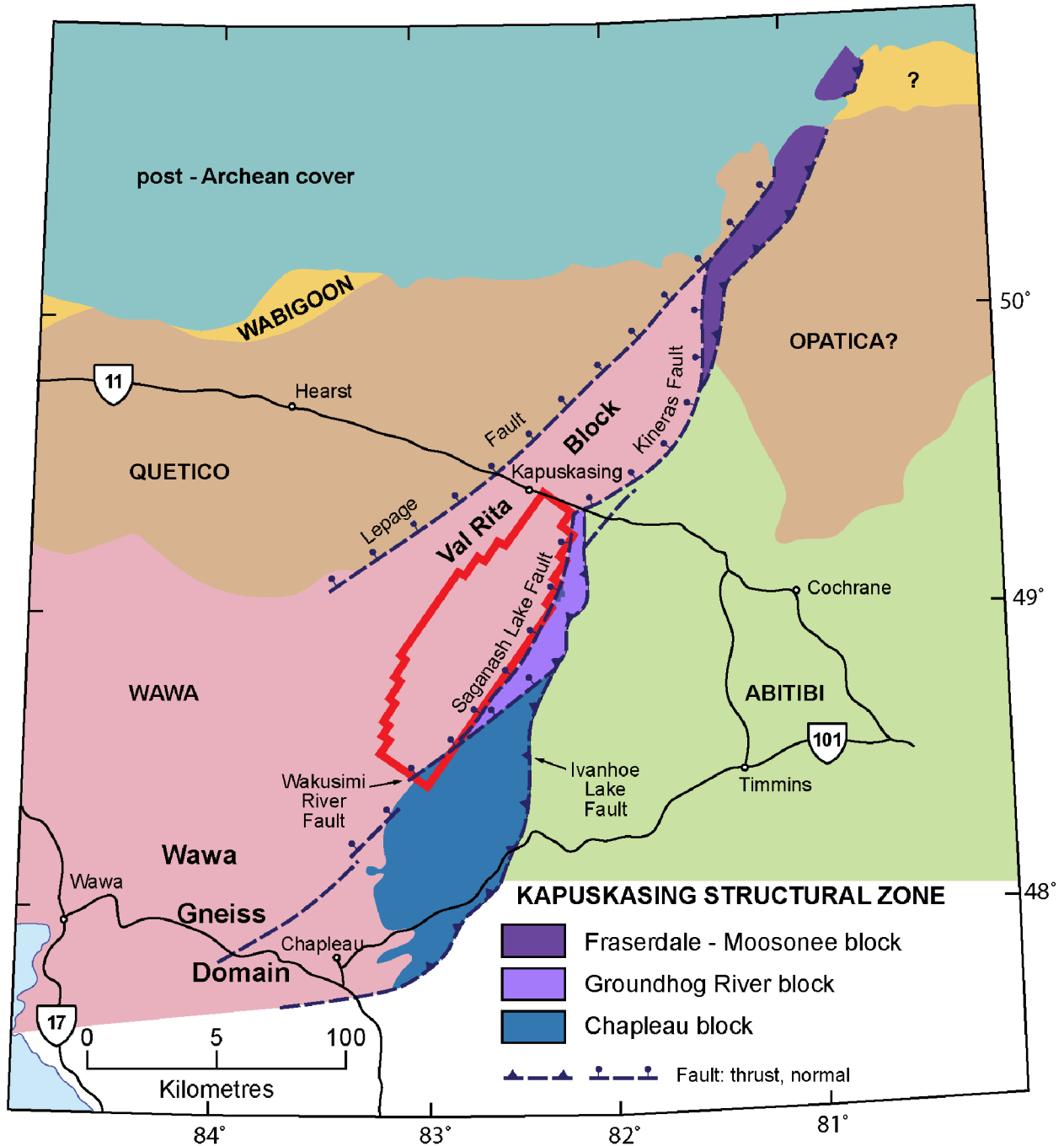


Figure 6.1. Generalized geological map of the Kapuskasing structural zone and neighbouring areas showing distribution of geological subprovinces and major structural elements of the central Superior Province (*modified from* Leclair et al. 1994). Box outlined in red indicates the area of the Saganash Lake airborne survey. The Kapuskasing Structural Zone includes the Chapleau, Groundhog River and Fraserdale–Moosonee blocks, whereas the Val Rita block and the Wawa gneiss domain are part of the Wawa Subprovince.

No stratigraphic framework is available for the Saganash Lake greenstone belt, but, based on the existing mapping and geophysical data (Ontario Geological Survey 2002), it appears to consist of a core of predominantly mafic metavolcanic rocks, now largely amphibolites, in northern Fenton Township, which is overlain by a package of metamorphosed graphitic argillite, siltstone and ironstone, which is, in turn, overlain by metasediments, with the latter being present mainly along the margins of the greenstone belt. Much of the greenstone belt lies beneath younger overburden, with most of the outcrop exposure of the greenstone belt being restricted to Fenton and Seaton townships.

The Saganash Lake greenstone belt is divided into a northern segment and a southern segment by the Nansen Creek fault (Leclair and Nagerl 1988; Leclair and Poirier 1989; Leclair et al. 1994), which appears to have minimal throw on surface, but which may be a much more significant feature at depth (Leclair et al. 1994). Interestingly, the magnetic pattern of the Saganash Lake greenstone belt is more subdued north of the Nansen Creek fault, which may indicate that the greenstone belt is either thinner, or of different composition, on the north side of the fault.

Hogg (1948, p.3) notes that “there are places where elongated pillows are recognizable, and there are also a few narrow bands of fragmental material” locally present. He goes on to note that “even in these recognizable pillow lavas, the pillow rims are generally replaced by coarsely crystalline hornblende, and a study of thin sections shows that the entire rock is converted to fine-textured hornblende and quartz”. According to (Hogg 1948, p.3), the “iron formation varies considerably along the strike. In places it is made up of bands of granular quartz and magnetite with minor amounts of black cherty quartz. In other places, it is a rusty siliceous type showing little banding and only a small amount of disseminated magnetite. This type may make up the entire width of the iron formation, or it may occur interbanded with the magnetite-quartz variety”.

The lack of known ages and geochemistry on the metavolcanic rocks of the Saganash Lake greenstone belt makes correlation with other greenstone belts of either the Abitibi or Wawa subprovinces difficult. If the iron formation indeed caps the mafic metavolcanic sequence, then the belt may be equivalent to the Deloro tectonic assemblage (*circa* 2734–2724 Ma) (*cf.* Ayer et al. 2002, 2005). The dominance of mafic metavolcanic rocks, however, is also consistent with the Stoughton–Roquemaure tectonic assemblage (*circa* 2723–2720 Ma) (*cf.* Ayer et al. 2002, 2005), rocks of which are present approximately 35 km to the east in the northernmost Abitibi Subprovince.

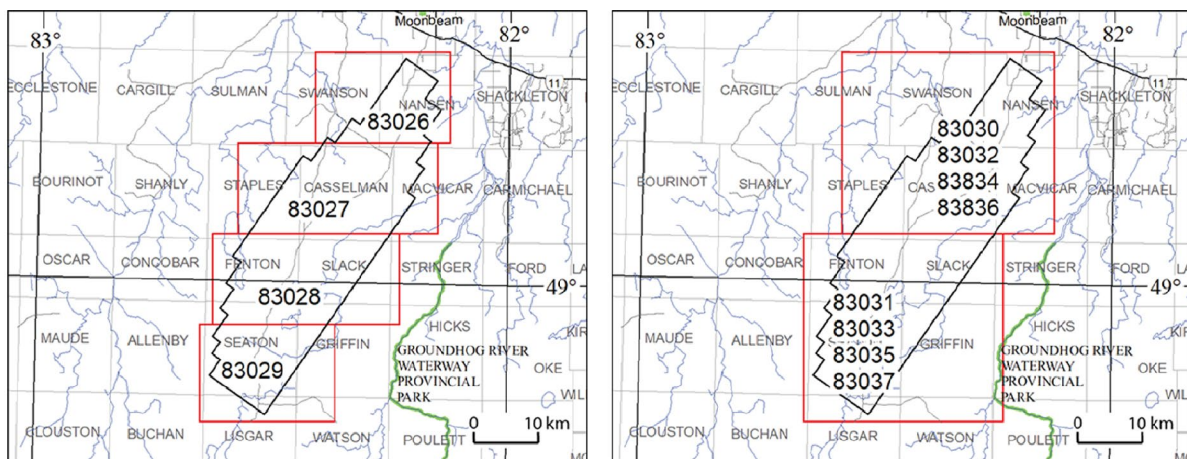


Figure 6.2. Map of northeastern Ontario showing the area covered by the Saganash Lake airborne electromagnetic survey (black outline) (Ontario Geological Survey 2021a) and the areas covered by the hard-copy geophysical maps (red outline) released in October 2021 (Ontario Geological Survey 2021b-m). Left map indicates residual magnetic field, second vertical derivative of the residual magnetic field, EM decay constant and apparent conductivity maps at 1:50 000 scale (Ontario Geological Survey 2021f-m); right map indicates residual magnetic field maps at 1:20 000 scale (Ontario Geological Survey 2021b-e). The light grey lines indicate township boundaries.

The Borden Lake greenstone belt, located approximately 135 km to the south, occurs in a similar tectonic setting, that is, it is a metavolcanic sequence situated atop migmatitic gneisses of the Kapuskasing Structural Zone (Duguet and Szumylo 2018). Key differences between the Saganash Lake and Borden Lake greenstone belts include 1) the apparent absence of Timiskaming-age metasedimentary rocks in the former, 2) the greater abundance of iron formation in the former, 3) the apparent absence of deformation younger than 2691 Ma in the former, and 4) the possible older age of the mafic metavolcanic package in the former.

GEOPHYSICAL INTERPRETATION

The airborne geophysical survey delineated many continuous or discontinuous formational electromagnetic (EM) conductors along with areas of highly varied magnetic responses. In view of the scarcity and vintage of geological information available for this belt, a preliminary geophysical interpretation is made in terms of structure and geophysical domains, which are then ascribed to probable geological sources. The magnetic responses are displayed at full colour saturation as ternary (Figure 6.3) and second vertical derivative images (Figure 6.4). Features discussed in the interpretation are displayed in (Figure 6.5). Electromagnetic data, although discussed in the text, are not displayed on Figures 6.3, 6.4 or 6.5 because of the density and complexity of the features.

Domains 1 and 5 (*see* Figure 6.5) contain almost no EM conductors and express very similar magnetic responses. Previous mapping (McMurchy 1960a) has documented biotite granites in both areas. The 1:250 000 scale bedrock geology of Ontario (Ontario Geological Survey 2011) has reclassified the geology as belonging to the gneissic tonalite and foliated tonalite suites for the areas corresponding to domains 1 and 5, respectively. Weak but continuous EM anomalies detected in the domain 5 area are probably caused by faults that are also apparent in the magnetic data.

The most prominent feature in the ternary magnetic image (*see* Figure 6.3) is a sinuous band of strongly linear magnetic anomalies striking northeast-southwest extending almost the whole length of the survey area (*see* Figure 6.5, domain 3). This domain terminates against the Kapuskasing Structural Zone to the northeast and against an inferred northeast-trending fault near the southern end of the survey. The central part of the domain is considerably thicker than its ends, reaching a width of approximately 4 km. This domain is also populated with numerous moderate to strong, long strike length EM conductors, many with strong magnetic correlation. The geophysical responses are consistent with sulphide- and oxide-facies iron formation in the amphibolitic mafic volcanic rocks that have been mapped in parts of this domain (McMurchy 1960a).

Domain 2 (*see* Figure 6.5) occupies much of the northern and western parts of the survey area. Similar to domain 3, numerous formational EM anomalies are present. However, the magnetic response is more subdued and fewer conductor trends have magnetic correlation in this domain. The presence of amphibolite and metasedimentary rocks in sparse outcrop (McMurchy 1960a), along with the geophysical character of the domain, suggests that this part of the greenstone belt has a higher proportion of non-magnetic metasedimentary rocks than in domain 3. The greenstone belt is significantly wider than anticipated in this area and it appears to extend beyond the northwest boundary of the survey. Near the northwest boundary, the magnetic response is further subdued, the EM conductors are more discontinuous and, in places, conductive horizons appear to be missing, suggesting that the surrounding granitoid rocks are becoming dominant in this part of the survey area.

The Nansen Creek fault of Leclair et al. (1994) does not appear to show magnetically. If present, it is sinuous and parallels the north limit of the strong, linear magnetic anomalies present along the northern boundary of domain 3 (*see* Figures 6.3 and 6.4).

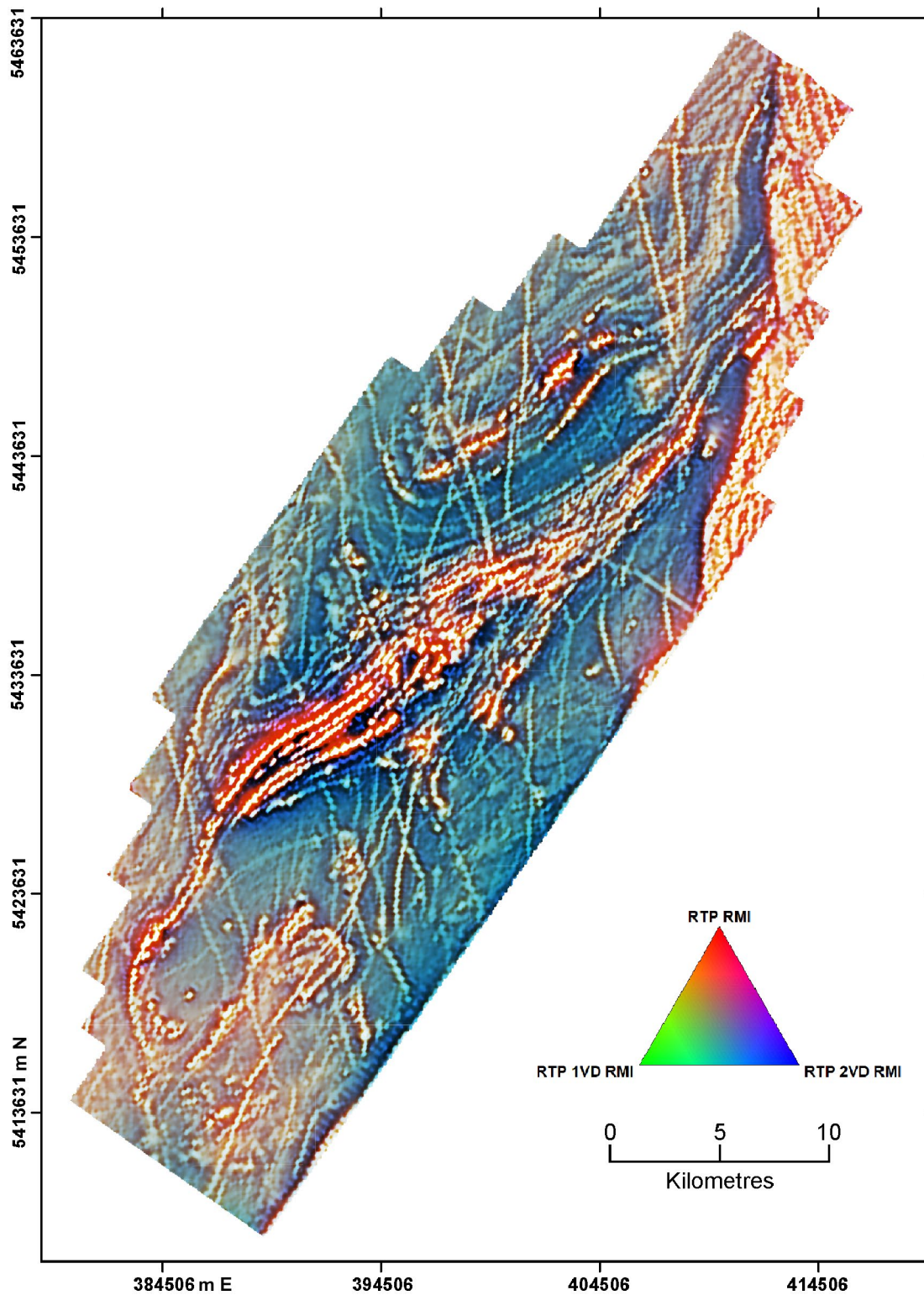


Figure 6.3. Pole-reduced magnetic ternary image (pole-reduced residual magnetic intensity (RTP RMI) = red; first vertical derivative of the pole-reduced residual magnetic intensity (RTP 1VD RMI) = green; second vertical derivative of the pole-reduced residual magnetic intensity (RTP 2VD RMI) = blue) for the Saganash Lake airborne electromagnetic survey area. Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 17.

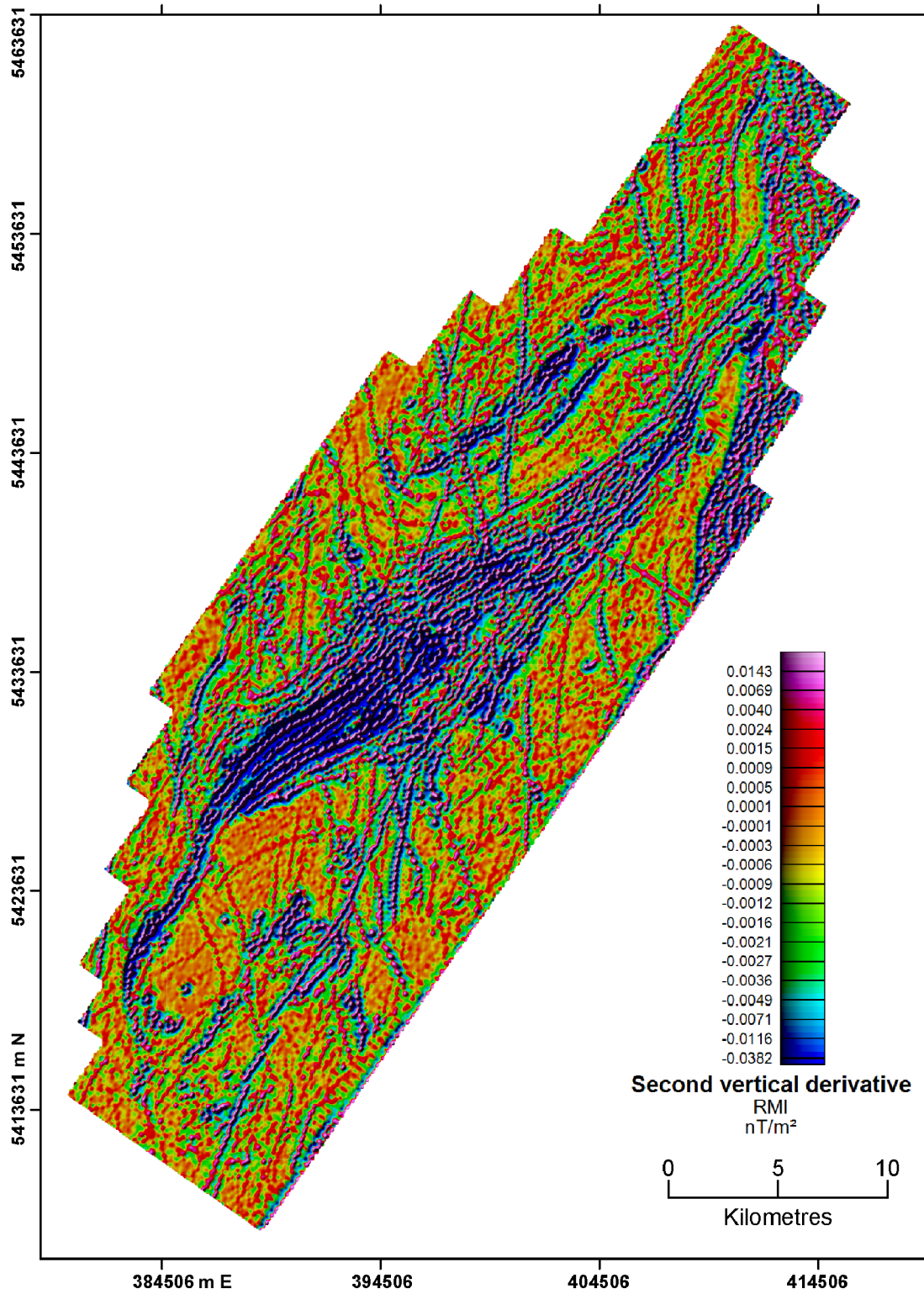


Figure 6.4. Second vertical derivative of the residual magnetic intensity (RMI) for the Saganash Lake airborne electromagnetic survey area. All UTM co-ordinates provided using NAD83 in Zone 17.

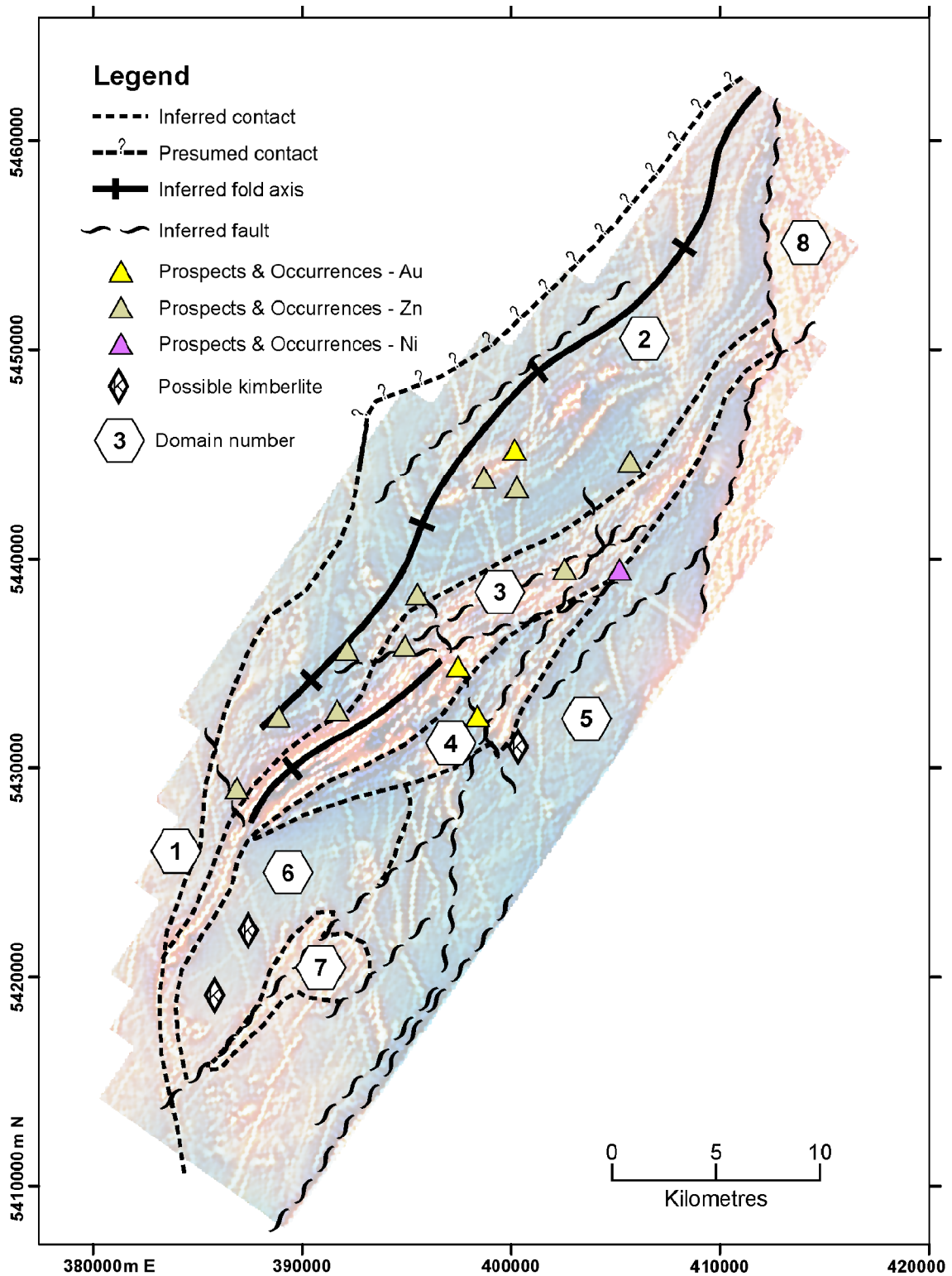


Figure 6.5. Pole-reduced magnetic ternary image (pole-reduced residual magnetic intensity (RTP RMI) = red; first vertical derivative of the pole-reduced residual magnetic intensity (RTP 1VD RMI) = green; second vertical derivative of the pole-reduced residual magnetic intensity (RTP 2VD RMI) = blue) for the Saganash Lake airborne electromagnetic survey area highlighting the main geological features present in the survey area. Numbers 1 to 8 refer to the domains discussed in the text. All UTM co-ordinates provided using NAD83 in Zone 17.

Domain 4 (*see* Figure 6.5), which abuts domain 3 to the southeast, exhibits a similar, but somewhat more subdued, magnetic fabric to domain 3, but is nearly devoid of EM conductors. In limited outcrop, previous mapping indicated the presence of amphibolites and metasedimentary rocks (McMurphy 1960a).

Domain 6 (*see* Figure 6.5), although similar in many ways to the magnetic expressions of domains 1 and 5, can be distinguished by its more uniform magnetic fabric that is best imaged by the second vertical derivative of the residual magnetic field (*see* Figure 6.4). No probable bedrock conductors are noted in this domain. The geophysical character of this domain is consistent with diorite outcrops of the Shack Lake pluton mapped by McMurphy (1960a) in the northern part of the domain.

Domain 7 (*see* Figure 6.5) is located in the southern part of the survey area along part of the interface between domains 5 and 6. A magnetically disturbed pattern, bounded by a highly irregular outline, is similar to that over mafic rocks elsewhere in the survey area. The existing geology map (McMurphy 1960a) documents outcrops of “metaporphry with some amphibolite” and “metagabbro with some amphibolite”. The shape and magnetic response of this domain suggests that it may be the expression of partially digested mafic volcanic rocks lying within plutonic bodies.

Domain 8 (*see* Figure 6.5), located along the northeastern margin of the survey, is strongly magnetic and has no EM conductivity associated with it. This domain is part of the Groundhog River block of the Kapuskasing Structural Zone and is underlain by tonalitic gneisses and migmatites.

Four sets of dikes are apparent in the magnetic data. North- and northwest-trending dikes are the most abundant and distributed throughout the survey area. The north-trending dikes are part of the Matachewan dike swarm (*circa* 2460 Ma: Bleeker et al. 2012), whereas the northwest-trending dikes are part of the Marathon dike swarm (2126–2101 Ma: Halls et al. 2008). A few wide, west-northwest-trending dikes occur in the centre of the survey area and are likely part of the Sudbury dike swarm (*circa* 1240 Ma: Krogh et al. 1988). Northeast-trending dikes appear to be less plentiful and are located mostly in the southern half of the survey area. The northeast-trending dikes have not been assigned to any specific dike swarm. North-, northwest- and northeast-trending faults have also been inferred from the magnetic data (*see* Figure 6.5) and, in some cases, appear to be associated with magnetic dikes.

Two regional-scale folds have been interpreted from the magnetic and EM results (*see* Figure 6.5). The first interpreted fold is apparent in the inferred mafic metavolcanic and metasedimentary rocks of domain 2. The fold, the axis of which trends approximately northeast, closes to the southwest. The second interpreted fold, located in domain 3, also with a northeasterly axis, closes to the northeast. The type of either of these folds has not been determined.

MINERAL POTENTIAL

Two main bands of magnetite-chert iron formation are present in the Saganash Lake greenstone belt and are located in domain 3 in Fenton and Slack townships (*see* Figures 6.3, 6.4 and 6.5). First discovered in 1946, samples from the iron formation assayed between 19.0 and 25.7% Fe (Bennett et al. 1967, p.59). Both the previous (Ontario Geological Survey 2002) and current (Ontario Geological Survey 2021a) magnetic surveys indicate that the iron formation extends beneath overburden several kilometres farther to the east than shown on current geological maps (e.g., Hogg 1948; McMurphy 1960a). Gold has been reported from the southernmost of the 2 main iron formation bands (0.05 oz/ton, MDI42G01SE00003).

Four discretionary zinc mineral occurrences are present in the main segment of the Saganash Lake greenstone belt north of the main iron formation belt and are located in the magnetic low that forms the core of the greenstone belt in domain 3 (*see* Figure 6.5). All but 1 occurrence are based on diamond drilling by either Falconbridge Limited or Matagami Lake Mines Limited, with the highest assay values,

from west to east, being 4950 ppm, 1655 ppm, 2180 ppm and 1400 ppm Zn (MDI42G02SE000001, MDI42G01SW000001, MDI42G01SW000017 and MDI42G01SW000018, respectively). Copper is also present at anomalous levels at all 4 occurrences. Host rocks are quartz-mica schists, garnet schists, graphitic argillites and garnet-bearing impure sandstones. The presence of the zinc occurrences in the main mafic volcanic pile, and association with fine-grained metasedimentary rocks, may indicate the presence of an exhalative horizon(s), perhaps of volcanogenic massive sulphide (VMS) origin.

Four discretionary mineral occurrences are present in the northern segment of the Saganash Lake greenstone belt north of the Nansen Creek fault in Casselman Township in domain 2 (*see* Figure 6.5), and are associated with a linear, moderate magnetic high (MDI42G01NW00004, MDI42G01NW00008, MDI42G01NW00009, MDI42G01NW00010). All 4 occurrences are based on drilling by Matagami Lake Mines Limited, and all were anomalous for zinc, as well as gold, copper and/or manganese and nickel. All are associated with quartz-sericite and garnet schists and/or siltstone and ironstone, with gold being present in the drill holes that contained ironstone (MDI42G01NW00008, MDI42G01NW00009).

Some of the numerous EM responses delineated by the recent survey have the potential to be VMS targets. However, as limited previous drilling has shown, many of the EM anomalies are likely to be caused by graphitic metasedimentary rocks. The identification of favourable host rocks will be key to identifying EM targets with the greatest base metal potential. Inferred folding, faulting and known gold occurrences suggest that the central parts of domains 3 and 4 are particularly attractive for gold exploration. Similarly, folded iron formation, delineated by magnetic and EM data in domain 3 (*see* Figure 6.5), is prospective for precious metals.

Three isolated circular magnetic anomalies are observed in the southern part of the survey area within domains 5 and 6 (*see* Figure 6.4 and 6.5). They are readily apparent because of the subdued magnetic response of the surrounding areas, specifically the 2 anomalies located in the Shack Lake diorite pluton. The shape and size of these features is consistent with magnetic kimberlite bodies, although it is possible that the anomalies could be caused by undigested fragments of magnetic iron formation and/or small non-kimberlitic intrusions. It should be noted that the northernmost of the 2 anomalies located in the Shack Lake pluton occurs near a perturbation in a flight line related to a cultural feature; thus, there is a small possibility that this anomaly might not be wholly geological. Regardless, if all these features are kimberlites, it is likely that others could be present nearby in the more magnetically active areas.

ACKNOWLEDGMENTS

We would like to thank the Moose Cree First Nation and the Flying Post First Nation for allowing the Ontario Geological Survey to fly this airborne survey over their traditional land use territory. Brenda Sharp, *P.Geo.*, is acknowledged as the originator of the ternary magnetic display technique used to create Figures 6.3 and 6.5. Pat Gervais (OGS) is thanked for his assistance with the figures.

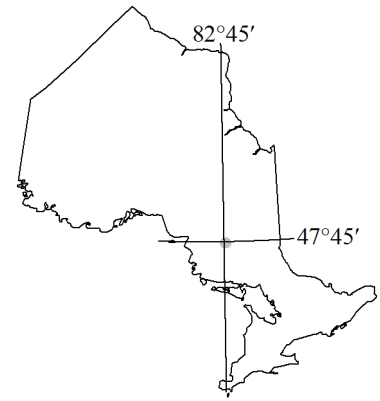
REFERENCES

- Ayer, J., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J.F., Kwok, K. and Trowell, N.F. 2002. Evolution of the Abitibi greenstone belt based on U-Pb geochronology: Autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation: *Precambrian Research*, v.115, p.63-95.
- 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.J., Ispolatov, V., Lafrance, B., Leshner, 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, 125p.

- Bennett, G., Brown, D.D., George, P.T. and Leahy, E.J. 1967. Operation Kapuskasing; Ontario Department of Mines, Miscellaneous Paper 10, 98p.
- Bleeker, W., Hamilton, M.A., Ernst, R.E. and Soderlund, U. 2012. Resolving the age structure of the Matachewan event: Magmatic pulses at c. 2445-2452 Ma, 2458-2461 Ma and 2475-2480 Ma; unpublished CAMIRO Reports A96, A97 and A98, 17p.
- Duguet, M., and Szumylo, N. 2018. Precambrian geology of Cochrane and Borden townships, Kapuskasing Structural Zone, Wawa–Abitibi terrane; Ontario Geological Survey, Preliminary Map P.3821, scale 1:20 000.
- Halls, H.C., Davis, D.W., Stott, G.M. and Ernst, R.E. 2008. The Paleoproterozoic Marathon large igneous province: New evidence for a 2.1 Ga long-lived mantle plume event along the southern margin of the North American Superior Province; *Precambrian Research*, v.162, p.327-353.
- Hogg, N. 1948. Geological report on portion of Fenton Township, District of Cochrane; Ontario Department of Mines, Preliminary Report 1948-01, 6p.
- 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. 1988. 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.
- Leclair, A.D. and Nagerl, P. 1988. Geology of the Chapleau, Groundhog River and Val Rita blocks, Kapuskasing area, Ontario; *in* Current Research, Part C, Geological Survey of Canada, Paper 88-1C, p.83-91.
- Leclair, A.D., Percival, J.A., Green, A.G., Wu, J., West, G.F. and Wang, W. 1994. Seismic reflection profiles across the central Kapuskasing uplift; *Canadian Journal of Earth Sciences*, v.31, p.1016-1026.
- Leclair, A.D. and Poirier, G.G. 1989. The Kapuskasing uplift in the Kapuskasing area, Ontario; *in* Current Research. Part C, Geological Survey of Canada, Paper 89-1C, p.225-234.
- Leclair, A.D. and Sullivan, R.W. 1991. U-Pb zircon and titanite ages of upper and lower crustal rocks in the central Kapuskasing uplift, northern Ontario; *in* Radiogenic Age and Isotopic Studies: Report 4, Geological Survey of Canada, Paper 90-2, p.45-59.
- McMurphy, R.C. 1960a. Saganash Lake area, District of Cochrane; Ontario Department of Mines, Map 1960a, scale 1:63 360.
- 1960b. Geology of the Saganash Lake–Wakusimi River area, District of Cochrane; Ontario Department of Mines, Annual Report 1960, v.69, pt.3, 19p.
- Ontario Geological Survey 2002. Ontario airborne geophysical surveys, magnetic data, Kapuskasing–Chapleau area; Ontario Geological Survey, Geophysical Data Set 1040.
- 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.
- 2021a. Ontario airborne geophysical surveys, magnetic and electromagnetic data, grid and profile data (ASCII and Geosoft® formats) and vector data, Saganash Lake area; Ontario Geological Survey, Geophysical Data Set 1089.
- 2021b. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 026, scale 1:20 000.
- 2021c. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 027, scale 1:20 000.

- 2021d. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 028, scale 1:20 000.
- 2021e. Airborne magnetic and electromagnetic surveys, residual magnetic field contours with electromagnetic anomalies and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 029, scale 1:20 000.
- 2021f. Airborne magnetic and electromagnetic surveys, colour-filled contours of the residual magnetic field and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 030, scale 1:50 000.
- 2021g. Airborne magnetic and electromagnetic surveys, colour-filled contours of the residual magnetic field and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 031, scale 1:50 000.
- 2021h. Airborne magnetic and electromagnetic surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 032, scale 1:50 000.
- 2021i. Airborne magnetic and electromagnetic surveys, shaded colour image of the second vertical derivative of the residual magnetic field and Keating correlation coefficients, Saganash Lake area; Ontario Geological Survey, Map 83 033, scale 1:50 000.
- 2021j. Airborne magnetic and electromagnetic surveys, colour-filled contours of the EM decay constant and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 034, scale 1:50 000.
- 2021k. Airborne magnetic and electromagnetic surveys, colour-filled contours of the EM decay constant and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 035, scale 1:50 000.
- 2021l. Airborne magnetic and electromagnetic surveys, colour-filled contours of the apparent conductivity and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 036, scale 1:50 000.
- 2021m. Airborne magnetic and electromagnetic surveys, colour-filled contours of the apparent conductivity and electromagnetic anomalies, Saganash Lake area; Ontario Geological Survey, Map 83 037, scale 1:50 000.

7. Project NE-17-002. Geological Investigation of the Shunsby Base Metal Prospects Area, Southern Swayze Area of the Abitibi Greenstone Belt



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INTRODUCTION

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

This thematic and mapping project is part of the author’s PhD thesis work, which complements the Ontario Geological Survey’s multi-year project, started in 2014, to update the geology and assess the mineral potential of the Swayze area (previous year’s project numbers: Project Unit 14-008, and Projects NE-17-001, NE 17-002, NE-18-002 and NE-19-003). This year (2021) focussed on the Shunsby base metal prospects (A: Shunsby and B: Shunsby South on Figure 7.2) in Cunningham Township (*see* Figure 7.1).

REGIONAL GEOLOGY

The Abitibi greenstone belt is located in the eastern part of the Wawa–Abitibi terrane of the southern Superior Province (Percival et al. 2006). It is composed predominantly of mafic to felsic metavolcanic rocks with minor ultramafic metavolcanic rocks, as well as clastic and chemical metasedimentary deposits. The volcanic and sedimentary episodes in the Abitibi greenstone belt are most recently defined by Thurston et al. (2008, and references therein) and Monecke et al. (2017, and references therein), and for correlation purposes, the groups defined by Heather (2001) for the Swayze area are written within parentheses following the episode name, where applicable: pre-2750 Ma, 2750–2735 Ma Pacaud volcanic episode (Chester group), 2734–2724 Ma Deloro volcanic episode (Marion group), 2720–2710 Ma Kidd–Munro volcanic episode (Biscotasing group), 2710–2704 Ma Tisdale volcanic episode (Trailbreaker group) and the 2704–2695 Ma Blake River volcanic episode (Swayze group). Overlying the volcanic episodes in Ontario are 2 dominantly sedimentary episodes referred to as the Porcupine-type (2690–2682 Ma) and the Timiskaming-type (2676–2670 Ma; Ridout group) sedimentary basins.

Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.7-1 to 7-9.

The Swayze area (see Figure 7.1) of the Abitibi greenstone belt is mainly composed of mafic, intermediate and felsic metavolcanic rocks, with localized ultramafic metavolcanic rocks, clastic and chemical metasedimentary rocks, and synvolcanic to syntectonic to posttectonic felsic to ultramafic intrusive rocks (Heather 2001). It is bounded by the Kenogamissi Batholith (locally known as the Rice Lake batholith; Becker and Benn 2003) to the east, Ramsey–Algoma granitoid complex to the south, Kapuskasing Structural Zone to the west and the Nat River complex to the north (see Figure 7.1).

GEOLOGY OF THE SHUNSBY PROSPECTS AREA IN CUNNINGHAM TOWNSHIP

The geology of the Shunsby prospects area in Cunningham Township consists primarily of chemical metasedimentary rocks with minor siliciclastic components, metavolcanic rocks and intrusive rocks (see Figure 7.2). The supracrustal rocks are also intruded and crosscut by smaller bodies of felsic to ultramafic intrusive rocks. The area to the southwest has been intruded by the Isaiah Creek Stock (Heather 2001; see Figure 7.2). Both the Shunsby and the Shunsby south prospects (A and B, respectively, on Figure 7.2) will be referred as Shunsby prospects in the remainder of the text.

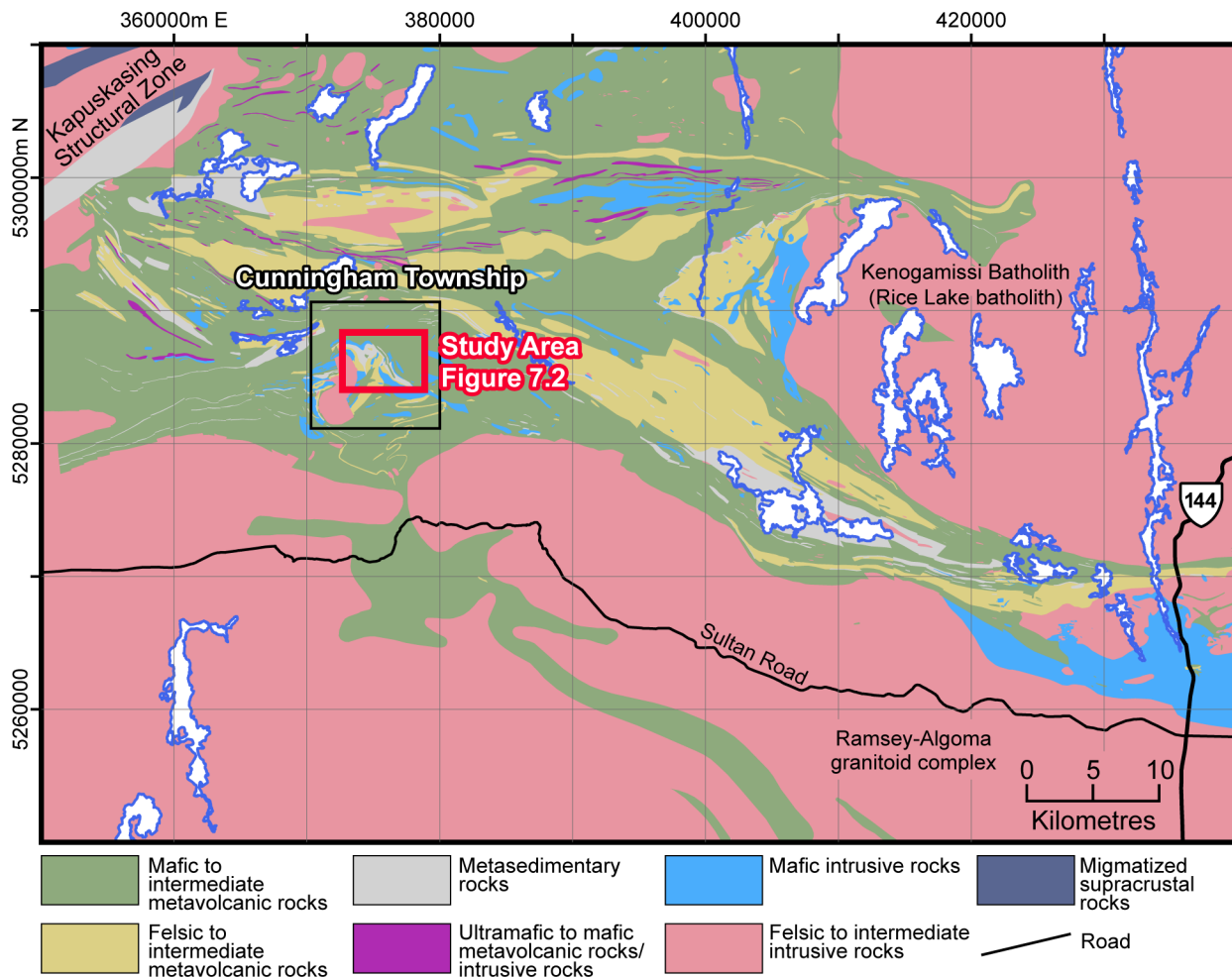


Figure 7.1. Simplified geological map of the southern Swayze area of the Abitibi greenstone belt displaying Cunningham Township and the study area (outlined by red box). Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 17.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

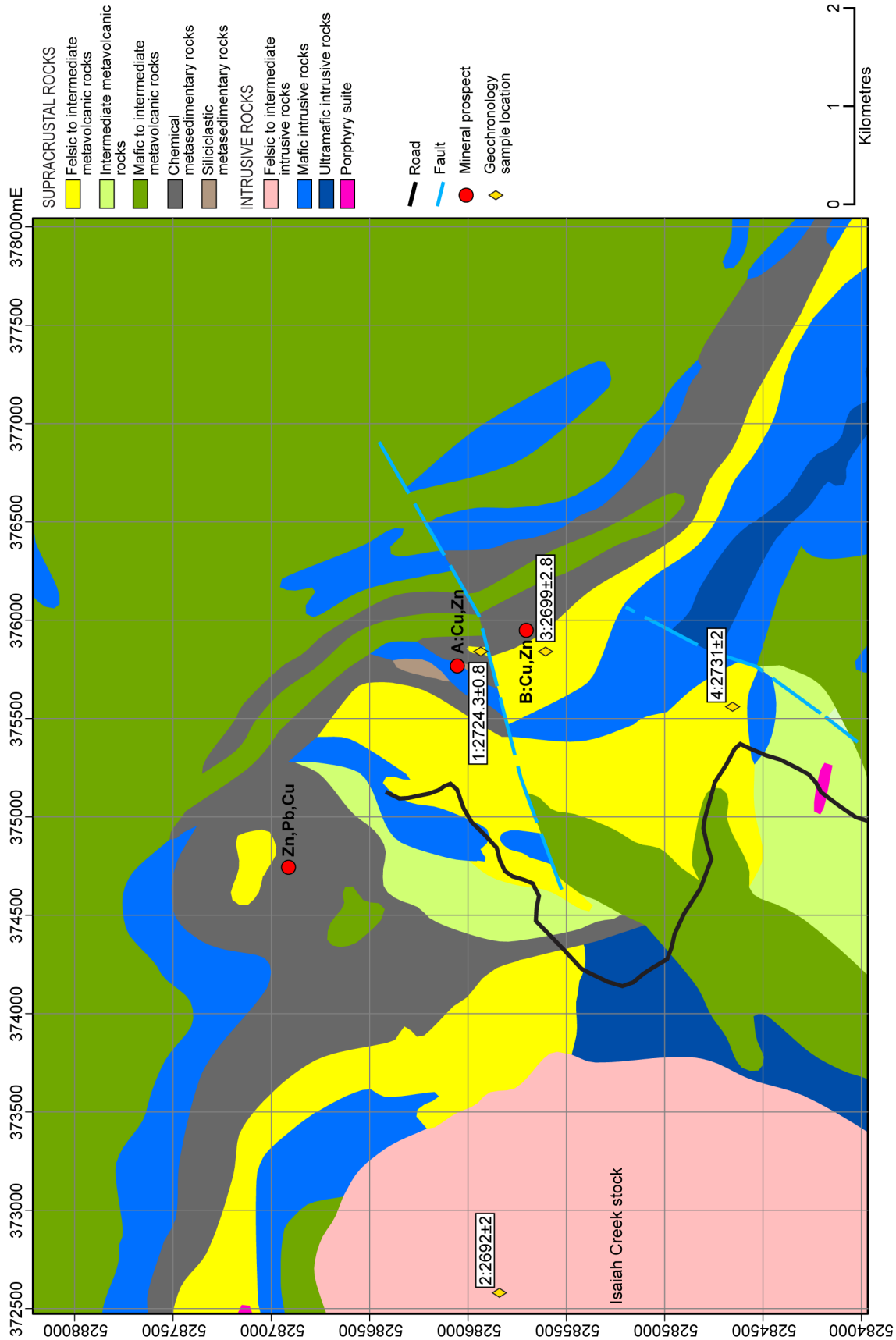


Figure 7.2. Simplified geological map of the Shunshby prospects area in Cunningham Township. Geochronology data are presented in million years before present (Ma); see Table 7.1 for additional information. Mineral Deposit Inventory (MDI) prospects (Ontario Geological Survey 2021) display documented primary commodities, including A: Shunshby prospect and B: Shunshby South prospect. Abbreviations: Cu, copper; Pb, lead; Zn, zinc. Location information provided as UTM co-ordinates using NAD83 in Zone 17. Geology modified from Ayer and Chartrand (2011).

Table 7.1. Geochronological data referred to in the text and shown on Figure 7.2.

Number ^a	Zircon Method ^b	Age ^c (Ma)	Interpretation	Rock Type	Easting ^d (m)	Northing ^d (m)
1	TIMS	2724.3±0.8	Volcanism	Felsic metavolcanic rocks	375210	5286432
2	TIMS	2692±2	Emplacement	Granodiorite	372593	5285833
3	TIMS	2699±2.8	Emplacement	Quartz feldspar porphyry within felsic metavolcanic rocks	375257	5286520
4	TIMS	2731±2	Volcanism	Felsic metavolcanic rocks	375570	5284656

^a "Number" indicates the sample location on the map in Figure 7.2.

^b Methods abbreviations: TIMS, U/Pb thermal ionization mass spectrometry.

^c Data from Heather (2001) and van Breemen, Heather and Ayer (2006).

^d Locations provided as UTM co-ordinates in NAD83, Zone 17.

Metasedimentary Rocks

Metasedimentary rocks in the study area (see Figure 7.2) primarily occur as chemical metasedimentary rocks with local punctuations of clastic metasedimentary rocks.

Chemical metasedimentary rocks primarily occur in the central portion of Cunningham Township over a strike length of approximately 10 km, are up to 350 m thick and are primarily chert and chert breccias (Photo 7.1A) with lesser oxide-facies banded iron formation and siltstones. The chert fragments within the breccias are generally composed of massive chert, banded chert and muddy chert. Similar, chert breccias have been observed in the 2734–2724 Ma Deloro volcanic episode of the Bartlett dome area south of Timmins (Houlé and Solgadi 2007; Thurston et al. 2008; Baldwin 2009). Baldwin (2009) interpreted this brecciation to be the result of subseafloor hydrothermal circulation. Oxide-facies banded iron formations are interbedded between breccia layers and have alternating layers of light to dark chert with sparse, lightly hematized layers.

Clastic metasedimentary rocks are primarily mudstones (Photo 7.1B) with sparse interbedded siltstones. The mudstones can be interbedded with cherts layers and sporadically contain bedded and/or replaced pyrite.

Metavolcanic Rocks

Metavolcanic rocks of the study area include abundant mafic to intermediate massive to pillowed flows with lesser felsic massive flows.

Mafic to intermediate and intermediate metavolcanic rocks vary from dark green to light green and are typically cryptocrystalline to very fine-grained, massive and pillowed (locally variolitic) lava flows (Photo 7.1C). Pillows are typically ameoboid shaped, range in size from 25 to 50 cm wide and have thin 1 to 3 cm interpillow material.

Felsic to intermediate metavolcanic rocks are commonly massive, white to light yellow-grey with sparse quartz and plagioclase phenocrysts up to 2 mm wide. Contacts are not observed thus an intrusive mode of emplacement cannot be ruled out. Two historical samples have yielded ages of 2724.3±0.8 Ma and 2731±2 Ma (geochronology sample 1 and 2, respectively, on Figure 7.2 and Table 7.1: Heather (2001) and van Breemen, Heather and Ayer (2006)), which would assign the felsic metavolcanic rocks, including the 3 prospects as well as the metavolcanic rocks to the southwest, within the 2734–2724 Ma Deloro volcanic episode. Both sample locations have not yet been validated.

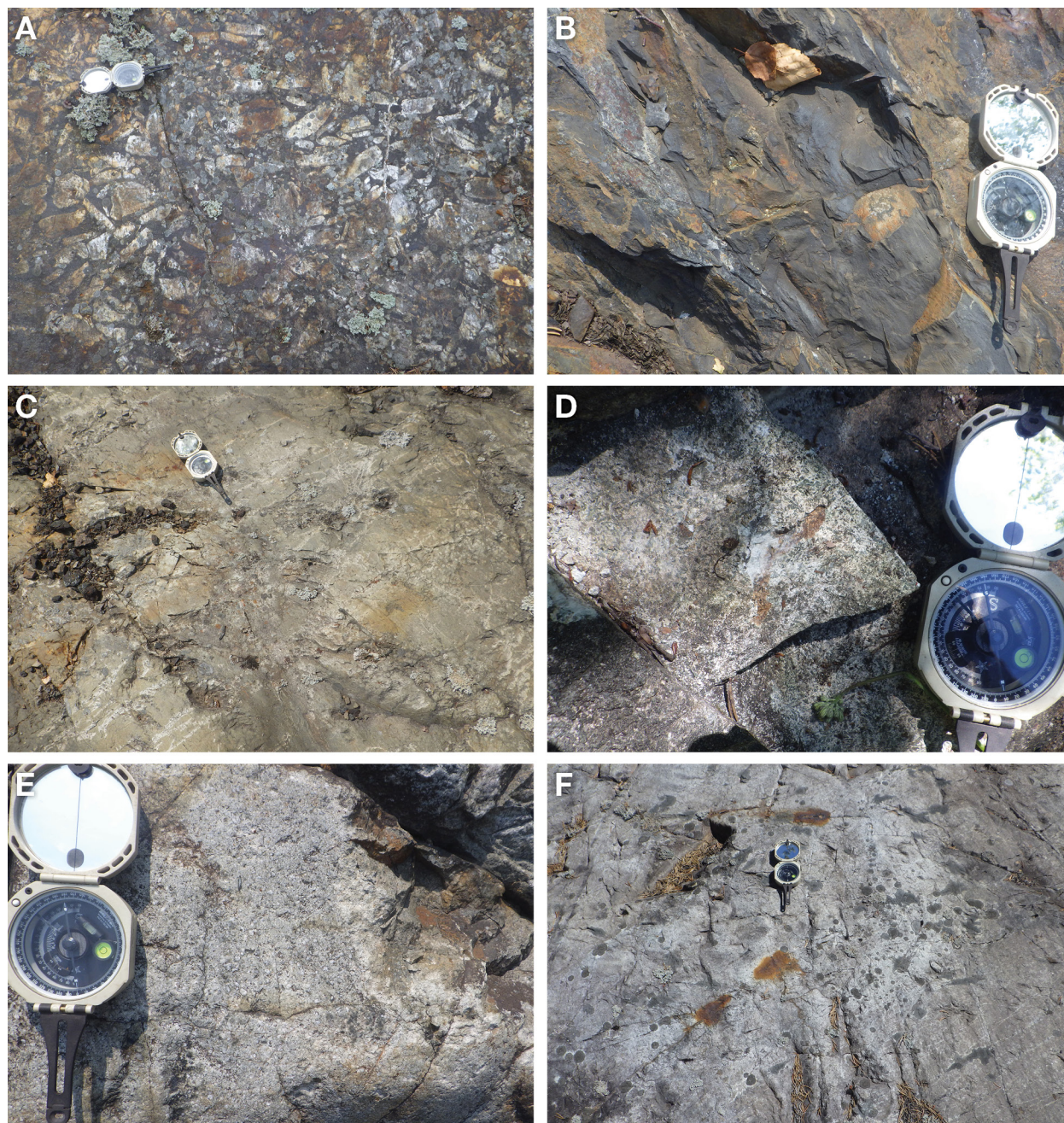


Photo 7.1. Selected photographs of lithological units. **A)** Chert breccia with massive to banded chert fragments (21TG014: 375808E 5285945N). **B)** Slightly graphitic mudstone with trace pyrite (21TG038: 376010E 5285705N). **C)** Variolitic intermediate intrusion or flow (21TG011: 375775E 5286145N). **D)** Gabbro with acicular chloritized amphibole phenocrysts (21TG029: 374894E 5285911N). **E)** Quartz feldspar porphyry intrusion (21TG038: 376010E 5285705N). **F)** Fine- to medium-grained granodiorite intrusion with pyrite along fractures (21TG032: 374287E 5285459N). Compass for scale is 22 cm long with sighting arm pointing north. All location information provided as UTM co-ordinates using NAD83 in Zone 17.

Intrusive Rocks

Archean intrusive rocks present in the map area are felsic to ultramafic with lesser felsic porphyritic intrusions.

Several ultramafic to mafic intrusions occur across the study area. Vaillancourt et al. (2003) described the ultramafic intrusive rocks as mainly altered peridotite. These were not visited during the summer of 2021. The mafic to intermediate intrusive rocks are fine- to medium-grained, equigranular with interlocking amphiboles and plagioclase, including secondary chlorite (Photo 7.1D). These intrusions were interpreted to locally represent synvolcanic intrusions (Vaillancourt et al. 2003).

Throughout the study area, small (metres to tens of metres wide) intermediate to felsic porphyritic intrusions were observed truncating the supracrustal rocks. They are typically fine grained with medium-grained quartz and/or plagioclase phenocrysts (Photo 7.1E). One of these intrusions in the Shunsby prospects area has an age of 2699 ± 2 Ma (geochronology sample 3 on Figure 7.2 and in Table 7.1: Heather (2001) and van Breemen, Heather and Ayer (2006)).

The Isaiah Creek stock, located in the southwestern portion of the study area, has yielded an age of 2692 ± 2 Ma (geochronology sample 4 on Figure 7.2 and in Table 7.1: Heather (2001) and van Breemen, Heather and Ayer (2006)) and has been observed as a fine- to medium-grained, equigranular granodioritic intrusion (Photo 7.1F).

STRUCTURAL GEOLOGY

The dominant fabric within the study area is a penetrative metamorphic foliation defined by sericite and chlorite that is northwest trending ($\sim 320^\circ$) and shallowly to steeply dipping ($45\text{--}90^\circ$, Photo 7.2A). The penetrative foliation in the Shunsby prospects area is most likely related to emplacement of the Isaiah Creek intrusion; however, further field investigation is required to better understand this relationship.

Locally, several ductile to brittle deformation zones and fractures have been observed. They are commonly characterized by the destruction of primary textures and commonly contain abundant iron-carbonate alteration and/or sulphides. They locally exhibit both sinistral and dextral kinematic indicators such as local folding and or drag folds within the deformation zones (Photo 7.2B).

The study area has been crosscut by minor, late north-northwest-trending brittle faults that exhibit both strike-slip and dip-slip components.

ALTERATION AND METAMORPHISM

The earliest observed alteration is local vein-controlled replacement of amphiboles and feldspars by chlorite and sericite, respectively, in mafic to felsic metavolcanic rocks. Later phases of alteration overprinting the supracrustal rocks within high-strain zones include iron-carbonate, sericite, chlorite and quartz veining. The latter overprinting alteration is interpreted to be related to hydrothermal fluids.

Regional metamorphism of the area is typically lower greenschist facies, which is characterized by chlorite replacing mafic minerals in the metavolcanic, metasedimentary and intrusive rocks.

The chert and chert breccia associated with the Shunsby prospects have been extensively silicified and locally sericitized and chloritized. The genetic association of these alterations are currently being studied as a part of the author's PhD thesis.

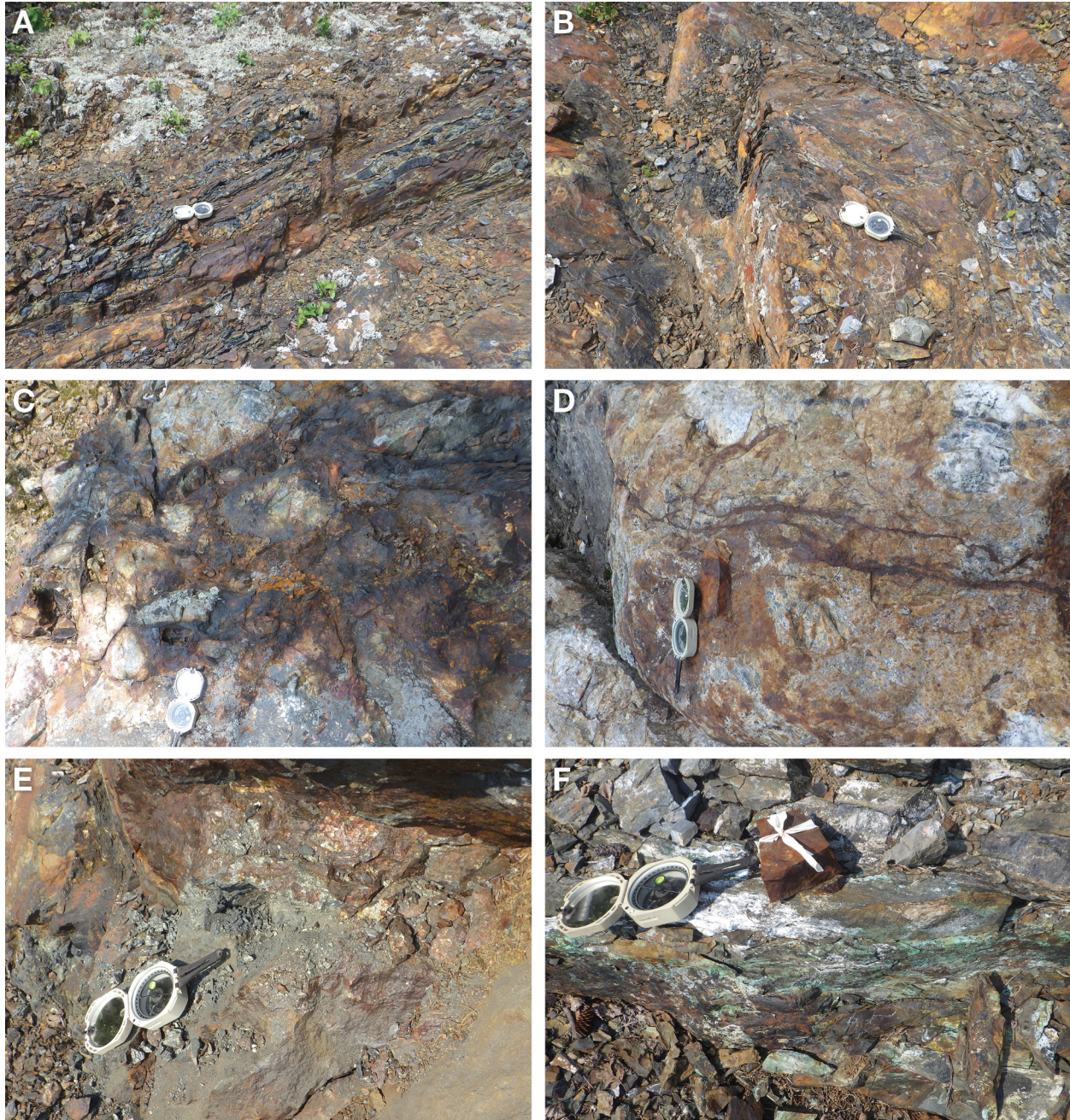


Photo 7.2. Selected photographs of features of structure and mineralization. **A)** Deformed cherty mudstone with abundant pyrite (21TG023: 374919E 5285891N). **B)** Z-fold in cherty mudstone within deformation zone (21TG039: 375800E 5286151N). **C)** Mineralized fracture through chert breccia (21TG010: 375720E 5286165N). **D)** Chert breccia crosscut by chalcopyrite stringers (21TG010: 375720E 5286165N). **E)** Local massive chalcopyrite (>50%) at irregular contact of mudstone–chert breccia with variolitic intrusion–volcanic flow (21TG011: 375775E 5286145N). **F)** Mudstone with pyrite, sphalerite and chalcopyrite within beds (21TG011: 375775E 5286145N). Compass for scale is 22 cm long with sighting arm pointing north. All location information provided as UTM co-ordinates using NAD83 in Zone 17.

MINERALIZATION

The base metal mineralization at the Shunsby prospects has been historically interpreted as a volcanogenic massive sulphide deposit (Thurston et al. 2008); however, a more detailed study re-examining this interpretation is currently in progress as part of the author's PhD thesis. The bulk of the mineralization is fracture-controlled chalcopyrite with lesser sphalerite and galena (Photo 7.2C) within the chert breccias and banded chert beds. The chalcopyrite may also form stringers (Photo 7.2D) or, when present at the intersection of structures, may form massive sulphide (>50% sulphide, Photo 7.2E). Mudstone layers may also contain fine- to medium-grained pyrite, pyrrhotite, chalcopyrite, sphalerite and galena (Photo 7.2F); however, the current genetic relationship is unknown.

FUTURE WORK

Regional and detailed mapping will continue along the chemical metasedimentary rock horizon. Litho-geochemistry, thin section and microprobe analyses will be used to further characterize the base metal system, which will then be compared against other base metal systems in the Swayze area as well as other mineralized systems found in the rest of the Abitibi greenstone belt.

ACKNOWLEDGMENTS

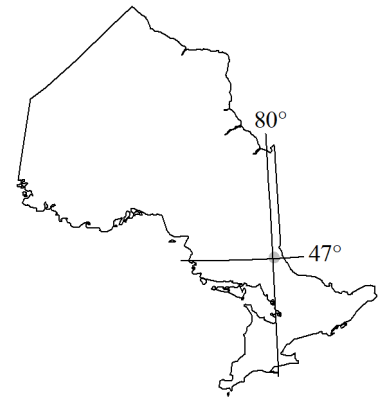
This project is an Ontario Geological Survey–supported thesis done at Laurentian University (Metal Earth). This project has benefited from the advice and guidance of Sonia Préfontaine and Peter MacDonald from the Ontario Geological Survey, Rasmus Haugaard from Metal Earth (Laurentian University), David Diekrup from University of Ottawa, and the assistance of Nicholas Lucas (Metal Earth field assistant), Steve Scott and Robert Gemmell. The author is thankful to the staff of the Ontario Geological Survey, in particular Patrick Gervais for aiding with drafting figures, Shannon Evers for aiding in sample preparation, and Sheree Hinz, of the Resident Geologists Office in Timmins, for help with the Mineral Deposits Inventory information. The author also benefited from many discussions with, and comments from, Dr. Harold Gibson, Dr. Bruno Lafrance and Dr. John Ayer, from Laurentian University (Harquail School of Earth Sciences). The author would like to thank Brunswick House First Nation, Flying Post First Nation, and Mattagami First Nation for the opportunity of working on their traditional land-use area. Partial funding for this study came from the Harquail School of Earth Sciences. This is Mineral Exploration Research Centre (MERC)–Metal Earth publication number MERC-ME-2021-67.

REFERENCES

- Ayer, J.A. and Chartrand, J.E. 2011. Geological compilation of the Abitibi greenstone belt; Ontario Geological Survey, Miscellaneous Release—Data 282.
- Baldwin, G.J. 2009. The sedimentology and geochemistry of banded iron formations of the Deloro assemblage, Bartlett Dome area, Abitibi greenstone belt, Ontario, Canada: Implications for BIF deposition and greenstone belt formation; unpublished MSc thesis, Laurentian University, Sudbury, Ontario, 113p.
- Becker, J.K. and Benn, K. 2003. The Neoproterozoic Rice Lake batholith and its place in the tectonomagnetic evolution of the Swayze and Abitibi granite–greenstone belts, northeastern Ontario; Ontario Geological Survey, Open File Report 6105, 42p.
- Heather, K.B. 2001. The geological evolution of the Archean Swayze greenstone belt, Superior Province, Canada; unpublished PhD thesis, Keele University, Keele, England, 370p.

- Houlé, M.G. and Solgadi, F. 2007. Geological and mineral potential of Bartlett and Geikie townships in the Bartlett dome, Abitibi greenstone belt; *in* Summary of Field Work and Other Activities, 2007, Ontario Geological Survey, Open File Report 6213, p.7-1 to 7-15.
- Monecke, T., Mercier-Langevin, P., Dubé, B. and Frieman, B.M. 2017. Geology of the Abitibi greenstone belt; *in* Abitibi base and precious metal deposits, southern Abitibi greenstone belt, Canada, 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.
- 2021. Mineral Deposit Inventory; Ontario Geological Survey, Mineral Deposit Inventory (August 2021 update), online database.
- Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; Canadian Journal of Earth Sciences, v.43, p.1085-1117.
- 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.
- Vaillancourt, C., Sproule, R.A., MacDonald, C.A. and Leshner, C.M. 2003. Investigation of mafic-ultramafic intrusions in Ontario and implications for platinum group element mineralization: Operation Treasure Hunt; Ontario Geological Survey, Open File Report 6102, 335p.
- van Breemen, O., Heather, K.B. and Ayer, J.A. 2006. U-Pb geochronology of the Neoproterozoic Swayze sector of the southern Abitibi greenstone belt; *in* Geological Survey of Canada, Current Research 2006-F1, 32p.

8. Project NE-19-001. New Uranium–Lead Geochronology from the Temagami Greenstone Belt, Northeastern Ontario



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INTRODUCTION

The Temagami greenstone belt bedrock geology mapping project was initiated in 2019 by the Earth Resources and Geoscience Mapping Section of the Ontario Geological Survey (*see* MacDonald 2019). The objectives of the multi-year project are to 1) update the bedrock geology maps; 2) correlate the Temagami greenstone belt with the chronostratigraphic episodes of the Abitibi greenstone belt; 3) investigate the architecture of the belt; and 4) document geological controls on nickel-copper-platinum group elements, copper-lead-zinc and gold-silver mineralization.

This article will present 3 new uranium–lead (U/Pb) zircon age results from the Temagami greenstone belt. Results were obtained by chemical abrasion (CA) isotope dilution thermal ionization mass spectrometry (ID-TIMS) geochronological methods. The samples were collected in 2019 during a reconnaissance field program and submitted to the Jack Satterly Geochronology Laboratory at the University of Toronto for analysis. The rock samples include 1 metavolcanic rock and 2 intrusive rocks. The metavolcanic sample was collected to test an anomalously old age reported by Ayer et al. (2006). The 2 intrusive rocks samples were obtained to determine emplacement ages of 2 plutonic bodies, for which geochronological analyses had not been determined previously.

REGIONAL GEOLOGY

The Abitibi greenstone belt is in the eastern part of the Wawa–Abitibi granite–greenstone terrane in the southern Superior Province (Percival et al. 2006). The supracrustal rocks of the Abitibi greenstone belt in Ontario include 7 chronostratigraphic volcanic episodes and 2 younger types of sedimentary basins (Ayer et al. 2002; Thurston et al. 2008; Monecke et al. 2017). These volcanic episodes and sedimentary basins include the pre-2750 Ma; the 2750–2735 Ma Pacaud; the 2734–2724 Ma Deloro; the 2723–2720 Ma Stoughton–Roquemaure; the 2720–2710 Ma Kidd–Munro; the 2710–2704 Ma Tisdale; the 2704–2695 Ma Blake River volcanic episodes; as well as the Porcupine-type (2690–2685 Ma) and Timiskaming-type (2679–2669 Ma) sedimentary basins (Ayer et al. 2002; Thurston et al. 2008; Monecke et al. 2017). Plutonic rocks of the Abitibi greenstone belt are divided into 3 groups, including synvolcanic (2750–2695 Ma), syntectonic (*circa* 2694–2680 Ma) and post-tectonic (2679–2670 Ma), with some overlap in the larger batholiths (Beakhouse 2011).

The Temagami greenstone belt is a granite–greenstone inlier of the Neoproterozoic Abitibi greenstone belt surrounded by Paleoproterozoic Huronian Supergroup metasedimentary rocks of the Cobalt Embayment (Figure 8.1; Bennett, Dressler and Robertson 1991; Ayer et al. 2006). Based on available geochronological

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.8-1 to 8-9.*

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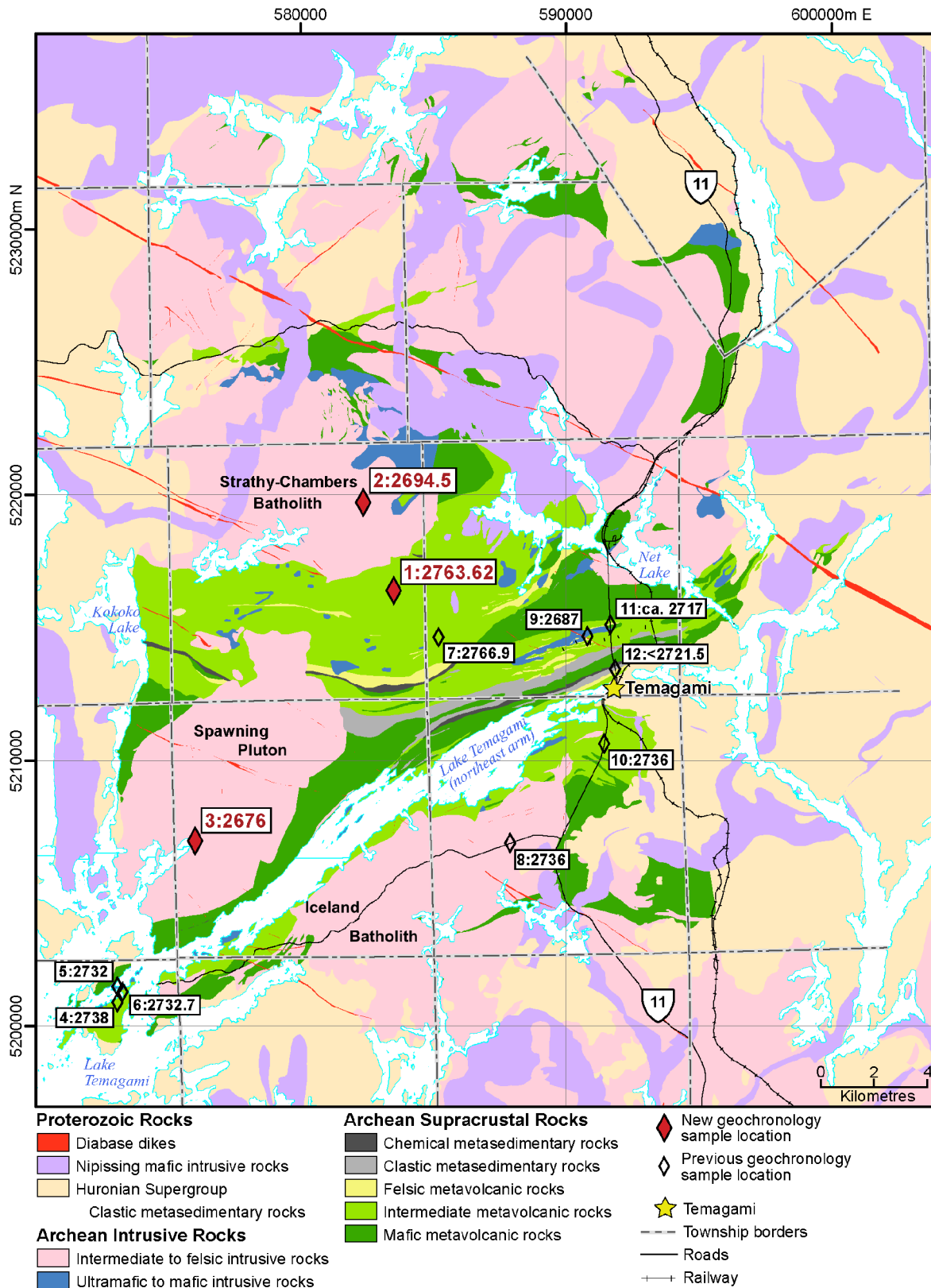


Figure 8.1. Simplified geological map of the Temagami greenstone belt displaying the location of intrusions and available geochronology data. Geochronology data is keyed to Table 8.1. Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 17 (geology modified from Ayer et al. 2006).

Table 8.1. Zircon U/Pb CA-ID-TIMS geochronological results for samples from the Temagami greenstone belt.

Number	Sample ID	Age (Ma)	Interpretation	Rock Type	Easting (m)	Northing (m)	Source
1	18PM565	2763.62±0.98	Volcanism	Intermediate metavolcanic rock	583463	5216649	this study; Kamo (2020)
2	19PM566	2694.5±1.1	Emplacement	Granodiorite (Strathy–Chambers Batholith)	582393	5219722	this study; Kamo (2020)
3	19PM562	2676.0±1.2	Emplacement	Granite (Spawning Pluton)	576043	5206888	this study; Kamo (2020)
4	S-8761	2738±2	Volcanism	Felsic metavolcanic rock	573100	5200900	Unpublished GSC; Ayer et al. (2006)
5	KF-010	2732±2	Emplacement	Gabbro	573100	5201500	Unpublished GSC; Ayer et al. (2006)
6	KF-115-013	2732.7±1.5	Emplacement	Gabbro	573300	5201300	Unpublished GSC; Ayer et al. (2006)
7	05JAA-0047	2766.9±1.1	Volcanism	Felsic metavolcanic rock	585188	5214653	Ayer et al. (2006)
8	—	2736±2	Emplacement	Granitoid (Iceland Batholith)	587900	5206900	Bowins and Heaman (1991)
9	—	2687±2	Emplacement	Porphyry dike	590800	5214690	Bowins and Heaman (1991)
10	—	2736 ^{+3/-1}	Volcanism	Felsic porphyry flow	591430	5210650	Bowins and Heaman (1991)
11	05JAA-0036	circa 2717	Volcanism	Felsic metavolcanic rock	591664	5215121	Ayer et al. (2006)
12	05JAA-0037	2721.5±1.1	Maximum depositional age	Sandstone metasedimentary rock	591839	5213450	Ayer et al. (2006)

^a “Number” indicates the sample location on the map in Figure 8.1.

^b Abbreviations: GSC = Geological Survey of Canada.

^c Locations provided as UTM co-ordinates in NAD83, Zone 17.

data, the Archean supracrustal rocks of the Temagami greenstone belt correlate with the pre-2750 Ma, the 2750–2735 Ma Pacaud and the 2720–2710 Ma Kidd–Munro volcanic episodes (Ayer et al. 2006; see Figure 8.1). Archean granitoid intrusions of the Temagami greenstone belt inlier include the Iceland Batholith (also known as Ingall Lake Batholith), Strathy–Chambers Batholith and the Spawning Pluton (see Figure 8.1). Only the Iceland Batholith has a previously determined synvolcanic age of 2736±2 Ma (Bowins and Heaman 1991; number 8 on Figure 8.1).

URANIUM–LEAD ISOTOPE DILUTION THERMAL IONIZATION MASS SPECTROMETRY ANALYTICAL METHODS ANALYTICAL METHODS

Rock samples were crushed and milled using standard methods (jaw crusher and Bico disk mill, respectively) followed by processing on a Wilfley table to produce a heavy mineral concentrate. Further processing using magnetic and heavy liquid (methylene iodide) separation methods resulted in the production of a zircon concentrate.

Uranium–lead analysis was by ID-TIMS methods on chemically abraded zircon crystals at the Jack Satterly Geochronology Laboratory, Department of Earth Sciences, University of Toronto. Prior to analysis, zircon crystals were thermally annealed and chemically etched (chemical abrasion), which has the advantage of penetrative removal of alteration zones where lead loss has occurred and generally improving concordance (Mattinson 2005). The pre-treatment involved placing zircon grains in a muffle furnace at ~900°C for ~48 hours to restore crystallinity, followed by a modified single-step partial dissolution procedure in ~0.10 mL of ~50% HF and 0.020 mL 7N HNO₃ in Teflon™ dissolution vessels

at 200°C for several hours. Zircon was rinsed in 8N HNO₃ at room temperature prior to dissolution. A mixed ²⁰⁵Pb/²³⁵U spike was added to the Teflon™ dissolution capsules during sample loading. Single zircon crystals were dissolved using ~0.10 mL of concentrated HF acid and ~0.02 mL of 7N HNO₃ at 200°C for 3 to 4 days. Samples were dried to a precipitate and re-dissolved in ~0.15 mL of 3N HCl overnight (Krogh 1973). Uranium and lead were isolated from the zircon using miniaturized ~50 µL anion exchange columns using HCl, dried in 0.05N phosphoric acid, 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 ²⁰⁶Pb/²³⁸U ages for initial ²³⁰Th disequilibrium in the zircon have been made assuming a Th/U ratio in the magma of 4.2. All common lead was assigned to procedural lead blank. 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). All age errors quoted in the text and table, and error ellipses in the concordia diagrams are given at the 95% confidence interval. VG Sector software was used for data acquisition. In-house data reduction software in Microsoft® Visual Basic® by D.W. Davis was used. Plotting and age calculations were done using Isoplot 3.31 (Ludwig 2003).

RESULTS AND DISCUSSION

A summary of U/Pb zircon age results from rocks of the Temagami greenstone belt is presented in Table 8.1. The U/Pb analytical results for the 3 samples in this study are discussed below and plotted on concordia diagrams in Figure 8.2. The U/Pb isotopic data for individual zircon grains are presented in Table 8.2.

Sample 19PM565 (Pre-2750 Ma Volcanic Episode)

The Temagami greenstone belt can be separated into at least 3 metavolcanic packages (*see* MacDonald 2019). Along the northern margin of the belt, in Strathy and Chambers townships, is a package of intermediate metavolcanic rocks that generally young southward and transition from more mafic at the base to felsic at the top (*see* Figure 8.1). A sample collected near the top of this package, in Strathy Township, by Ayer et al. (2006) has an age determination of 2766.9±1.1 Ma (number 7 on Figure 8.1 and Table 8.1), making this package the oldest known metavolcanic rocks of the Abitibi greenstone belt in Ontario. In comparison, the pre-2750 Ma volcanic episode ages determination found in the Abitibi greenstone belt in Québec are much older: 2791–2798 Ma (Bandyayera et al. 2004; David et al. 2011; Davis et al. 2014). Thus making this area the only known occurrence of volcanism *circa* 2765 Ma in the entire Abitibi greenstone belt.

Sample 19PM565 (number 1 on Figure 8.1), a fine-grained, intermediate metavolcanic rock sample from the Temagami greenstone belt, was selected for U/Pb analysis to confirm the pre-2750 Ma volcanic episode rock age reported by Ayer et al. (2006). Abundant, euhedral and translucent zircons were recovered from the metavolcanic sample (*see* Figure 8.2). The U/Pb data for 3 such grains gave concordant, overlapping results that have a weighted mean ²⁰⁷Pb/²⁰⁶Pb age of 2763.62±0.98 Ma (MSWD=0.43; *see* Figure 8.2; *see* Table 8.2).

Given the homogeneity of the zircon population and simple U/Pb systematics of the results, an age of 2763.62 Ma for deposition of the metavolcanic unit in this part of the sequence is considered robust. The sample confirms the presence of pre-2750 Ma volcanic episode rocks in the Temagami greenstone belt; however, it is several million years younger than the age reported by Ayer et al. (2006) for a sample collected higher in the stratigraphic sequence. If accurate, this suggests an age reversal in the package, presumably related to structural complexity (*i.e.*, folding or faulting) within the metavolcanic package that has not been previously recognized.

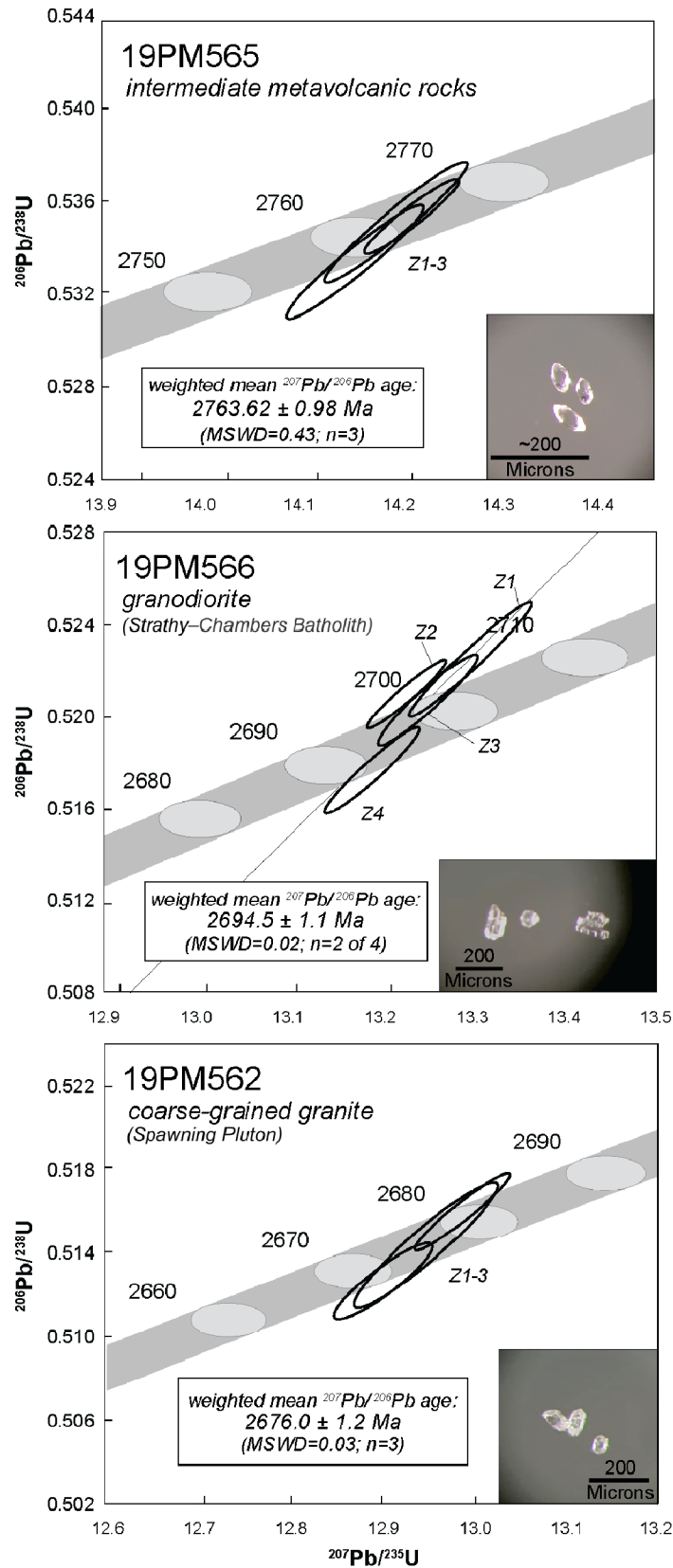


Figure 8.2. Concordia diagrams and grain images of Temagami greenstone belt samples analyzed by chemical abrasion (CA) ID-TIMS; modified from Kamo (2020).

Table 8.2. Zircon U/Pb CA-ID-TIMS isotopic data for samples from the Temagami greenstone belt.

Analysis No.	Weight (µg)	U (ppm)	Th/U	Pb _c (pg)	²⁰⁶ Pb/ ²⁰⁴ Pb Measured	²⁰⁷ Pb/ ²³⁵ U	2σ	²⁰⁶ Pb/ ²³⁸ U	2σ	Error Corr.	²⁰⁷ Pb/ ²⁰⁶ Pb	2σ	²⁰⁶ Pb/ ²³⁸ U Age	2σ	²⁰⁷ Pb/ ²³⁵ U Age	2σ	²⁰⁷ Pb/ ²⁰⁶ Pb Age	2σ	% Disc.
19PM-565: intermediate metavolcanic rock, Chambers Township (UTM 583463E 5216649N, NAD83, Zone 17)																			
z1	1.5	58	0.59	0.1	21758	14.212	0.039	0.5353	0.0013	0.948	0.19255	0.00017	2763.86	5.53	2763.98	2.62	2764.07	1.46	0.0
z2	1.5	23	0.64	0.2	7694	14.196	0.059	0.5351	0.0021	0.963	0.19243	0.00021	2762.79	8.93	2762.92	3.93	2763.02	1.83	0.0
z3	1.5	32	0.56	0.3	4957	14.155	0.057	0.5334	0.0020	0.957	0.19248	0.00022	2755.58	8.43	2760.15	3.79	2763.50	1.91	0.4
19PM-566: medium-grained granodiorite, Strath-Chambers Batholith, Chambers Township (UTM 582393E 5219722N, NAD83, Zone 17)																			
z1	2.2	106	0.44	0.1	70566	13.298	0.055	0.5225	0.0020	0.974	0.18459	0.00017	2709.71	8.67	2701.06	3.88	2694.59	1.53	-0.7
z2	3.0	98	0.47	0.2	58683	13.229	0.035	0.5210	0.0012	0.961	0.18417	0.00014	2703.27	5.16	2696.15	2.53	2690.81	1.29	-0.6
z3	2.1	27	0.29	0.2	10183	13.252	0.044	0.5207	0.0016	0.951	0.18458	0.00019	2702.20	6.83	2697.76	3.15	2694.43	1.70	-0.4
z4	1.0	170	0.39	0.3	22490	13.191	0.042	0.5176	0.0015	0.958	0.18482	0.00017	2689.17	6.54	2693.41	3.04	2696.59	1.54	0.3
19PM-562: medium- to coarse-grained granite, Spawning Pluton, Briggs Township (UTM 576043E 5206888N, NAD83, Zone 17)																			
z1	1.0	63	0.25	0.5	4624	12.987	0.042	0.5160	0.0015	0.959	0.18254	0.00017	2682.19	6.47	2678.71	3.08	2676.09	1.57	-0.3
z2	0.3	90	0.32	0.5	1925	12.947	0.064	0.5144	0.0025	0.944	0.18254	0.00030	2675.38	10.44	2675.80	4.68	2676.12	2.71	0.0
z3	1.0	80	0.18	1.7	1605	12.901	0.044	0.5127	0.0015	0.905	0.18251	0.00027	2667.98	6.37	2672.41	3.21	2675.77	2.42	0.4

Notes: All zircon (z) grains have been thermally annealed and etched in HF (Mattinson 2005).

Th/U calculated from radiogenic ²⁰⁸Pb/²⁰⁶Pb ratio and ²⁰⁷Pb/²⁰⁶Pb age assuming concordance.

Pb_c is total common Pb assuming the isotopic composition of laboratory blank:

assigned the isotopic composition of laboratory blank (²⁰⁶Pb/²⁰⁴Pb=18.49±0.4%; ²⁰⁷Pb/²⁰⁴Pb=15.59±0.4%; ²⁰⁸Pb/²⁰⁴Pb=39.36±0.4%).

²⁰⁶Pb/²⁰⁴Pb corrected for fractionation and common Pb in the spike.

Pb/U ratios corrected for fractionation, common Pb in the spike, and blank.

Correction for ²³⁰Th disequilibrium in ²⁰⁶Pb/²³⁸U and ²⁰⁷Pb/²⁰⁶Pb assuming Th/U of 4.2 in the magma.

Disc is percent discordance for the given ²⁰⁷Pb/²⁰⁶Pb age.

Error Corr. is correlation coefficients of X-Y errors on the concordia plot.

Decay constants are those of Jaffey et al. (1971): ²³⁸U and ²³⁵U are 1.55125 × 10¹⁰/yr and 9.8485 × 10¹⁰/yr.

²³⁸U/²³⁵U ratio of 137.88 used for ²⁰⁷Pb/²⁰⁶Pb model age calculations.

Sample 19PM566 (Strathy–Chambers Batholith)

The Temagami greenstone belt is bound by large Archean granitoid intrusions. Along the southern margin of the belt is the Iceland Batholith, which has an U/Pb zircon age of 2736 ± 2 Ma (Bowins and Heaman 1991; *see* number 8 on Figure 8.1), suggesting it is synvolcanic and may be coeval with the 2750–2735 Ma Pacaud volcanic episode with which it is in contact (*see* Figure 8.1). The northern margin of the Temagami greenstone belt is bound by the Strathy–Chambers Batholith (*see* Figure 8.1), which is in contact with the pre-2750 Ma volcanic episode rocks and has no previous age determination.

Sample 19PM566 (number 2 on Figure 8.1) is a massive, medium-grained, granodiorite sample from the Strathy–Chambers Batholith that was selected for U/Pb analysis to determine an emplacement age of the intrusion. A generally homogeneous population of relatively small brown, stubby zircon crystals was recovered from the sample (*see* Figure 8.2). The U/Pb data for 4 single grains were concordant, or partially concordant, and showed minor scatter with $^{207}\text{Pb}/^{206}\text{Pb}$ ages that range from 2697 Ma to 2691 Ma, and with data for 2 analyses overlapping at 2694.5 ± 1.1 Ma (*see* Figure 8.2; *see* Table 8.2).

Further analytical work would help confirm the age for the intrusion. A cautious interpretation utilizing the 2 overlapping age results at 2694.5 Ma is the best estimate for the time of emplacement of the intrusion. This age, as well as the scatter from 2697 Ma to 2691 Ma for the other 2 analyzed zircons, suggests the Strathy–Chambers Batholith is an early phase of the syntectonic group of Abitibi granitoids based on Beakhouse (2011) classification. Future bedrock mapping and sampling will aim to confirm this age of emplacement, and identify if it represents the entire batholith, or only a single phase of a multiphase intrusion.

Sample 19PM562 (Spawning Pluton)

Numerous ultramafic through felsic intrusions of varying sizes exist within the supracrustal rocks of the Temagami greenstone belt. The largest of these intrabelt intrusions is the Spawning Pluton, which is in the west-central portion of the belt (*see* Figure 8.1) The Spawning Pluton has no previous age determinations.

Sample 19PM562 (number 3 on Figure 8.1) is a massive, medium- to coarse-grained biotite-bearing granite, with potassium feldspar megacrysts from near the centre of the Spawning Pluton (*see* Figure 8.1). It was selected for U/Pb analysis to determine the time of emplacement of the intrusion. Zircon grains recovered from this intrusion were generally well preserved, small, 2/1 prismatic crystals. The U/Pb data for 3 such grains gave concordant and overlapping results that have a weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of 2676.0 ± 1.2 Ma (MSWD=0.03; *see* Figure 8.2; *see* Table 8.2).

The age of 2676 Ma is interpreted as the best estimate for the time of emplacement of the Spawning Pluton. This age indicates the pluton is post-tectonic based on the classification of Beakhouse (2011). The Spawning Pluton crosscuts the metavolcanic stratigraphy and regional deformation zones, as well as appearing to be located in the core of a regional syncline, which further supports its post-tectonic emplacement (*see* MacDonald 2019). The age also indicates that the tectonic architecture and positioning of volcanic episodes against each other within the Temagami greenstone belt predates 2676 Ma.

ACKNOWLEDGMENTS

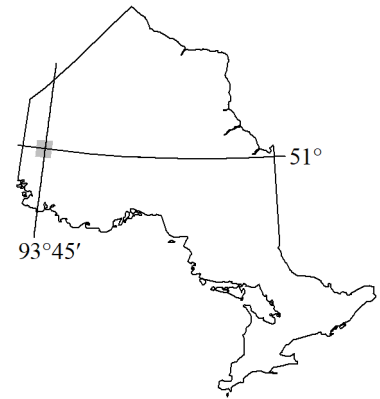
The authors thank Temagami First Nation for continued support of the project on their traditional land-use area. Additionally, we acknowledge Kyle Dzuirban for his field assistance in 2019; Sonia Préfontaine, Desmond Rainsford and Peter Chadwick of the Ontario Geological Survey for project support; Patrick Gervais (OGS) for aiding with figures; Monica Gaiswinkler Easton (OGS) for editorial assistance; and John Ayer for discussions on the geology of the Temagami area.

REFERENCES

- Ayer, J., Amelin, Y., Corfu, F., Kamo, S., Ketchum, J., Kwok, K. and Trowell, N. 2002. Evolution of the southern Abitibi greenstone belt based on U-Pb geochronology: Autochthonous volcanic construction followed by plutonism, regional deformation and sedimentation; *Precambrian Research*, v.115, p.63-95.
- 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.
- Bandyayera, D., Rhéaume, P., Doyon, J. and Sharma, N.M. 2004. Géologie de la région du lac Hébert (32G/03); Ministère de l'énergie et des ressources naturelles, RG 2003-07, 57p.
- Beakhouse, G.P. 2011. The Abitibi Subprovince plutonic record: Tectonic and metallogenic implications; Ontario Geological Survey, Open File Report 6268, 161p.
- 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
- 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.
- David, J., McNicoll, V., Simard, M., Bandyayera, D., Hammouche, H., Goutier, J., Pilote, P., Rhéaume, P., Leclerc, F. and Dion, C. 2011. Datations U-Pb effectuées dans les provinces du Supérieur et de Churchill en 2009–2010; Ministère de l'énergie et des ressources naturelles, RP 2011-02, 37p.
- Davis, D.W., Simard, M., Hammouche, H., Bandyayera, D., Goutier, J., Pilote, P., Leclerc, F. and Dion, C. 2014. Datations U-Pb effectuées dans les provinces du Supérieur et de Churchill en 2011–2012; Ministère de l'énergie et des ressources naturelles, RP 2014-05, 60p.
- 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.
- 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*, v.4, p.1889-1906.
- Kamo, S.L. 2020. Part A: Report on U-Pb ID-TIMS geochronology for the Ontario Geological Survey: Bedrock Mapping Projects, Ontario Year 5: 2019-2020; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, University of Toronto, Toronto, Ontario, 55p.
- 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.
- Ludwig, K.R. 2003. User's manual for Isoplot 3.00: A geochronological toolkit for Microsoft® Excel®; Berkeley Geochronology Center, Special Publication No. 4, 71p.
- 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.

- 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.
- Monecke, T., Mercier-Langevin, P., Dubé, B. and Frieman, B.M. 2017. Geology of the Abitibi greenstone belt; *in* Archean base and precious metal deposits, southern Abitibi greenstone belt, Canada, *Reviews in Economic Geology*, v.19, p.7-49.
- Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; *Canadian Journal of Earth Sciences*, v.43, p.1085-1117.
- 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.

9. Project NW-21-001. Introduction to the Red Lake Bedrock Geology Mapping Compilation Project, Northwestern Ontario



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INTRODUCTION

The Red Lake greenstone belt (Figure 9.1) is one of Ontario's most significant gold mining areas, having produced over 29 million ounces of gold since its first discovery in 1925. The discovery by Goldcorp of the "high grade zone" in 1995 led to an exploration boom in the area, and subsequent discoveries of significant mineralization in the main gold mining camp at the Eagle Gold project (formerly named Bruce Channel discovery), the Bateman Gold project (formerly named Rubicon Minerals' Phoenix project/F2 gold system), and the reopening of the PureGold Mine (formerly named Madsen Mine; *see* Figure 9.1). South of the camp, considerable gold mineralization has been identified at the Dixie project (Adamova 2020; *see* Figure 9.1).

Over the past century, the Ontario Geological Survey (OGS) has completed numerous bedrock mapping projects in the Red Lake area, with projects generally following the OGS mapping cycle of publications every 20 to 30 years. The most recent township scale bedrock geology maps in the Red Lake and Dixie Lake areas were published in the 1990s (i.e., Atkinson 1993, 1995, 1999; Atkinson and Stone 1993; Stone, Atkinson and Fogal 1993; Muir 1994a, 1994b, 1994c). In 2004, 2 compilation maps were published, and include a 1:250 000 scale OGS and Geological Survey of Canada (GSC) collaboration on the east Uchi Subprovince (Sanborn-Barrie et al. 2004) and a 1:50 000 compilation of the main camp published by the GSC (Sanborn-Barrie, Skulski and Parker 2004).

The Red Lake bedrock geology mapping compilation project (herein termed "Red Lake project") proposes to publish an updated 1:50 000 scale bedrock geology map, complemented by new geochronology and a data set of new geochemical analysis. This project will also extend the previous GSC compilation map south to include the highly prospective Dixie Lake area that hosts the Dixie project. The new digital map will improve on the previous work by including publicly available data generated from the hundreds of millions of dollars of exploration work that has been completed in the belt and reported in NI 43-101 technical reports, assessment files, or published in journal articles, theses and presentations at scientific meetings, and possibly by in-kind donations of data from exploration companies. The new compilation map will also benefit from the recent OGS Separation Lake area geophysical survey (Ontario Geological Survey 2017), the first publicly available detailed aeromagnetic survey that included the Dixie Lake area.

Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.9-1 to 9-5.

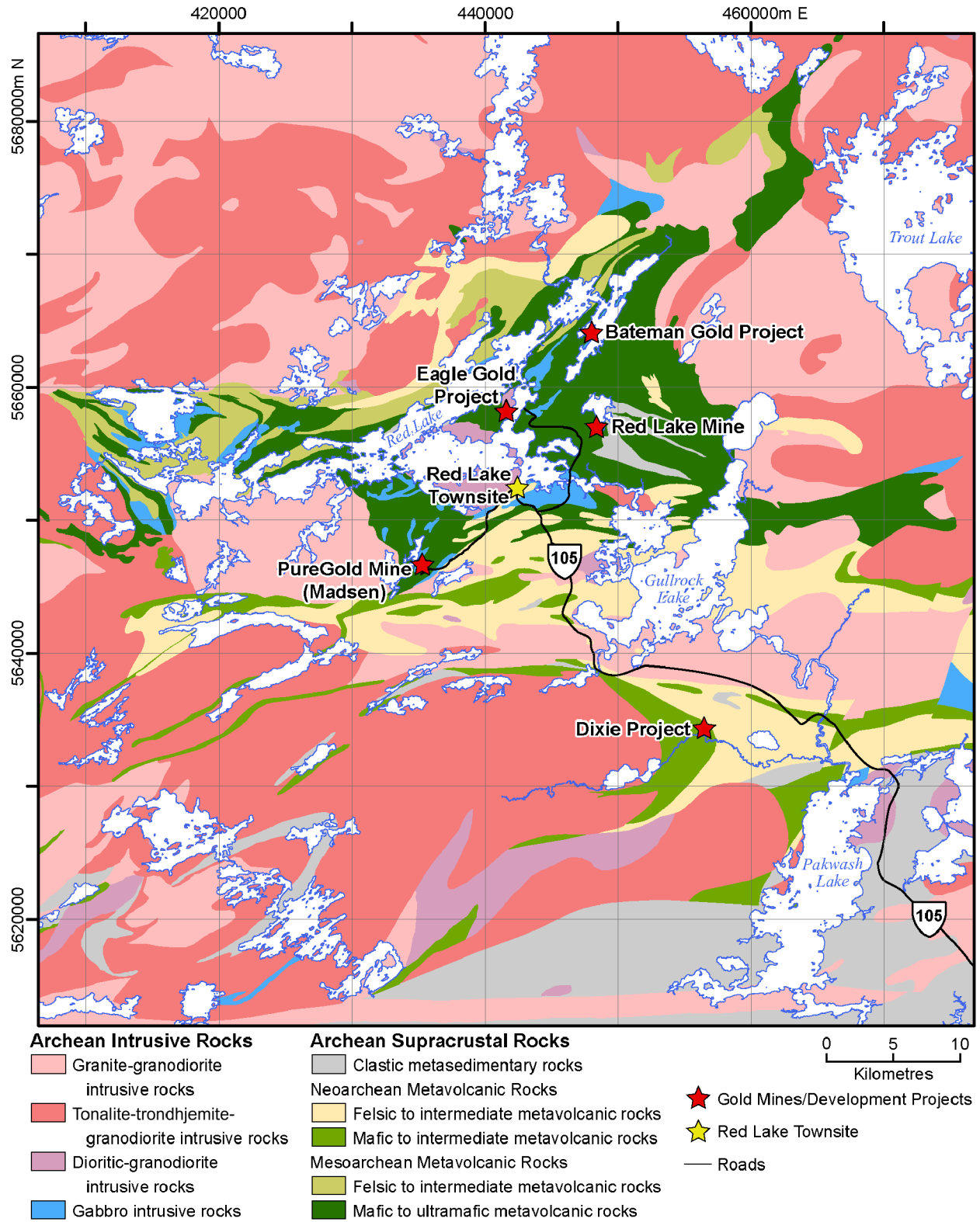


Figure 9.1. Simplified geological map of the Red Lake greenstone belt displaying the location of significant gold mines and exploration projects. Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 15 (geology modified from Sanborn-Barrie et al. 2004).

REGIONAL GEOLOGY

The Red Lake project area is located near the southern boundary of the Superior Province's granite–greenstone North Caribou terrane (Stott et al. 2010). The project focusses on the Red Lake greenstone belt and surrounding intrusive rocks, which occur along the boundary between the dominantly Mesoarchean North Caribou core and the Neoproterozoic Uchi domain (Stott et al. 2010). Along the southern edge of the Red Lake project area is Neoproterozoic metasedimentary rocks of the English River terrane (*see* Figure 9.1; Percival et al. 2006).

The Red Lake greenstone belt is composed of both Mesoarchean and Neoproterozoic supracrustal rocks (*see* Figure 9.1). Mesoarchean supracrustal rocks occur in the northern half of the belt and range in age from 2989 to 2852 Ma (*see* Figure 9.1; Sanborn-Barrie et al. 2004). Neoproterozoic supracrustal rocks occur along the northern edge of the Red Lake greenstone belt and in the entire southern half, ranging in age from 2750 to *circa* 2732 Ma (*see* Figure 9.1; Sanborn-Barrie et al. 2004). Most Mesoarchean metavolcanic rocks are of tholeiitic mafic and ultramafic compositions, with lesser calc-alkalic intermediate to felsic compositions, whereas Neoproterozoic metavolcanic rocks are of calc-alkalic mafic through felsic compositions.

Plutonic intrusive rocks within the Red Lake project area were emplaced in 4 phases during the Mesoarchean and Neoproterozoic (Sanborn-Barrie et al. 2004). The oldest phase includes Mesoarchean synvolcanic gabbros and the tonalite–trondhjemite–granodiorite (TTG) Trout Lake plutonic suite (2860–2805 Ma). Neoproterozoic intrusive phases include synvolcanic TTG plutons (*circa* 2730 Ma), syntectonic diorite and TTG intrusions (*circa* 2720 Ma) and post-tectonic granite–granodiorite intrusions (*circa* 2700 Ma).

The Red Lake greenstone belt has undergone several phases of deformation and metamorphism. The earliest phase of deformation is non-penetrative, exhibited by facing reversals across the Mesoarchean–Neoproterozoic unconformity, suggesting folding prior to 2750 Ma (Sanborn-Barrie et al. 2004). Two main phases of penetrative deformation include early north-trending folding between 2744 to 2733 Ma, followed by east-trending folding *circa* 2718 Ma (Sanborn-Barrie et al. 2004). The last phase of deformation is exhibited by east-trending fabrics, formed *circa* 2691 Ma, in the southern part of the belt (Sanborn-Barrie et al. 2004). Regional metamorphism in the belt is greenschist to amphibolite facies, occurring with deformation in three main phases *circa* 2735, 2718 and 2690 Ma (Sanborn-Barrie et al. 2004).

GOLD MINERALIZATION

Gold mineralization in the Red Lake greenstone belt is hosted principally in the Mesoarchean mafic metavolcanic rocks proximal to the unconformity with the Neoproterozoic metavolcanic rocks (Dubé et al. 2004). Gold mineralization is generally associated with quartz-carbonate veins, emplaced into southeast-trending (*circa* 2718 Ma) structures during at least 2 mineralization events between 2723 and 2699 Ma (Dubé et al. 2004). Hydrothermal alteration footprints to gold mineralization includes proximal iron-carbonate and potassic alteration, as well as silicification, haloed by widespread calcium carbonate alteration (Dubé, Williamson and Malo 2003).

When compared, the Neoproterozoic metavolcanic rocks can be perceived as less fertile, hosting less than 10% of the over 300 MDI occurrences of gold in the Red Lake greenstone belt (Ontario Geological Survey 2021) than the Mesoarchean supracrustal rocks from which most historical gold production has been attained. Recent exploration at the Dixie project, which is a cluster of 7 mineral occurrences and prospects approximately 20 km south of the Red Lake townsite (*see* Figure 9.1), has discovered significant high-grade disseminated gold mineralization (Adamova 2020). Unlike the vein-related gold

mineralization in the Mesoproterozoic mafic metavolcanic rocks discussed above, mineralization at the Dixie project within the LP fault is characterized as disseminated visible gold within strongly deformed Neoproterozoic felsic metavolcanic rocks (Adamova 2020). This style of disseminated, felsic metavolcanic hosted, mineralization is unlike previous known deposits of the belt and, so far, has only been seen in the Dixie Lake area.

PROJECT GOALS AND IMPLICATIONS

The goal of the Red Lake project is to update the regional 1:50 000 bedrock geology map of the Red Lake greenstone belt. The compilation project aims to synthesize and update features, such as stratigraphy, structure (at various scales), and alteration patterns and distribution, especially those features relevant to the recognition of prospective areas for mineral exploration, while also extending the compilation to the south of the main greenstone belt to include the Dixie Lake area. New geochemical and geochronological data, to be obtained in future from the Dixie Lake area, will greatly enhance the data from the previous bedrock geology maps. In addition, the geophysical data from the recent airborne survey (Ontario Geological Survey 2017) will help in defining geological units and structural features in the Dixie Lake area that were not identified on the previous maps because of limited outcrop exposure. This new map should put the recent discovery at the Dixie project into its regional geological context and allow comparison to the gold deposits in Red Lake itself.

ACKNOWLEDGMENTS

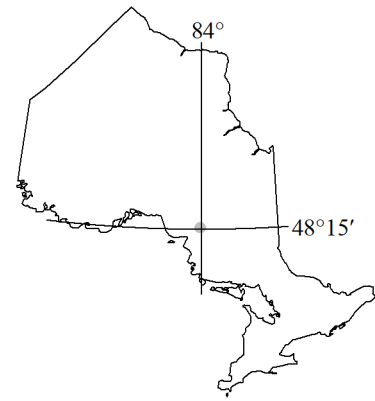
The authors would like to thank the geological staff at Great Bear Resources, PureGold Mining, Evolution Mining and BTU minerals for helpful feedback and in-kind support. Additionally, we acknowledge Ontario Geological Survey staff: Kyle Duval for data compilation; Ethan Amyotte and Cyrus Adrianwalla for project support; Manuel Duguet and Michael Easton for scientific review; Patrick Gervais for aiding with figures; and Monica Gaiswinkler Easton for editorial assistance.

REFERENCES

- Adamova, A. 2020. Technical report on the Dixie project, Red Lake, Ontario, prepared for Great Bear Resources Ltd.; 105p., available from <https://greatbearresources.ca/projects/overview/technical-report>. [accessed October 8, 2021]
- Atkinson, B.T. 1993. Precambrian geology, Heyson Township; Ontario Geological Survey, Preliminary Map P.3197, scale 1:20 000.
- 1995. Precambrian geology, Killala Township; Ontario Geological Survey, Preliminary Map P.3248, scale 1:12 000.
- 1999. Precambrian geology, Medicine Stone Lake area; Ontario Geological Survey, Preliminary Map P.3397, scale 1:50 000.
- Atkinson, B.T. and Stone, D. 1993. Precambrian geology, Red Lake area; Ontario Geological Survey, Preliminary Map P.3227, scale 1: 50 000.
- Dubé, B., Williamson, K. and Malo, M. 2003. Gold mineralization within the Red Lake mine trend: Example from the Cochenour–Willans Mine area, Red Lake, Ontario, with new key information from the Red Lake Mine and potential analogy with the Timmins camp; Geological Survey of Canada, Current Research 2003-C21, 15p.

- Dubé, B., Williamson, K., McNicoll, V., Malo, M., Skulski, T., Twomey, T. and Sanborn-Barrie, M. 2004. Timing of gold mineralization at Red Lake, northwestern Ontario, Canada: New constraints from U-Pb geochronology at the Goldcorp high-grade zone, Red Lake Mine and the Madsen Mine; *Economic Geology*, v.99, p.1611-1641.
- Muir, T.L. 1994a. Precambrian geology, Dixie Lake area (west), District of Kenora (Patricia Portion); Ontario Geological Survey, Preliminary Map P.3299, scale 1:20 000.
- 1994b. Precambrian geology, Dixie Lake area (east), District of Kenora (Patricia Portion); Ontario Geological Survey, Preliminary Map P.3301, scale 1:20 000.
- 1994c. Precambrian geology, Dixie Lake area (central), District of Kenora (Patricia Portion); Ontario Geological Survey, Preliminary Map P.3300, scale 1:20 000.
- Ontario Geological Survey 2017. Ontario airborne geophysical surveys, magnetic gradiometer and gamma-ray spectrometric data, grid and profile data (ASCII format) and vector data, Separation Lake area; Ontario Geological Survey, Geophysical Data Set 1083a.
- 2021. Mineral Deposit Inventory; Ontario Geological Survey, Mineral Deposit Inventory (July 2021 update), online database.
- Percival, J.A., Sanborn-Barrie, M., Skulski, T., Stott, G.M., Helmstaedt, H. and White, D.J. 2006. Tectonic evolution of the western Superior Province from NATMAP and Lithoprobe studies; *Canadian Journal of Earth Sciences*, v.43, p.1085-1117.
- 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 / Ontario Geological Survey, Preliminary Map P.3460, scale 1:250 000.
- Sanborn-Barrie, M., Skulski, T., and Parker, J. 2004. Geology, Red Lake greenstone belt, western Superior Province, Ontario; Geological Survey of Canada, Open File 4594.
- Stone, D., Atkinson, B.T. and Fogal, R. 1993. Precambrian geology, Pipestone Bay; Ontario Geological Survey, Preliminary Map P.3223, scale 1:50 000.
- 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.

10. Project NE-18-007. Evidence for Geon 12 Carbonatitic Magmatism in the Wawa Area: A Distal Manifestation of the Sudbury Dike Swarm Mantle Plume?



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INTRODUCTION

Walker and Robichaud (2018) reported on bedrock geology mapping at 1:20 000 scale of West Township as part of a regional mapping initiative focussed on mapping the northeastern Michipicoten greenstone belt. Further examination of samples collected during the summer of 2018 by Walker and Robichaud (2019) revealed occurrences of calcite-carbonatite and silico-carbonatite dikes in West Township that may indicate the occurrence of another carbonatite complex in the Michipicoten area, which is in addition to the Firesand carbonatite complex (*circa* 1143 Ma). This article discusses a newly obtained U/Pb age from one of these carbonatite dikes indicating a previously unknown carbonatite magmatic event in Ontario and discusses the regional significance of this event.

GEOCHRONOLOGY

Uranium–Lead Isotope Dilution Thermal Ionization Mass Spectrometry Analytical Methods

Rock samples were crushed and milled at the Jack Satterly Geochronology Laboratory at the University of Toronto using standard methods (jaw crusher and Bico disk mill, respectively). Heavy mineral concentrates were achieved by re-processing on the Wilfley table. This was followed by magnetic separation and methylene iodide methods.

Uranium–lead (U/Pb) analysis was by isotope dilution thermal ionization mass spectrometry methods (ID-TIMS). Prior to analysis, zircon crystals were thermally annealed and chemically etched (chemical abrasion), which has the advantage of penetrative removal of alteration zones where lead loss has occurred and generally improving concordance (Mattinson 2005). The pre-treatment 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 7N HNO₃ in Teflon™ dissolution vessels at 200°C for 4.5 hours. Zircon and schorlomite were rinsed in 8N HNO₃ at room temperature prior to dissolution. A ²⁰⁵Pb/²³⁵U spike was added to the Krogh-type Teflon™ dissolution capsules during sample loading. The minerals were dissolved using ~0.10 mL of concentrated HF acid and ~0.02 mL of 7N HNO₃ at 200° C for 3 to 5 days. All samples were dried to a precipitate and re-dissolved in ~0.15 mL of 3N HCl overnight (Krogh 1973). Uranium and lead

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.10-1 to 10-11.*

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were isolated from the minerals using miniaturized ~50 µL anion exchange columns for zircon using HCl, or HBr for schorlomite, deposited onto outgassed rhenium filaments with silica gel (Gerstenberger and Haase 1997), and analyzed with a VG354 mass spectrometer using either a Daly detector in pulse-counting mode, or multiple Faraday collectors in static mode. Corrections to the $^{206}\text{Pb}/^{238}\text{U}$ ages for initial ^{230}Th disequilibrium in the zircon have been made assuming a Th/U ratio in the magma of 4.2. All common lead was assigned to procedural lead blank for zircon and 3 of 4 schorlomite analyses. For 1 schorlomite grain with high uranium content, initial lead was corrected using the model and Stacey and Kramers (1975). 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). All age errors quoted herein, and error ellipses in the concordia diagrams, are given at the 95% confidence interval. VG Sector software was used for data acquisition. In-house data reduction software in Microsoft® Visual Basic® by D.W. Davis was used. Plotting and age calculations were done using Isoplot 3.00 (Ludwig 2003).

Results for Sample 18JW-335B, Silico-carbonatite Dike

The Ash Lake pluton in the central part of West Township hosts silico-carbonatite dikes, as described in detail by Walker and Robichaud (2019) and shown in Figure 10.1. Sample 18JW-335B (718679E 5355458N, NAD83, Zone 16) is from one of several narrow (5–10 cm) dikes that contain xenoliths of felsic intrusive rocks. Its groundmass comprises dolomite, phlogopite, biotite, alkali feldspar, plagioclase feldspar, magnesium-rich ilmenite, magnetite, aegirine, riebeckite, apatite and trace amounts of chalcopyrite, sphalerite, pentlandite, niobium-bearing rutile, barite, pyrite and rare earth element carbonate minerals (Walker and Robichaud 2019). A small amount of zircon and schorlomite was recovered from the heavy mineral concentrate of the rock sample. Schorlomite is a calcium-titanium-rich garnet ($\text{Ca}_3\text{Ti}_2(\text{SiO}_4)(\text{Fe}^{3+}\text{O}^4)_2$). It is dodecahedral with submetallic lustre, and is found in carbonatites, syenites, phonolites and skarn deposits.

Four grains of schorlomite were selected based on clarity and lack of alteration. Two orange-brown crystals (similar in colour to rutile, but without the submetallic lustre) and 2 dark grey-brown, semi-opaque, conchoidally fractured submetallic grains were selected for analysis (Photo 10.1). It was suspected that despite the variation in colour and lustre, they were the same mineral displaying a range typically observed in rutile.

Results are shown in Figure 10.2 and Table 10.1. The U/Pb analysis of 3 schorlomite grains (S1-3) gave concordant overlapping results, and a fourth analysis is 3% discordant. A conservative, and probably less accurate, estimate of the age is produced by a line calculated through all 4 data, which gives $1208^{+10/-8}$ Ma and 345 ± 180 Ma (see Figure 10.2). The slight reverse discordance of S1-2 will bias the results to too young an age. An alternative interpretation is to take the 2 oldest overlapping concordant results, which have a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age of 1221 ± 4 Ma. This is perhaps a more robust age interpretation given probable lead loss in grains S3 and S4. Also, the latter interpretation is supported by results for zircon, see below.

Uranium, lead and thorium concentrations and the initial common lead content were dramatically different in S4, the discordant orange-brown grain. This grain contained a much higher concentration of approximately 20 000 ppm U compared to a similar-looking orange grain (S2) and 2 dark brown opaque grains at 4 to 16 ppm U. The dark opaque grains (S1, S3) have low Th/U of 0.01, whereas the orange grains (S2, S4) have higher Th/U values of 0.15 and 0.26, respectively. Discordance correlated with higher uranium in grain S4, but results for grains S1-S3 suggest that schorlomite grains can vary in Th/U and exhibit similar U/Pb isotope systematics.

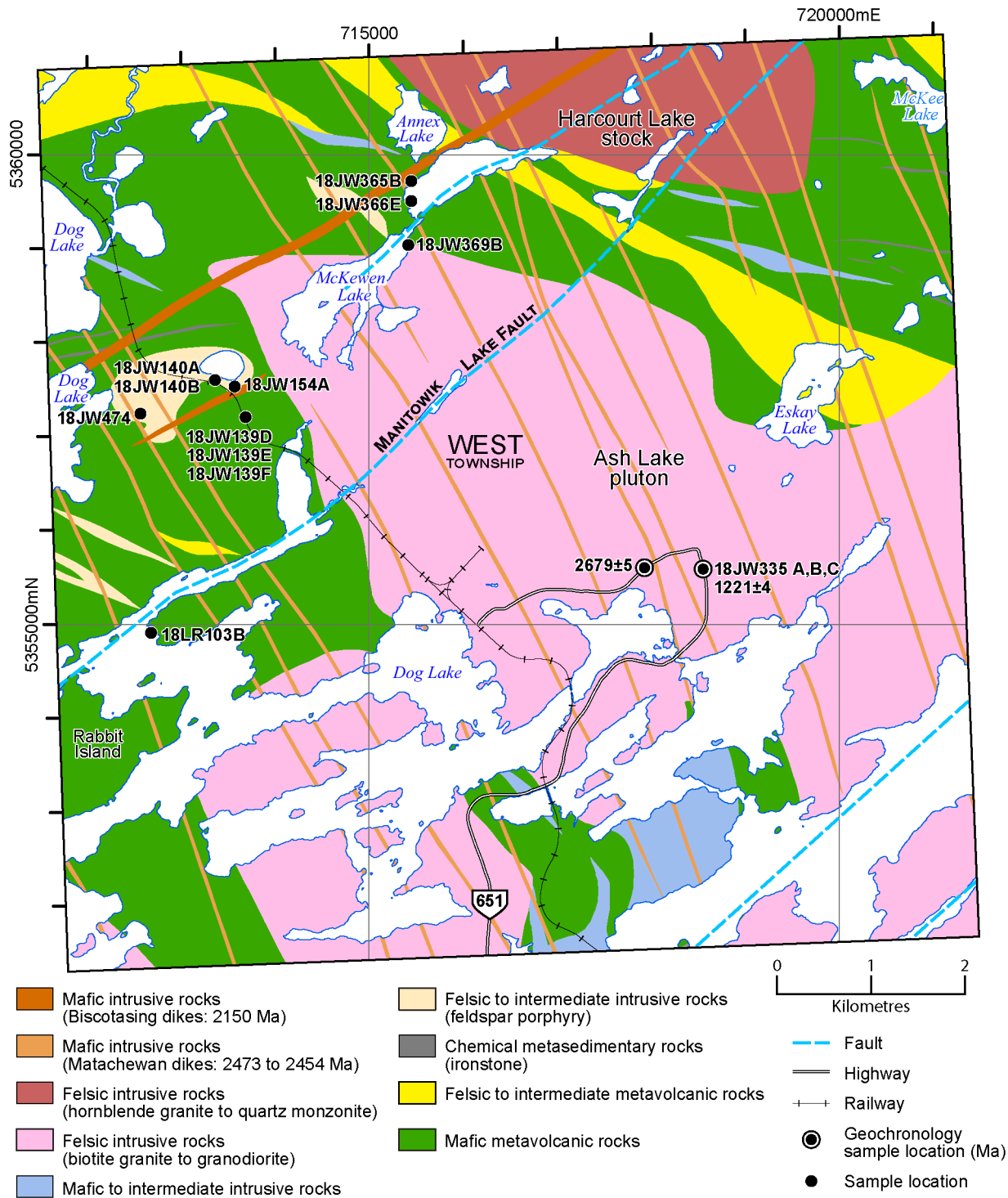


Figure 10.1. Simplified geological map of West Township (Universal Transverse Mercator (UTM) co-ordinates are provided in Zone 16 using North American Datum 1983 (NAD83)) from Walker and Robichaud (2019). Geochronology sample location and age is from Turek et al. (1996); geochronological data reported as Ma. Ages for the Matachewan and Biscotasing dike swarms are from Heaman (1997) and from Halls and Davis (2004). Locations displayed for calcite carbonatite dike (18JW335C), silico-carbonatite dike (18JW335B, geochronology sample), silico-carbonatite dike (18JW139F), alkalic gabbro (19JW139E1, 18JW140A, 18JW474), syenite cumulate (18JW154), biotite lamprophyre (18JW365B), syenite breccia (18JW369B, 18JW366E1), quartz diorite (19JW140B), biotite-plagioclase lamprophyre (18LR140B), zoned syenite porphyry dike (18JW139D1) and granite (18JW335A). Geochemical data for the carbonatite samples can be found in Walker and Robichaud (2019).

A small number of zircon grains (~3 dozen) was also recovered. Approximately two-thirds were slightly to extensively rounded and/or resorbed with varied colour and degree of alteration (*see* Photo 10.1). These were deemed likely to be inherited. The remaining grains were pale yellow, mostly translucent broken fragments with sharp crystal face intersections. These were deemed more likely to have crystallized in the carbonatitic magma. Similar grains were observed in thin section. After chemical abrasion, 3 of the clearest fragments, all similar looking, were analyzed for uranium and lead (*see* Photo 10.1).

One zircon (Z1) plots on top of the concordant schorlomite (S1) with a $^{206}\text{Pb}/^{238}\text{U}$ age of 1223 ± 4 Ma, within error of the schorlomite cluster (*see* Figure 10.2). This confirms intrusion of the carbonatite at *circa* 1221 Ma.

The Z3 is an inherited grain at 2672.9 ± 1.5 Ma, within error of the previously reported age of 2679 ± 5 Ma on the Ash Lake pluton (ID-TIMS, but not chemically abraded: Turek et al. 1996). The Z2 plots to the right of Z1 with a $^{207}\text{Pb}/^{206}\text{Pb}$ age of 1423 Ma and 15% discordance. It is unusual for high integrity zircon to plot so discordantly, and it may be that the etch was not sufficiently long to remove internal zones of lead loss and alteration, or it contained an inherited component. But another possibility is that it is an indicator of unusual U/Pb systematics in zircon from carbonatitic magma as a result of excess ^{231}Pa (protactinium), previously documented in baddeleyite systematics in carbonatite (Kamo et al. 2003). Further work is needed to evaluate that possibility.

A section of sample 18JW-335B was polished for U/Pb analysis by laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) analysis at the Jack Satterly Geochronology Laboratory. It was found to have insufficient uranium contents for U/Pb geochronology, at roughly an order of magnitude lower uranium than lead.

DISCUSSION

The interpreted schorlomite-zircon age of 1221 to 1223 Ma for the silico-carbonatite dike (18JW-335B) indicates that the dikes in West Township are distinct in emplacement age from the nearby carbonatite complexes with U/Pb ages, notably the Firesand alkali complex (1142.6 ± 1.6 Ma: Rukhlov and Bell 2010; Figure 10.3), and the Borden carbonatite complex (1882.0 ± 3.9 Ma: Rukhlov and Bell 2010; *see* Figure 10.3). These complexes, together with the location of sample 18JW-335B, occur along a trend parallel to the Kapuskasing Structural Zone, roughly straddling the boundary between the Michipicoten greenstone belt to the west and the Wawa Gneiss domain to the east (*see* Figure 10.3).

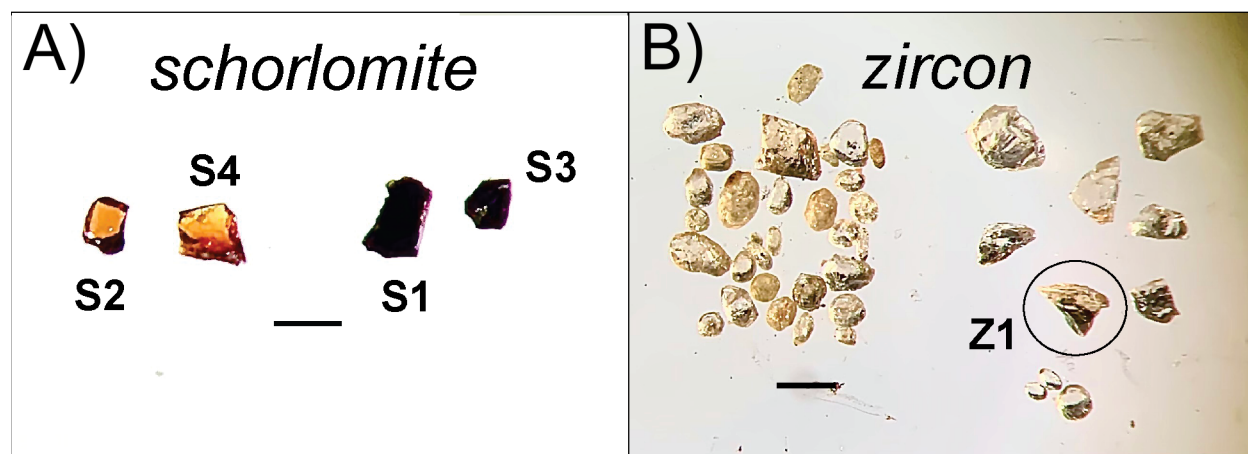


Photo 10.1. A) Photomicrographs of schorlomite (brown-orange to dark grey-brown) grains selected for U/Pb analysis. B) Photomicrograph of total recovered mixed zircon population (on left) and a subpopulation (on right) of well-faceted translucent zircon selected for chemical abrasion, with analyzed grain Z1 being highlighted. Scale bar on both sides are approximately 200 μm .

Although Geon 12 magmatism has not been documented previously within the Kapuskasing Structural Zone, it is commonplace in the southern Abitibi Subprovince and the northern Grenville Province, as summarized in Table 10.2 and Figure 10.3. The following events appear to be present, from oldest to youngest³.

1. A period of emplacement of felsic intrusions in the northern Grenville Province between 1260 to 1240 Ma.
2. A period of emplacement of mafic intrusions in the southern Abitibi Subprovince and the northern Grenville Province between 1245 to 1225 Ma.
3. And, coincident with emplacement of the mafic intrusions, the emplacement of the northwest-trending, alkalic, olivine gabbro dikes of the Sudbury dike swarm in the southern Abitibi Subprovince and the northern Grenville Province at 1238 ± 4 Ma (Krogh et al. 1987).
4. Carbonatitic magmatism in West Township at *circa* 1221 Ma occurred near the end of this 1260 to 1220 Ma magmatic event.

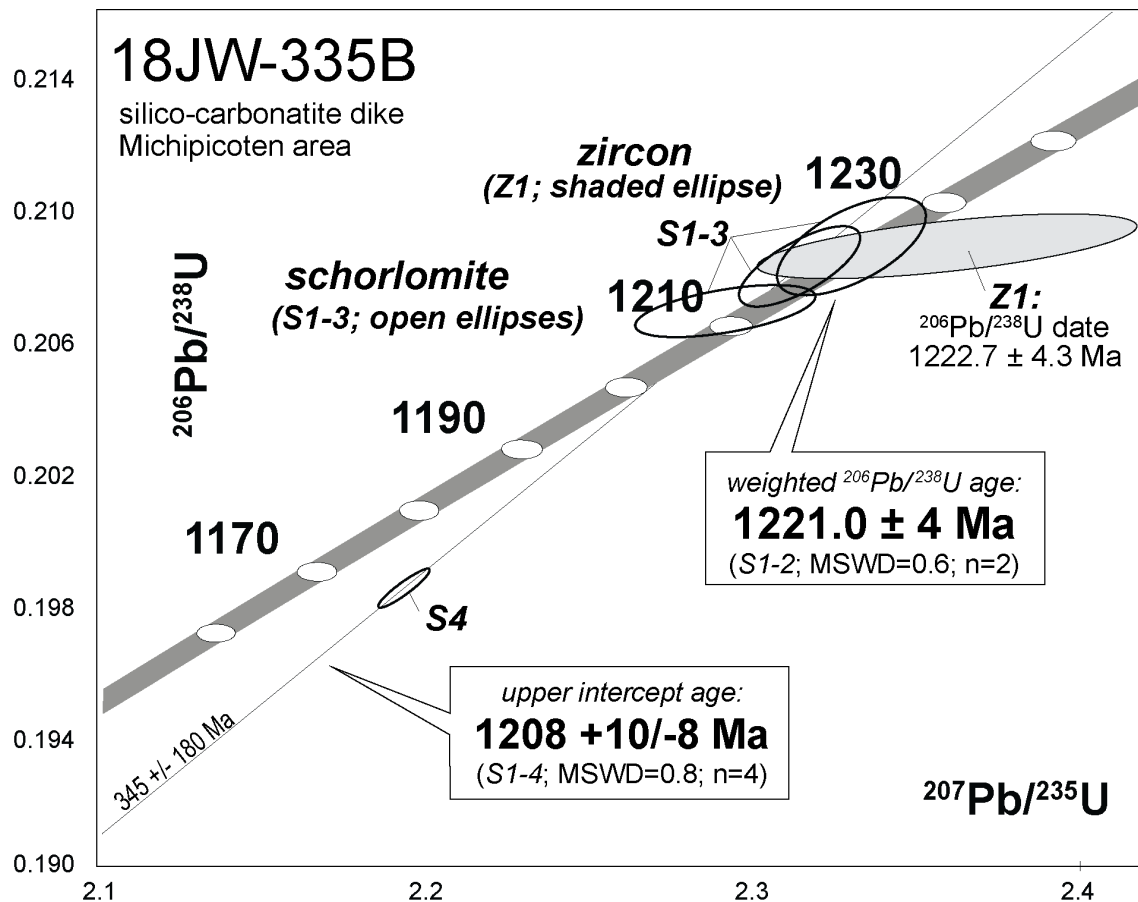


Figure 10.2. Concordia diagram showing U/Pb results for 4 schorlomite grains (S1-S4) that give an upper intercept age of $1208 +10/-8$ Ma and a weighted mean $^{206}\text{Pb}/^{238}\text{U}$ age (S1-S2) of 1221 ± 4 Ma, which is within error of that for zircon (Z1).

³ Note that the large age range for events in part reflects the fact that many of the ages are from mafic and felsic intrusions located in the Grenville Province that have been subjected to upper amphibolite facies metamorphism, resulting in lead loss. In addition, the ages listed in Table 10.2 were collected over a 35-year period, during which U/Pb methods advanced considerably, thus, ages from the 1990s may be less precise.

Table 10.1. Uranium–lead (U/Pb) ID-TIMS isotopic data for schorlomite and chemically abraded zircon from sample 18JW-335B.

Mineral Analysis Number	Weight (µg)	U ppm	Th/U	Pb _c (pg)	²⁰⁶ Pb/ ²⁰⁴ Pb Measured	²⁰⁷ Pb/ ²³⁵ U	2σ	²⁰⁶ Pb/ ²³⁸ U	2σ	Error Corr.
Schorlomite										
S1	7	4	0.01	0.7	609	2.3294	0.0187	0.20890	0.00122	0.611
S2	2	16	0.15	0.7	678	2.3135	0.0152	0.20830	0.00099	0.710
S3	5	11	0.01	0.8	875	2.2906	0.0225	0.20693	0.00064	0.552
S4	6	20982	0.26	166	9091	2.1921	0.0065	0.19852	0.00049	0.921
Zircon										
Z1	6	44	2.8	5.9	621	2.3586	0.0476	0.20885	0.00080	0.621
Z2	4	52	0.85	0.8	3394	2.6111	0.0088	0.21073	0.00051	0.746
Z3	4	84	0.74	1.3	8566	12.7920	0.0303	0.50924	0.00099	0.932

Mineral Analysis Number	²⁰⁷ Pb/ ²⁰⁶ Pb	2σ	²⁰⁶ Pb/ ²³⁸ Pb Age	2σ	²⁰⁷ Pb/ ²³⁵ U Age	2σ	²⁰⁷ Pb/ ²⁰⁶ Pb Age	2σ	Discordance
Schorlomite									
S1	0.08087	0.00052	1223.0	6.5	1221.3	5.7	1218.4	13	-0.4
S2	0.08056	0.00037	1219.7	5.3	1216.4	4.7	1210.6	9.1	-0.8
S3	0.08028	0.00069	1212.4	3.4	1209.4	7.0	1204.0	17	-0.8
S4	0.08009	0.00009	1167.3	2.6	1178.5	2.1	1199.1	2.3	2.9
Zircon									
Z1	0.08191	0.00148	1222.7	4.3	1230.2	14.4	1243.3	35	1.8
Z2	0.08986	0.00020	1232.7	2.7	1303.8	2.5	1422.6	4.3	15
Z3	0.18218	0.00016	2653.4	4.2	2664.5	2.2	2672.9	1.5	0.9

Notes: Zircon grains have been thermally annealed and etched in HF (Mattinson 2005).

S is schorlomite, Z is zircon.

Th/U calculated from radiogenic ²⁰⁸Pb/²⁰⁶Pb ratio and ²⁰⁷Pb/²⁰⁶Pb age assuming concordance.

Pb_c is total common Pb assuming the isotopic composition of laboratory blank: assigned the isotopic composition of laboratory blank (²⁰⁶Pb/²⁰⁴Pb=18.49±0.4%; ²⁰⁷Pb/²⁰⁴Pb=15.59±0.4%; ²⁰⁸Pb/²⁰⁴Pb=39.36±0.4%).

Initial Pb from geological sources in S4 using Stacey and Kramers (1975) Pb evolution model.

²⁰⁶Pb/²⁰⁴Pb corrected for fractionation and common Pb in the spike.

Pb/U ratios corrected for fractionation, common Pb in the spike, and blank.

Correction for ²³⁰Th disequilibrium in ²⁰⁶Pb/²³⁸U and ²⁰⁷Pb/²⁰⁶Pb assuming Th/U of 4.2 in the magma.

Discordance is percent discordance for the given ²⁰⁷Pb/²⁰⁶Pb age.

Error Corr. is correlation coefficients of X-Y errors on the concordia plot.

Decay constants are those of Jaffey et al. (1971): ²³⁸U and ²³⁵U are 1.55125 × 10⁻¹⁰/yr and 9.8485 10⁻¹⁰/yr.

²³⁸U/²³⁵U ratio of 137.88 used for ²⁰⁷Pb/²⁰⁶Pb model age calculations.

Fahrig (1987) and Ernst and Buchan (2001) both relate the Sudbury diabase dike swarm to the presence of a large mantle plume, possibly with an associated spreading centre, located southeast of Sudbury (see Figure 10.3). Unfortunately, the centre of the mantle plume and any associated spreading centre is now buried beneath allochthonous thrust sheets present within the Central Gneiss Belt of Ontario and Quebec. Easton (2002) and Easton and Ketchum (2002) proposed an alternative tectonic setting for the Sudbury dike swarm and the contemporaneous mafic intrusions: namely, an extensional rift (i.e., back-arc) basin in a continental arc setting, similar to that in which the Columbia River Basalt Group was deposited. In this model, the felsic plutons observed in the northwestern Grenville Province are the consequence of crustal melting related to mafic underplating associated with the mafic magmatism that generated the Sudbury diabase dike swarm. Such a model is consistent with the A-type chemistry of the plutons, and Nd/Sm isotopic data (Holmden and Dickin 1995) indicating significant crustal contamination, consistent with derivation of the plutons by crustal melting. The greater abundance of Geon 12 plutons as one goes from west to east from Sudbury to Mattawa might suggest that the source of the mantle upwelling was centred somewhere in the Mattawa area, as indicated in Figure 10.3.

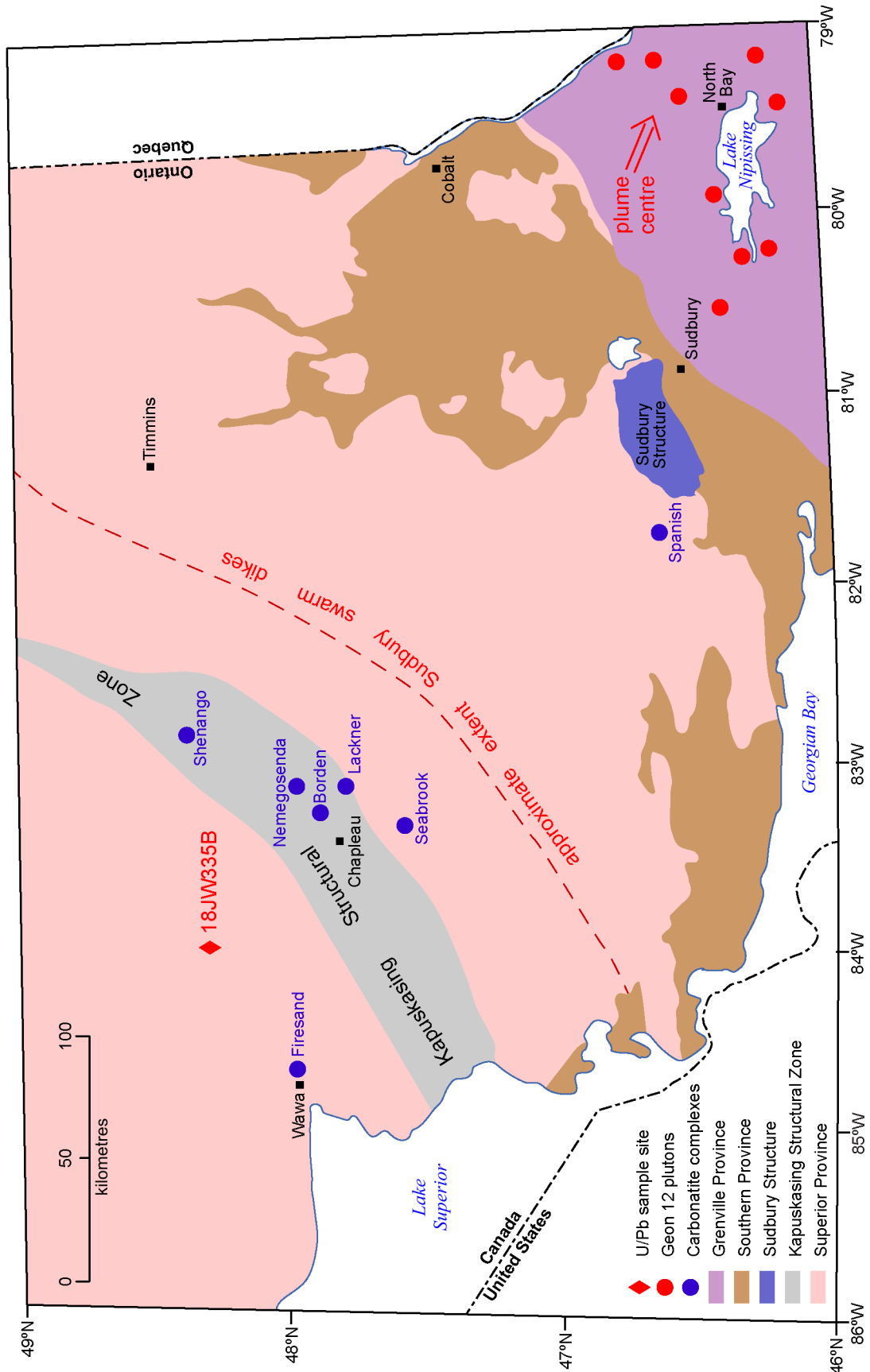


Figure 10.3. Map showing the distribution of Geon 12 rocks in the northwestern Grenville Province. Extent of western limit of the Sudbury dike swarm is from Buchan and Ernst (2004). Plutons indicated in the figure are listed in Table 10.2; full areal extent of the plutons is not shown. The possible plume centre that may have been responsible for magmatism in the region at about 1270 to 1230 Ma lies east-southeast of Lake Nipissing, likely beyond the extent of the figure.

Table 10.2. Geon 12 magmatic events in northeastern Ontario. Note the larger error limits for the samples affected by Grenvillian metamorphism; in all cases, these samples also yielded Grenvillian metamorphic ages on zircon or titanite.

Age (in Ma)	Unit	Comment	Method	Source
Sudbury Dike Swarm and Related Intrusions				
1238±4	diabase	Southern Province	U/Pb TIMS baddeleyite	Krogh et al. (1987)
1247 ^{+14/-13} 1235 ^{+7/-3}	diabase	Southern Province, zircon upper intercept, baddeleyite 4 near concordant grains, all from 3 sites	U/Pb TIMS zircon and baddeleyite	Dudas, Davidson and Bethune (1994)
1243 ^{+20/-14}	metadiabase	Grenville Province, average from 4 sites	U/Pb TIMS zircon and baddeleyite	Dudas, Davidson and Bethune (1994)
Felsic Intrusions in the Grenville Province				
<i>circa</i> 1271	breccia	Breccia dike matrix	U/Pb TIMS zircon	Easton (2006); Kamo (2005)
1250±10	Grey gneiss	Clarkson Township	U/Pb TIMS zircon	Easton (2006); Kamo (2004)
1257 ^{+4/-2}	Jocko pluton		U/Pb TIMS zircon	Easton (2006); Kamo (2004)
1244 ^{+4/-3} , 1250 ^{+10/-6}	Mulock granite		U/Pb TIMS zircon	Lumbers et al. (1991); Davidson and van Breemen (2001)
1270±3	Powassan pluton		U/Pb TIMS zircon	Davidson and van Breemen (2001)
1247±47	Red Pine Chute gneiss	Villedieu pluton, Quebec	U/Pb TIMS zircon	Currie and van Breemen (1996)
1255±20	Sturgeon Falls pluton	Quartz monzonite	U/Pb LA-ICP-MS zircon	Aldis (2016)
1245±12, 1252	West Bay pluton	Main phase monzogranite, late phase monzonite	U/Pb LA-ICP-MS zircon	Aldis (2016)
<i>circa</i> 1235	West Bay pluton	monzogranite	U/Pb TIMS zircon	L.M. Heaman <i>in</i> Davidson and van Breemen (2001)
1242±49 UI 1209±21 mean	Bonfield batholith	Monzogranite, in Tea Lake shear zone	U/Pb SHRIMP zircon	Foster (2012)
Mafic Intrusions in the Grenville Province				
1245±48	Mercer anorthosite	1222±2 Ma <i>in</i> Prevec (1992)	U/Pb TIMS zircon	Prevec (2004, 1992)
1244±100	St. Charles anorthosite	1206±36 Ma <i>in</i> Prevec (1993)	U/Pb SHRIMP zircon	Prevec (2004, 1993)
1235±2	Flett intrusion	average Pb ²⁰⁷ /Pb ²⁰⁶ age, n=3	U/Pb TIMS baddeleyite	Ketchum (2002); Easton (2002)
1238±2	Fanny Lake intrusion	average Pb ²⁰⁷ /Pb ²⁰⁶ age, n=2	U/Pb TIMS baddeleyite	Ketchum (2002); Easton (2002)

Abbreviations: LA-ICP-MS, laser ablation inductively coupled plasma mass spectrometry; SHRIMP, sensitive high-resolution ion microprobe; TIMS, thermal ionization mass spectrometry; UI, upper intercept.

It is also possible to invoke a model involving a combination of back-arc spreading and an upwelling mantle plume for the Geon 12 magmatic activity (Easton 2002). Such a model would result in the generation of mafic and felsic magmas in the lower crust, and a well-defined radiating dike swarm, but would not necessarily lead to the development of a spreading centre or a fully formed continental rift.

Emplacement of carbonatite complexes is a well-documented outcome of mantle plume upwelling and associated large igneous provinces (e.g., Ernst and Bell 2010; Ernst et al. 2019, 2021). Emplacement of carbonatites typically occurs many hundreds of kilometres away from the main plume centre and/or related rifted-continental margin. For example, 1890 to 1880 Ma carbonatite complexes in Ontario (Argor, Borden, Carb, Goldray, Cargill, Spanish River) associated with the Circum-Superior large igneous province occur at distances ranging from 700 to 1100 km from the plume centre. In the case of the West Township carbonatite dikes, they occur anywhere from 400 to 600 km distant from the inferred Geon 12 plume centre.

Table 10.3. Main pulses of carbonatite magmatism in Ontario and their association with documented Large Igneous Provinces (LIPS) in Ontario. Large Igneous Provinces from Ernst et al. (2021), carbonatite ages are summarized in Easton (2020).

Age Range (in Ma)	Associated Large Igneous Province	Distance from Plume Source (km)
1880–1870	Circum-Superior	700 to 1100
1255–1225	Sudbury dike swarm	400 to 600
1150–1140	Corson–Abitibi	unknown
1110–1090	Keweenawan	450 to 900
590–560	Central Igneous Magmatic Province (late pulse)	500 to 750

As summarized in Table 10.3, the previously recognized 4 main carbonatite emplacement events in Ontario, at 1890 to 1880 Ma, 1160 to 1140 Ma, 1110 to 1090 Ma and *circa* 590 Ma are all associated with known large igneous provinces. In addition, carbonatite complexes from 3 of these 4 events occur in proximity to the Kapuskasing Structural Zone, probably because it served as a zone of weakness where deep-seated magmas could rise from the mantle to upper-crustal levels with relative ease. Consequently, it would not be unusual for the West Township carbonatite dikes to have a similar association with a plume centre, and to be found proximal to the Kapuskasing Structural Zone.

MINERAL POTENTIAL

As noted by Walker and Robichaud (2019), although the silico-carbonatite and calcite-carbonatite dikes in West Township are too small to be of economic interest themselves, they may prove to be critical in finding a yet unidentified carbonatite intrusion(s) at depth that may be of economic interest. For example, the elevated concentrations of P₂O₅ observed in the dikes reported in Walker and Robichaud (2019) suggests that residual apatite deposits may be present above any unexposed carbonatite intrusion. In addition, both the dikes in West Township and those on Highway 129 in Villeneuve Township indicate that there may be yet other carbonatite intrusions present within the Kapuskasing Structural Zone waiting to be discovered.

Much of the southern Kapuskasing Structural Zone, and the Ramsey–Algoma granitoid complex of the southern Abitibi Subprovince remain poorly mapped and poorly explored. Thus, it is likely that other carbonatite dikes and complexes, as well as alkalic intrusions of Geon 18, 12 and 11 age, remain to be discovered.

ACKNOWLEDGMENTS

Joe Walker was instrumental in collecting the samples and doing much of the subsequent work on the samples. Thanks go to Sandra Clarke and Dave Crabtree of the OGS Geoscience Laboratories for their help on the scanning electron microscope (SEM), which led to the sample being submitted for geochronology.

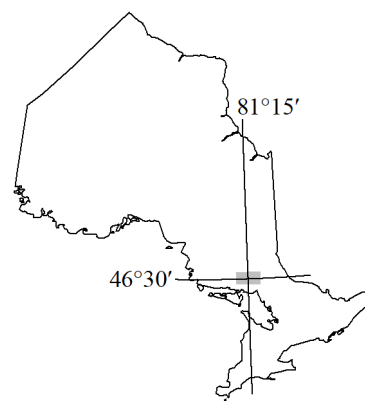
REFERENCES

- Aldis, C.H. 2016. Geochronology and geochemistry of Mesoproterozoic granitoids in the Nepewassi domain, Grenville Orogen; unpublished BSc thesis, University of Waterloo, Waterloo, Ontario, 82p.
- Buchan, K.L. and Ernst, R.E. 2004. Diabase dyke swarms and related units in Canada and adjacent regions; Geological Survey of Canada, Map 2022A, scale 1:5 000 000.
- Currie, K.L. and van Breemen, O. 1996. The origin of rare minerals in the Kipawa syenite complex, western Quebec; *The Canadian Mineralogist*, v.34, p.435-451.
- Davidson, A. and van Breemen, O. 2001. Mid-Mesoproterozoic granitoid rocks in the North Bay area, Grenville Province, Ontario; *in* Radiogenic Age and Isotopic Studies 14, Geological Survey of Canada, Current Research, Paper 2001-F8, 15p.

- Dudas, F.O., Davidson, A. and Bethune, K.M. 1994. Age of the Sudbury diabase dykes and their metamorphism in the Grenville Province, Ontario; *in* Radiogenic Age and Isotopic Studies: Report 8; Geological Survey of Canada, Paper 94-F, p.97-106.
- Easton, R.M. 2002. Geology of mafic intrusive rocks of Flett and Angus townships, Grenville Province; Ontario Geological Survey, Open File Report 6090, 70p.
- 2006. Geology and mineral potential of the eastern Tomiko terrane, Grenville Province; Ontario Geological Survey, Open File Report 5554, 117p.
- 2020. Exploration guidelines for carbonatites in Ontario; *in* Summary of Field Work and Other Activities, 2020, Ontario Geological Survey, Open File Report 6370, p.9-1 to 9-10.
- Easton, R.M. and Ketchum, J.W.F. 2002. Evidence for a major Mesoproterozoic magmatic province within the western Grenville Province near North Bay, Ontario; Geological Society of America, Abstracts with Program, v.34, no.6, p.242.
- Ernst, R.E. and Bell, K. 2010. Large Igneous Provinces (LIPS) and carbonatites; *Mineralogy and Petrology*, v.98, p.55-76.
- Ernst, R.E. and Buchan, K.L. 2001. Large mafic magmatic events through time and links to mantle-plume heads; *in* Mantle plumes: Their identification through time; Geological Society of America, Special Paper 352, p.483-575.
- Ernst, R.E., Liikane, D.A., Jowitt, S.M., Buchan, K.L. and Blanchard, J.A. 2019. A new plumbing system framework for mantle plume-related continental Large Igneous Provinces and their mafic-ultramafic intrusions; *Journal of Volcanology and Geothermal Research*, v.384, p.75-84.
- Ernst, R.E., Bond, D.P.G., Zhang, S-H, Buchan, K.L., Grasby, S.E., Youbi, N., El Bilali, H., Bekker, A. and Doucet, L.S. 2021. Large igneous province record through time and implications for secular environmental changes and geological time-scale boundaries; *in* Large igneous provinces: A driver of global environmental and biotic changes, American Geophysical Union, Geophysical Monograph 255, p.3-26.
- Fahrig, W.F. 1987. The tectonic settings of continental mafic dike swarms: Failed arm and early passive margin; *in* Mafic dike swarms, Geological Association of Canada, Special Paper 34, p.331-348.
- Foster, J.G.L. 2012. Tectonometamorphic evolution of the Kiosk domain, Central Gneiss Belt, Grenville Province, Ontario: Constraints from geochronology and thermobarometry; unpublished MSc thesis, Dalhousie University, Halifax, Nova Scotia, 253p.
- 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. and Davis, D.W. 2004. Paleomagnetism and U-Pb geochronology of the 2.17 Ga Biscotasing dyke swarm, Ontario, Canada: Evidence for vertical-axis crustal rotation across the Kapuskasing Zone; *Canadian Journal of Earth Sciences*, v.41, p.255-269.
- Heaman, L.M. 1997. Global mafic magmatism at 2.45 Ga: Remnants of an ancient large igneous province?; *Geology*, v.25, p.299-302.
- Holmden, C. and Dickin, A.P. 1995. Paleoproterozoic crustal history of the southwestern Grenville Province: Evidence from Nd isotopic mapping; *Canadian Journal of Earth Sciences*, v.32, p.472-485.
- 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*, v.4, p.1889-1906.
- Kamo, S.L. 2004. U-Pb geochronological investigations of rocks from the Lac des Iles area, northwestern Ontario, the Michipicoten greenstone belt, Wawa, and the Tomiko Terrane, Mattawa, Ontario; internal U/Pb age report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 9p.

- 2005. U-Pb zircon geochronology of rocks from the Central Metasedimentary Belt and the Tomiko Terrane, Grenville Province, Ontario; internal report for the Ontario Geological Survey, Jack Satterly Geochronology Laboratory, Department of Geology, University of Toronto, Toronto, Ontario, 12p.
- Kamo, S.L., Czamanske, G.K., Amelin, Y., Fedorenko, V.A., Davis, D.W. and Trofimov, V.R. 2003. Rapid eruption of Siberian flood-volcanic rocks, coincident with the Permian-Triassic boundary and mass extinction at 251 Ma; *Earth and Planetary Science Letters*, v.214, p.75-91.
- Ketchum, J.W.F. 2002. U-Pb geochronological data from the Superior and Grenville Provinces of Ontario; unpublished report prepared for the Precambrian Geoscience Section, Ontario Geological Survey, April 2002, 45p.
- 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.
- Ludwig, K.R. 2003. User's manual for Isoplot 3.00: A geochronological toolkit for Microsoft® Excel®; Berkeley Geochronology Center, Special Publication No. 4, 71p.
- Lumbers, S.B., Wu, T-W., Heaman, L.M., Vertolli, V.M. and MacRae, N.D. 1991. Petrology and age of the A-type Mulock granite batholith, northern Grenville Province, Ontario; *Precambrian Research*, v.53, p.199-231.
- 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.
- 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.
- 2004. Basement tracing using Mid-Proterozoic anorthosites straddling a palaeoterrane boundary, Ontario, Canada; *Precambrian Research*, v.129, p.169-184.
- Rukhlov, A.S. and Bell, L. 2010. Geochronology of carbonatites from the Canadian and Baltic shields, and the Canadian Cordillera: Clues to mantle evolution; *Mineralogy and Petrology*, v.98, p.11-54.
- Stacey, J. and Kramers, J. 1975. Approximation of terrestrial lead isotope evolution by a two-stage model; *Earth and Planetary Science Letters*, v.26, p.207-221.
- 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.
- Walker, J. and Robichaud, L. 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.
- 2019. Alkalic intrusive rocks and carbonatites in West Township, Michipicoten Greenstone Belt; *in* Summary of Field Work and Other Activities, 2019; Ontario Geological Survey, Open File Report 6360, p.6-1 to 6-10.

11. Project SO-21-003. Proterozoic Mafic Intrusions of the Sudbury Area: Compilation and Characterization Project



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INTRODUCTION

The Sudbury area is host to numerous nickel-copper-platinum group element (Ni-Cu-PGE) deposits and is one of the greatest nickel-producing districts in the world. Existing geological maps (e.g., Card and Lumbers 1975; Dressler 1984b; Ames et al. 2005) show that in addition to the Sudbury Igneous Complex (SIC) and associated quartz-diorite offset dikes, there are a variety of mafic intrusions of various type, composition and age in the Sudbury area. These mafic intrusions have differing potential for Ni-Cu-PGE mineralization and have been the focus of exploration and academic research. Despite the economic importance of these intrusions, most older geological maps of the Sudbury area provide limited subdivision of these rocks. This is, in part, the result of the lack of distinctive characteristics in the field and the limited characterization of the geochemical and geophysical properties of many of these mafic intrusive rocks.

The Proterozoic mafic intrusions of the Sudbury area compilation and characterization project, is a multi-year project initiated by the Ontario Geological Survey in 2021 to compile all available information on mafic intrusions in the Sudbury area into a single relational database and associated compilation map. The project area covers approximately 1400 km² and extends from Dunlop and Shakespeare townships in the west to Street and Scadding townships in the east (Figure 11.1). The compiled data will be used to produce a geochemical (major and trace element data, isotopic data), geophysical (specific gravity, gamma-ray response, magnetic susceptibility response) and geological (field characteristics, orientation of bodies, petrography, metamorphism) characterization of the different suites of mafic intrusions present in the Sudbury area.

PROJECT OBJECTIVES

Specific objectives for the Proterozoic mafic intrusions of the Sudbury area compilation and characterization project include

- compile all publicly available data on mafic intrusions in the Sudbury area into a relational database. Sources include scientific journals, assessment files, graduate theses and government publications.
- produce a compilation map of Proterozoic mafic intrusions in the Sudbury area. The map will be compiled from geological maps, written reports and traced from aeromagnetic maps. Although much smaller in scope, this compilation map will have a similar style to the Proterozoic mafic (diabase) dikes and other post-Archean intrusions of northwestern Ontario, north of latitude 49°30', compilation map by Stott and Josey (2009).

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.11-1 to 11-6.*

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- produce an Open File Report that summarizes the geochemical, geophysical and geological characteristics of the different mafic intrusive units in the study area. This report will provide users with the geochemical, geophysical and geological criteria to assist them in discriminating between the different mafic intrusive suites in the Sudbury area.
- provide users with geochemical criteria to assist in assessment of mineral potential of the different mafic intrusive suites.

GEOLOGICAL SETTING

The study area predominantly focusses on the Southern Province, northwest of the Grenville Front and south of the Sudbury Structure (see Figure 11.1). Within the study area, the Southern Province includes the supracrustal rocks of the Huronian Supergroup (2450–2219 Ma; Krogh, Davis and Corfu 1984; Bennett, Dressler and Robertson 1991) and rocks of the Sudbury Structure (Dressler 1984a). The Huronian Supergroup is composed of metamorphosed sandstone, mudstone, carbonate, conglomerate and minor volcanic rocks, which are subdivided into the Elliot Lake, Hough Lake, Quirke Lake and Cobalt groups (cf. Robertson, Card and Frarey 1969). The Sudbury Structure is the deformed remnant of an ancient meteorite crater formed at 1850 Ma (Dietz 1964; Krogh, Davis and Corfu 1984). The Sudbury

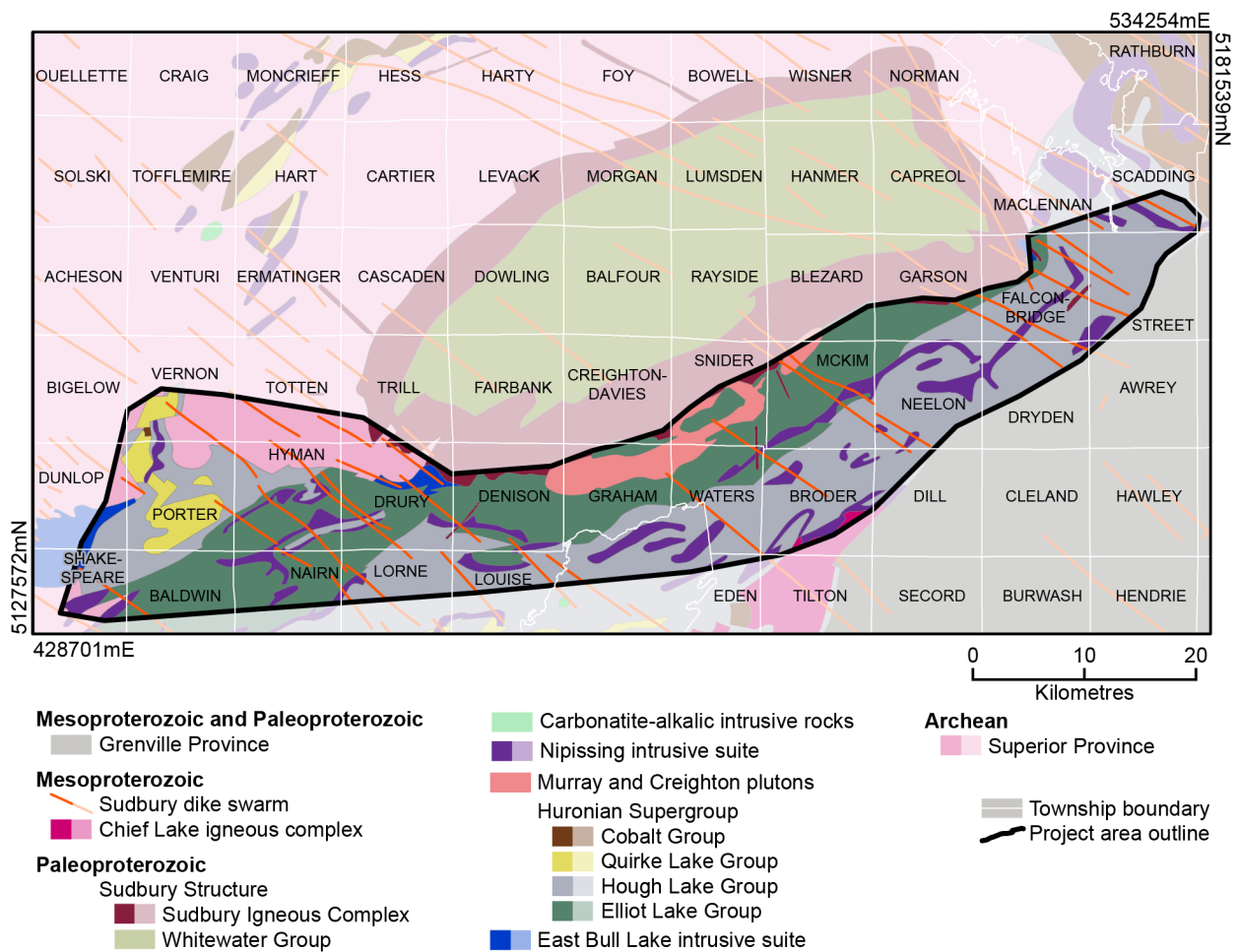


Figure 11.1. Simplified bedrock geology map of the Sudbury area. Geology *modified from* Ontario Geological Survey (2011). Note, darker colours indicate geological units within the project area. Project area outlined in black. Universal Transverse Mercator (UTM) co-ordinates provided using North American Datum 1983 (NAD83) in Zone 17.

Structure is made up of 1) the Main Mass of the Sudbury Igneous Complex (SIC) consisting of lower noritic to gabbroic cumulates, a transitional quartz gabbro and an upper granophyre; 2) the Sublayer; 3) quartz-diorite offset dikes; 4) brecciated and shock metamorphosed footwall rocks known as Sudbury breccia; and 5) crater-fill breccias overlain by sedimentary strata of the Whitewater Group (Dressler, Gupta and Muir 1991, and references therein). Within the northwestern portion of the study area, the Huronian Supergroup unconformably overlies basement rocks of the Archean Superior Province (see Figure 11.1). Here, the Archean rocks of the Superior Province consist of monzogranites of the Cartier (2642 Ma: Meldrum et al. 1997) and Birch Lake (2651 Ma: Kamo 2006; Easton and Heaman 2008) batholiths of the Ramsey–Algoma granitoid complex.

The Sudbury area has been intruded by numerous dikes, sills and plutons of various ages. Known intrusive suites include the 1) Matachewan–Hearst mafic dike swarm (2480–2446 Ma: Heaman 1997; Bleeker et al. 2012); 2) East Bull Lake intrusive suite (2480 Ma: Krogh, Davis and Corfu 1984), 3) Creighton and Murray plutons (2460 Ma: Bleeker et al. 2015); 4) Nipissing intrusive suite (2219–2210 Ma: Noble and Lightfoot 1992; Davey et al. 2019); 5) Trap dike swarm (1750 Ma: Bleeker et al. 2015); 6) Sudbury dike swarm (1238 Ma: Krogh et al. 1987); and 7) Grenville dike swarm (590 Ma: Kamo, Krogh and Kumarapeli 1995).

PREVIOUS WORK AND PROJECT RATIONALE

The study area was selected to focus on the Southern Province south of the main mass of the Sudbury Structure (see Figure 11.1) because, in this area, the presence of rocks of both the Huronian Supergroup and belts of Sudbury breccia help to provide relative age constraints on the emplacement of these mafic intrusions. In contrast, the area underlain by the Superior Province basement, to the north, provides fewer relative age constraints. Historically, most of the mafic intrusions in the study area were assigned to 1) the Matachewan dike swarm or the East Bull Lake intrusive suite if they cut the Superior Province basement, 2) the Nipissing intrusive suite if they cut the Huronian Supergroup supracrustal rocks, and 3) any of the Trap dike swarm, the Sudbury dike swarm, or the Grenville dike swarm if they cut the Huronian Supergroup and the Sudbury Igneous Complex rocks.

Work by Gordon, Simard and Généreux (2018), Gordon (2018), Easton (2005, 2009, 2010), Bleeker et al. (2015) and Davey et al. (2019) have used a combination of field relationships, geochemistry, geophysical properties and/or geochronology to further refine the subdivision of mafic intrusive rocks in the Sudbury and Elliot Lake areas. Recent work in the southwest corner of the Sudbury Structure by Gordon, Simard and Généreux (2018) and Gordon (2018) reclassified numerous mafic intrusions and breccia units that had previously been grouped together on older geological maps with the large masses of Nipissing gabbro. The new subdivisions include 1) breccia belts related to the Sudbury impact (Sudbury breccia), 2) subvolcanic mafic rocks of the Huronian Supergroup, 3) Trap dike swarm, and 4) dikes of unknown affinity. Work by Easton (2005, 2009, 2010) in Porter and Baldwin townships, and in the Whiskey–Pecors Lake area west of the study area, identified and refined various mafic intrusions cutting host rocks of the Superior and Southern provinces including 1) numerous Paleoproterozoic mafic dikes that are not related to currently known mafic intrusive suites in the area; 2) the Stone Ridge Intrusion, originally classified as a Nipissing gabbro, to be part of the East Bull Lake intrusive suite; 3) mafic dikes that possibly represent feeders to the East Bull Lake intrusive suite; 4) vesicular mafic dikes that possibly represent feeders to the Huronian Supergroup metavolcanic rocks; and 5) lamprophyre dikes of unknown age. Work by Bleeker et al. (2015) suggests that mafic dikes belonging to the Marathon (*circa* 2125 to 2100 Ma) and North Channel (*circa* 1900 to 1950 Ma) dike swarms may be present in the Sudbury area, but are currently misidentified and/or are grouped with the *circa* 1750 Ma Trap dike swarm.

This previous work highlights the need to consolidate all the available data on mafic intrusions in the Sudbury area into a single relational access-style database and to determine the geochemical, geophysical, geochronological and field characteristics of each intrusive suite. Collectively, the data will provide users with a framework to use in discriminating between the different mafic intrusive suites in the Sudbury area and to assist in the assessment of their mineral potential.

PROJECT STATUS

In the summer of 2021, work on the project consisted of

- compiling a list of all Ontario Geological Survey geological maps, reports and data sets pertinent to the study area
- compiling the analytical methods and detection limits, both current and historical, for the Ontario Geological Survey lithogeochemical data
- creating and designing the Mafic Intrusion Database, including designating standardized analytical methods to accommodate data from various sources
- starting compilation of the Ontario Geological Survey geochemical data into a geochemistry database
- starting compilation of geochemical data from assessment file reports into a geochemistry database
- creating the geodatabase for the compilation map

ACKNOWLEDGMENTS

The authors would like to thank J. Nieva and M. Foster for their assistance and hard work on this project during the summer of 2021. R.M. Easton and S. Préfontaine, of the Ontario Geological Survey are thanked for their ongoing advice and assistance on this project; and J.E. Chartrand, S.A. Evers, J.L. Webb and P. Gervais, of the Ontario Geological Survey, for all the assistance with databases, software logistics and drafting.

REFERENCES

- 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.
- 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.
- Bleeker, W., Hamilton, M.A., Ernst, R.E. and Söderlund, U. 2012. Resolving the age structure of the Matachewan event: Magmatic pulses at ca. 2445-2452 Ma, 2458-2461 Ma, and 2475-2480 Ma; unpublished CAMIRO Reports A96, A97, and A98, 17p.
- 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. and Lumbers, S.B. 1975. Sudbury–Cobalt; Ontario Geological Survey, Map 2361, scale 1:253 440.

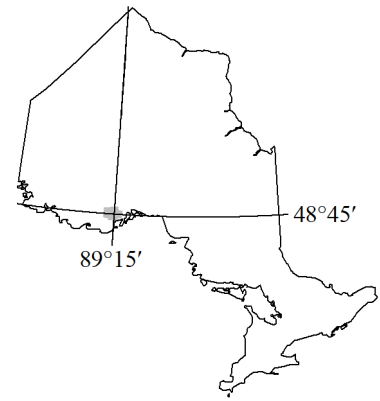
- Davey, S., Bleeker, W., Kamo, S., Davis, D., Easton, M. and Sutcliffe, R.H. 2019. Ni-Cu-PGE potential of the Nipissing sills as part of the ca. 2.2 Ga Ungava large igneous province; *in* Targeted Geoscience Initiative: 2018 Report of Activities, Geological Survey of Canada, Open File 8549, p.404-419.
- Dietz, R.S. 1964. Sudbury Structure as an astrobleme; *Journal of Geology*, v.72, p.412-434.
- 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. Sudbury geological compilation; Ontario Geological Survey, Map 2491, scale 1:50 000.
- Dressler, B.O., Gupta, V.K. and Muir, T.L. 1991. The Sudbury Structure; Chapter 15 *in* The geology and ore deposits of the Sudbury Structure, Ontario Geological Survey, Special Volume 4, Part 1, p.593-625.
- Easton, R.M. 2005. Geology and mineral potential of Porter and Vernon townships, Southern Province; *in* Summary of Field Work and Other Activities, 2005, Ontario Geological Survey, Open File Report 6172, p.13-1 to 13-20.
- 2009. Compilation mapping, Pectors–Whiskey Lake area, Southern and Superior provinces; *in* Summary of Field Work and Other Activities, 2009, Ontario Geological Survey, Open File Report 6240, p.10-1 to 10-21.
- 2010. Compilation mapping, Pectors–Whiskey Lake area, Southern and Superior 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. and Heaman, L.M. 2008. Detrital zircon geochronology of Huronian Supergroup sandstones located within the Vernon structure, north of Espanola, Ontario; abstract *in* 54th Institute on Lake Superior Geology, Proceedings, v.54, pt.1, p.21-22.
- 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.
- 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.
- Heaman, L.M. 1997. Global mafic magmatism at 2.45 Ga: Remnants of an ancient large igneous province?; *Geology*, v.25, p.299-302.
- 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 from the Jack Satterly Geochronology Laboratory for the Ontario Geological Survey, Department of Geology, University of Toronto, Toronto, Ontario, 20p.
- Kamo, S.L., Krogh, T.E. and Kumarapeli, P.S. 1995. Age of the Grenville dyke swarm, Ontario-Quebec: Implications for the timing of the Iapetan rifting; *Canadian Journal of Earth Sciences*, v.32, p.273-280.
- 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 area; *in* The geology and ore deposits of the Sudbury Structure; Ontario Geological Survey, Special Volume 1, p.431-446.
- 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.
- Noble, S.R. and Lightfoot, P.C. 1992. U–Pb baddeleyite ages for the Kerns and Triangle Mountain intrusions, Nipissing diabase, Ontario; *Canadian Journal of Earth Sciences*, v.29, p.1124-1129.

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

Robertson, J.A., Card, K.D. and Frarey, M.J. 1969. The Federal–Provincial Committee on Huronian stratigraphy progress report; Ontario Department of Mines, Miscellaneous Paper 31, 26p.

Stott, G.M. and Josey, S. 2009. Proterozoic mafic (diabase) dikes and other post-Archean intrusions of northwestern Ontario, north of latitude 46°30'; Ontario Geological Survey, Preliminary Map P.3606, scale 1:1 000 000.

12. Project NW-19-001. A Uranium–Lead Baddeleyite Age for the Midcontinent Rift–Related Lone Island Lake Intrusion, Northwestern Ontario



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INTRODUCTION

This brief article presents a uranium–lead (U/Pb) baddeleyite age estimate and associated analytical data for an occurrence of undeformed mafic intrusive rocks in the vicinity of Lone Island Lake, approximately 35 km north of the City of Thunder Bay. These mafic intrusive rocks are exposed in several outcrops and have been intersected in a limited number of cored diamond-drill holes. These rocks are collectively referred to in this article as the “Lone Island Lake intrusion” (LILI), although they may represent multiple discrete intrusions. The new age estimate, 1106.3 ± 2.1 Ma, supports the inclusion of the LILI as part of the larger, provisionally named, “Thunder Bay North intrusive complex” (TBNIC; e.g., Bleeker et al. 2020), which has an age estimate of 1106.6 ± 1.6 Ma based on a sample from the Current Lake intrusion (Bleeker et al. 2020), one of its component intrusions. The TBNIC intrusion nomenclature used here differs from Bleeker et al. (2020) in that subunits comprising the TBNIC are named as individual intrusions rather than intrusive complexes (this is entirely semantic) (Figure 12.1). The TBNIC hosts several zones of platinum group elements–nickel–copper (PGE–Ni–Cu) mineralization, including National Instrument 43-101–compliant indicated and inferred resource estimates on the Escape and Current deposits (*see* Kuntz and Jones 2021). Limited drilling of mafic intrusive rocks of the LILI has revealed sporadic orthomagmatic sulphide mineralization (*cf.* Kuntz and Jones 2021), but extensive exploration has not been carried out on the LILI.

The geochronological sampling and analysis of gabbro sample 19JW-365GC reported here was done as part of an ongoing Ontario Geological Survey (OGS) bedrock geology mapping project, the goal of which is to produce 1:50 000 scale bedrock geology maps of a large area (hereafter referred to as the “project area”), north of Thunder Bay, that is underlain by Archean rocks of the Quetico, Wawa and Wabigoon subprovinces, a diverse array of Proterozoic mafic and ultramafic intrusive rocks, and local Proterozoic metasedimentary and sedimentary rocks. Readers are referred to Metsaranta (2015), Metsaranta and Walker (2019) and Metsaranta and Hamilton (2020) for additional geological information generated so far during the project based on 2 partial seasons of field data collection (2015, 2019). Limitations related to the ongoing COVID-19 pandemic prevented additional field data acquisition during 2020 and 2021.

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.12-1 to 12-8.*

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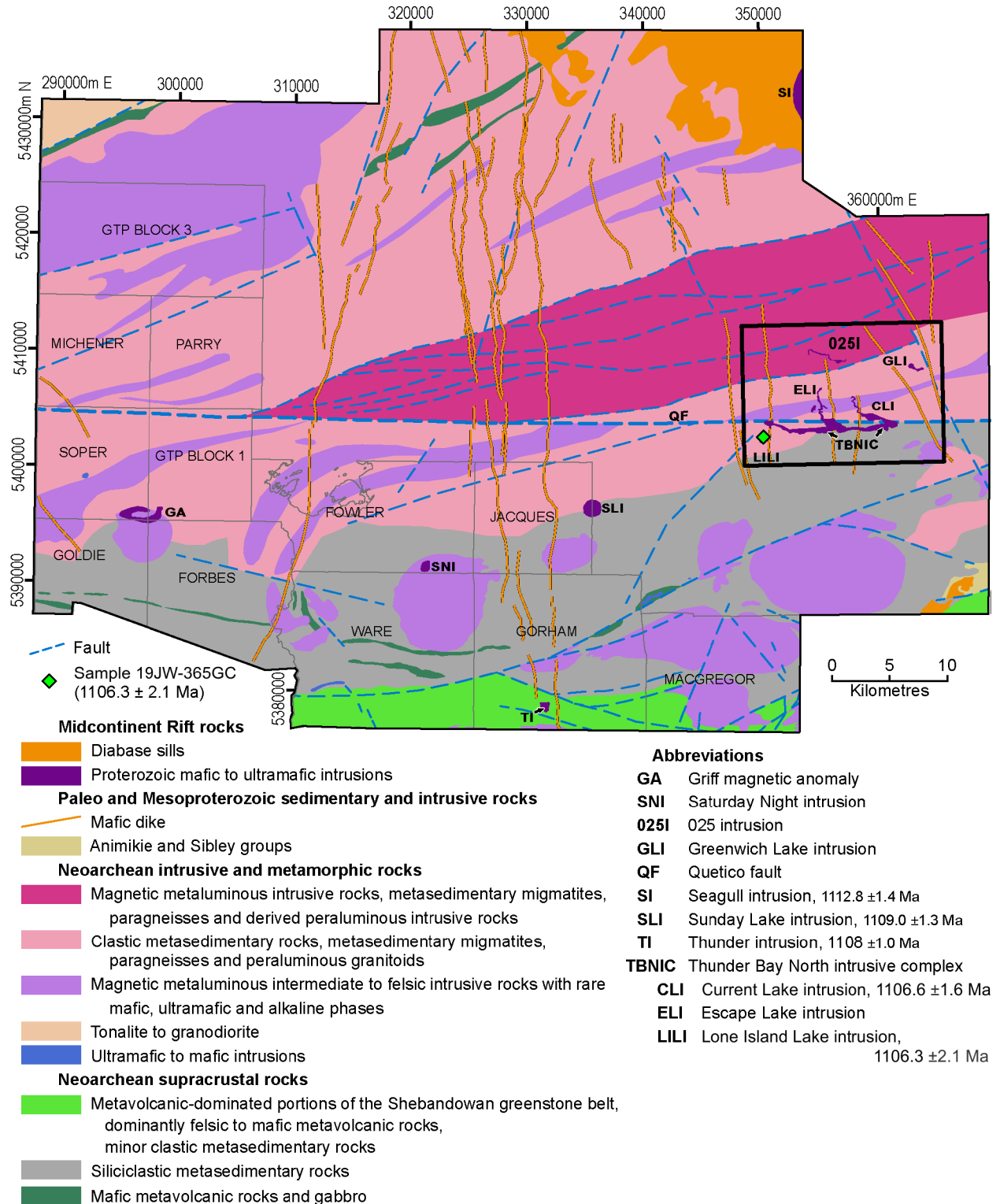


Figure 12.1. Generalized geology of the project area showing location of sample 19JW-365GC and age constraints on other Midcontinent Rift-related intrusions in the project area. The depiction of the Griff magnetic anomaly (“GA”) as a Proterozoic mafic to ultramafic intrusion is speculative. *Modified from* Metsaranta (2015), Kuntz and Jones (2021) and Carter (1985). Ages other than the Lone Island Lake intrusion are those reported by Bleeker et al. (2020). Universal Transverse Mercator (UTM) coordinates provided using North American Datum 1983 (NAD83) in Zone 16.

LOCATION AND SAMPLE DETAILS

Figure 12.1 shows the generalized geology of the project area, the location of gabbro sample 19JW-365GC and age constraints on other Midcontinent Rift–related intrusions in the project area from Bleeker et al. (2020) and references therein. Figure 12.2 shows the location of sample 19JW-365GC on a larger scale depiction of the contacts of the TBNIC (based mainly on Kuntz and Jones 2021) overlain on a composite image consisting of a semi-transparent total magnetic field image and digital elevation model image (Ontario Geological Survey 2017). Outcrops of TBNIC rocks are rare; the interpreted contacts are mainly vertical projections from depth based on drilling or geophysical interpretation. Where drilling is sparse, projected contacts are highly idealized as the strikes and dips of contacts in these areas are not well constrained. Although outcrops of the TBNIC are rare, sample 19JW-365GC was collected from a large exposure of the central part of the LILI (UTM 349385E 5401023N, NAD83, Zone 16).

Photo 12.1 shows a representative specimen of geochronology sample 19JW-365GC. Regrettably, the outcrop from which the sample was taken is lichen covered and not conducive to high-quality outcrop photographs. The outcrop has pale pink weathered surfaces and contains localized pods, 1 to 10 cm in

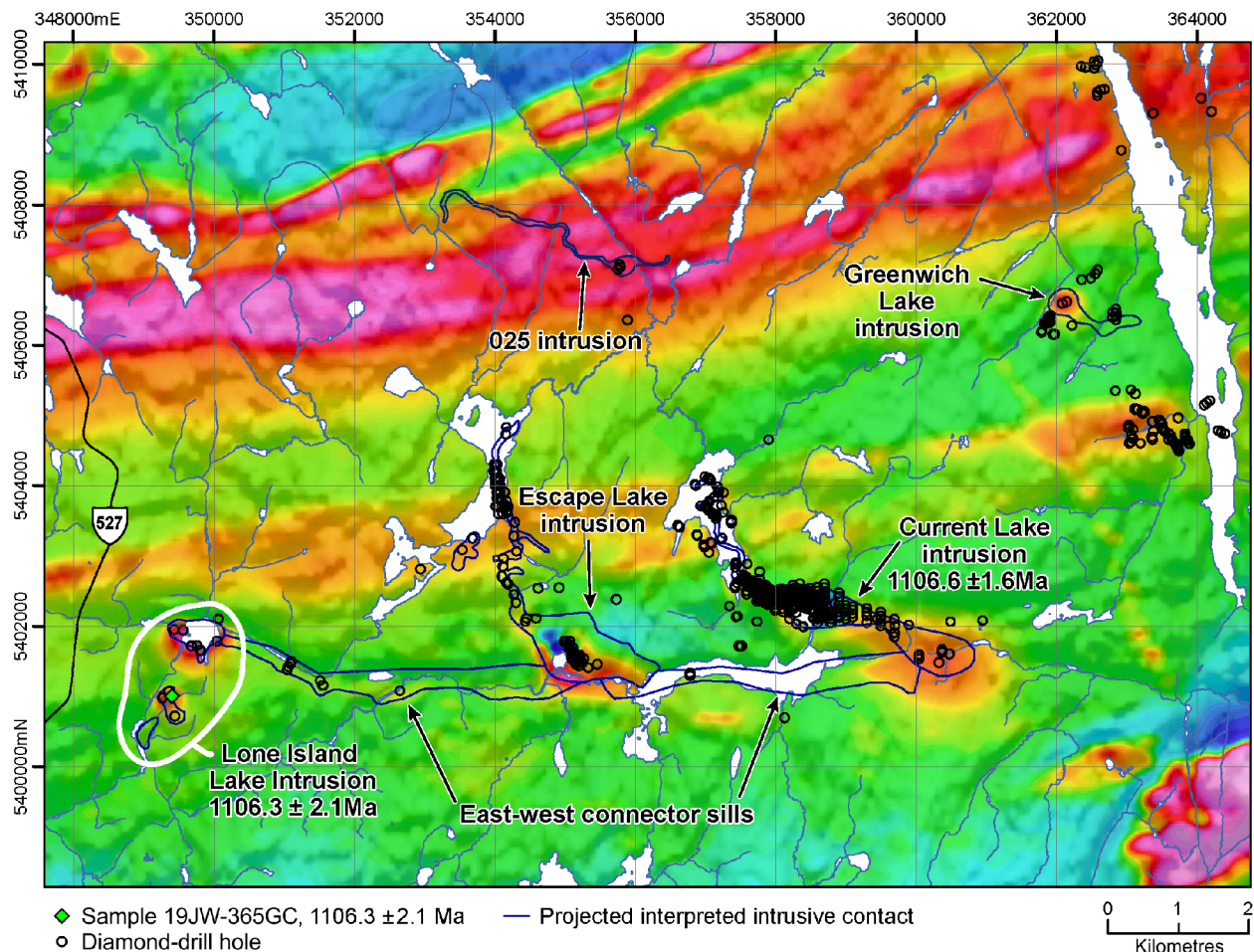


Figure 12.2. Location of sample 19JW-365GC, remnant magnetic intensity overlain on digital elevation model and interpreted intrusive contacts (mainly vertically projected to surface from depth) of the Thunder Bay North intrusive complex and other occurrences of probable Midcontinent Rift–related intrusions in its vicinity (Ontario Geological Survey 2017; contacts modified from Kuntz and Jones 2021). White ellipse indicates the extent of the components of the Lone Island Lake intrusion. Current Lake intrusion age is from Bleeker et al. (2020). Diamond-drill hole locations are from Ontario Geological Survey (2021). All UTM co-ordinates provided using NAD83 in Zone 16.

diameter with apparent amphibole and pink feldspar crystals (although mineralogy of these pods has not been confirmed), in a matrix of homogenous oxide-rich gabbro. Magnetic susceptibility at the outcrop is high and an average of 10 magnetic susceptibility measurements yielded a mean of approximately 75×10^{-3} SI units.

Preliminary petrographic observations revealed that the sample is a somewhat atypical oxide-rich gabbro characterized by relatively fresh pyroxene, olivine and oxide crystals in a matrix of poikilitic plagioclase containing trace apatite and rare biotite and quartz. Very localized chlorite and serpentine alteration of ferromagnesian phases, moderate fine-grained alteration of feldspar and local carbonate veins are also present. Preliminary geochemical data for 3 samples (final analyses remain in progress at the time of writing) indicate iron- and titanium-rich (total iron as Fe_2O_3 ~13–15% and TiO_2 ~2.5–3.0%) and magnesian (MgO ~8–12%) compositions.

GEOCHRONOLOGY

Uranium–Lead Analytical Methods

Uranium-lead (U/Pb) analysis of baddeleyite was by isotope dilution thermal ionization mass spectrometry methods (ID-TIMS) at the Jack Satterly Geochronology Laboratory of the University of Toronto. Baddeleyite was recovered using a modified Söderlund and Johannson (2002) procedure. Prior to analysis, baddeleyite was rinsed in 8N HNO_3 at room temperature prior to dissolution. A mixed ^{205}Pb – ^{235}U spike was added to the Teflon™ dissolution capsules during sample loading. Single crystals were dissolved using ~0.10 mL of concentrated HF acid and ~0.02 mL of 7N HNO_3 at 200°C for 3 to 4 days.

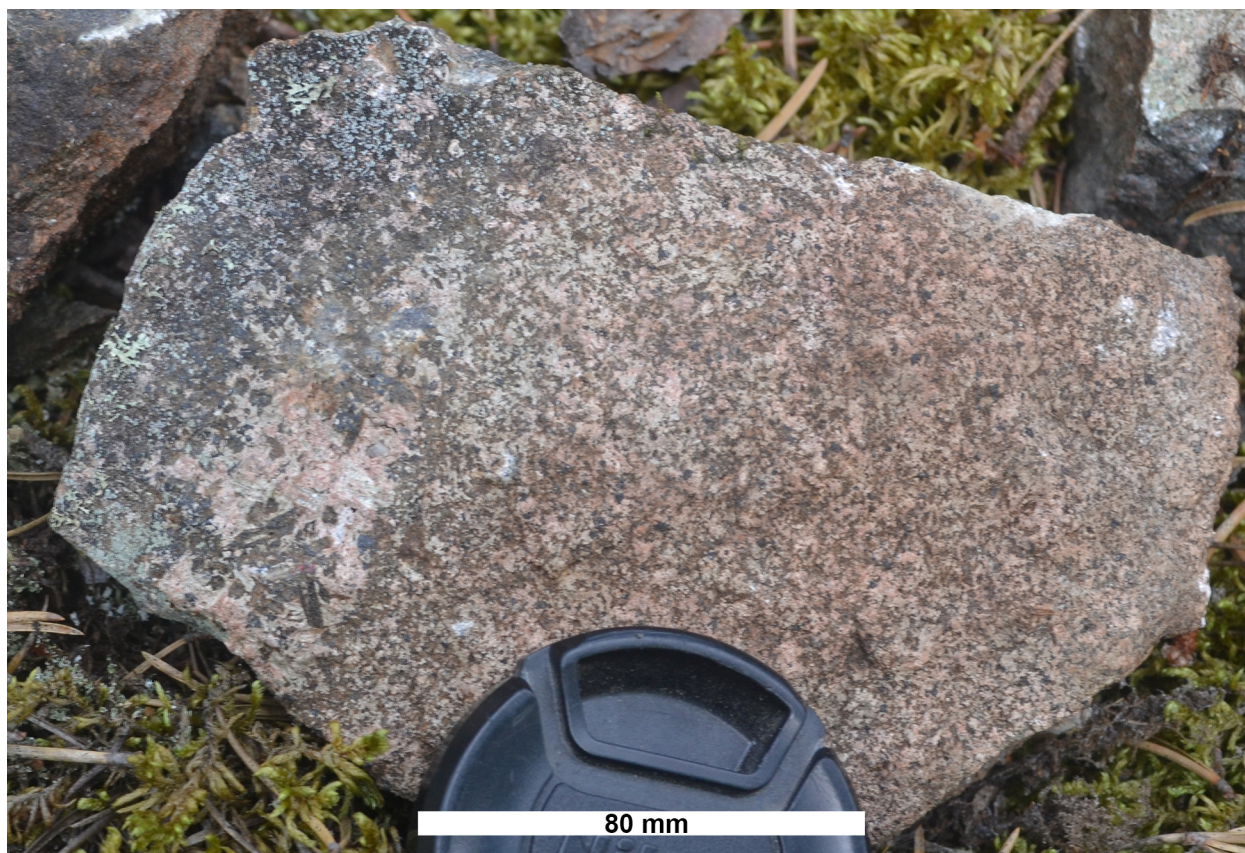


Photo 12.1. A representative photograph of sample 19JW-365GC.

Samples were dried to a precipitate and re-dissolved in ~0.15 mL of 3N HCl overnight (Krogh 1973). No column chemistry was performed, and samples were dried in 0.05N phosphoric acid, 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 in the baddeleyite have been made assuming a Th/U ratio in the magma of 4.2. All common lead was assigned to procedural lead blank. 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). All age errors quoted in the text and table, and error ellipses in the concordia diagrams are given at the 95% confidence interval. VG Sector software was used for data acquisition. In-house data reduction software in Microsoft® Visual Basic® by D.W. Davis was used. Plotting and age calculations were done using Isoplot 3.31 (Ludwig 2003).

Uranium–Lead Results

Table 12.1 shows the analytical data for baddeleyite extracted from 19JW-365GC. Figure 12.3 shows a concordia plot of the data along with baddeleyite images. Baddeleyite extracted from the sample is relatively fresh with minimal alteration. Zircon was not recovered from the sample. Three of four, medium brown, shiny, translucent baddeleyite fractions (1 to 3 laths) gave concordant and overlapping results.

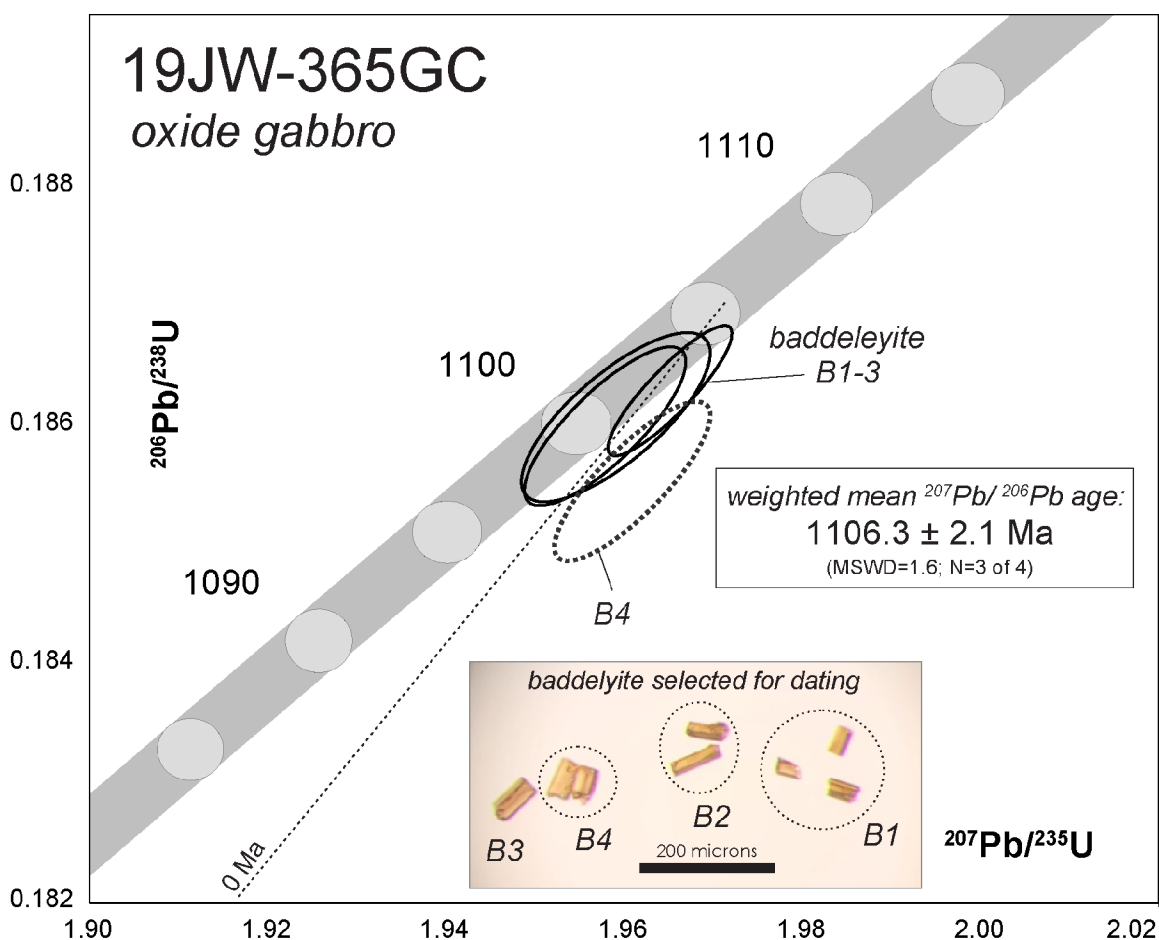


Figure 12.3. Concordia plot and images of baddeleyite fractions from sample 19JW-365GC used for age estimate.

Table 12.1. Uranium–lead (U/Pb) baddeleyite isotope dilution thermal ionization mass spectrometry (ID-TIMS) data for sample 19JW-365GC, Lone Island Lake intrusion, oxide gabbro (UTM 349386E 5401023N, NAD83, Zone 16).

Analysis No.	Weight (µg)	U (ppm)	Th/U	Pb _C (pg)	Measured														
					²⁰⁶ Pb/ ²⁰⁴ Pb	²⁰⁷ Pb/ ²³⁵ U	2σ	²⁰⁶ Pb/ ²³⁸ U	2σ	Error Corr.	²⁰⁷ Pb/ ²⁰⁶ Pb	2σ	²⁰⁶ Pb/ ²³⁸ U	2σ	²⁰⁷ Pb/ ²³⁵ U	2σ	²⁰⁷ Pb/ ²⁰⁶ Pb	2σ	% Disc.
19JW-365GC: oxide gabbro (UTM 349386E 5401023N, NAD83, Zone 16)																			
B1	0.5	294	0.05	0.2	8570	1.965	0.006	0.1863	0.0004	0.881	0.07649	0.00010	1101.5	2.4	1103.6	1.9	1107.8	2.7	0.6
B2	0.5	176	0.08	0.4	2963	1.959	0.009	0.1861	0.0006	0.757	0.07634	0.00022	1100.2	3.1	1101.5	3.0	1104.1	5.8	0.4
B3	0.3	337	0.13	0.3	4253	1.958	0.007	0.1860	0.0005	0.810	0.07633	0.00017	1099.8	3.0	1101.1	2.5	1103.7	4.4	0.4
B4	1.0	135	0.30	0.3	4907	1.961	0.007	0.1856	0.0005	0.829	0.07663	0.00016	1097.3	3.0	1102.2	2.5	1111.7	4.1	1.4

Notes: Grain weights and U concentrations are approximations; B is baddeleyite.

Th/U calculated from radiogenic ²⁰⁸Pb/²⁰⁶Pb ratio and ²⁰⁷Pb/²⁰⁶Pb age assuming concordance.

Pb_C is total common Pb assuming the isotopic composition of laboratory blank: assigned the isotopic composition of laboratory blank (²⁰⁶Pb/²⁰⁴Pb=18.49±0.4%;

²⁰⁷Pb/²⁰⁴Pb=15.59±0.4%; ²⁰⁸Pb/²⁰⁴Pb=39.36±0.4%).

²⁰⁶Pb/²⁰⁴Pb corrected for fractionation and common Pb in the spike.

Pb/U ratios corrected for fractionation, common Pb in the spike, and blank.

Correction for ²³⁰Th disequilibrium in ²⁰⁶Pb/²³⁸U and ²⁰⁷Pb/²⁰⁶Pb assuming Th/U of 4.2 in the magma.

% Disc. (Percent Discordance) is calculated for the given ²⁰⁷Pb/²⁰⁶Pb age.

Error Corr. (Error Correlation) is correlation coefficient of X–Y errors on the concordia plot.

Decay constants are those of Jaffey et al. (1971): ²³⁸U and ²³⁵U are 1.55125 × 10⁻¹⁰/yr and 9.8485 × 10⁻¹⁰/yr.

²³⁸U/²³⁵U ratio of 137.88 used for ²⁰⁷Pb/²⁰⁶Pb model age calculations.

A fourth result has an equivalent $^{207}\text{Pb}/^{235}\text{U}$ age, but a younger $^{206}\text{Pb}/^{238}\text{U}$ age from the cluster and is not included in the age calculation because it plots outside the decay constant uncertainties of the concordia curve, which indicates it has lost lead. A weighted mean $^{207}\text{Pb}/^{206}\text{Pb}$ age of fractions B1-3 is 1106.3 ± 2.1 Ma (MSWD=1.6) (*see* Figure 12.3) and is considered the best age estimate for crystallization of the gabbro.

DISCUSSION

The age estimate above provides good evidence that the Lone Island Lake intrusion (LILI) is part of the PGE-Ni-Cu mineralized Thunder Bay North intrusive complex (TBNIC). The relatively iron-titanium-rich and magnesium-rich preliminary geochemistry, outcrop and petrographic features (hydrous pods, biotite, quartz, apatite iron-titanium oxide minerals coexisting with olivine) are comparable to rock types found in other parts of the TBNIC (cf. Chaffee 2015; Kuntz and Jones 2021). Speculatively, the LILI surface exposures may be most similar to the ferrogabbroic rocks found at depth in the southeastern part of the Current Lake intrusion (“South East Anomaly”: Bleeker et al. 2020; Kuntz and Jones 2021). From an exploration standpoint, the recognition of relatively primitive magnesium-rich and olivine-bearing rocks in the LILI suggests that it could be a favourable exploration target comparable to other parts of the TBNIC. However, the gross intrusion morphology of the LILI apparently differs from intrusions in the eastern TBNIC in that it lacks the geophysical expression of a narrow conduit-like geometry (*see* Figure 12.2) that is a hallmark of mineralized portions of the TBNIC (e.g., Bleeker et al. 2020).

ACKNOWLEDGMENTS

We would like to thank Fort William First Nation, Lac Des Milles Lac First Nation, Kiashke Zaaging Anishinaabek, Red Rock Indian Band, 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.

Michael Easton (ERGMS) and Monica Gaiswinkler Easton (Publication Services) are thanked for technical and editorial reviews, respectively. Joseph Walker is thanked for mapping a portion of the project area during 2019. R. Culver and C. Bachowsky are thanked for their assistance during sample collection. Thanks to Pat Gervais (ERGMS) for drafting the figures.

REFERENCES

- Bleeker, W., Smith, J., Hamilton, M.[A.], Kamo, S.[L.], Liikane, D., Hollings, P., Cundari, R.[M.], Easton, [R.]M. and Davis, D.[W.] 2020. The Midcontinent Rift and its mineral systems: Overview and temporal constraints of Ni-Cu-PGE mineralized intrusions; *in* Targeted Geoscience Initiative 5: Advances in the understanding of Canadian Ni-Cu-PGE and Cr ore systems – Examples from the Midcontinent Rift, the Circum-Superior Belt, the Archean Superior Province, and Cordilleran Alaskan-type intrusions, Geological Survey of Canada, Open File 8722, p.7-35. doi.org/10.4095/326880
- Carter, M.W. 1985. Precambrian geology of Goldie Township, Thunder Bay District; Ontario Geological Survey, Preliminary Map P.2855, scale 1:15 840.
- Chaffee, M.R. 2015. Petrographic and geochemical study of the hybrid rock unit associated with the Current Lake Intrusive Complex; unpublished MSc thesis, University of Minnesota, Minneapolis, Minnesota, 139p.
- 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.
- 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*, 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.
- Kuntz, G. and Jones, L. 2021. NI 43-101 Technical report and mineral resource estimate, Thunder Bay North project, Thunder Bay, Ontario, prepared for Clean Air Metals Inc. by Nordmin Resource and Industrial Engineering; NI 43-101 Technical Report and Mineral Resource Estimate, 378p., Available at www.cleanairmetals.ca/projects/technical-reports [accessed September 26, 2021]
- Ludwig, K.R. 2003. User's manual for Isoplot 3.00: A geochronological toolkit for Microsoft® Excel®; Berkeley Geochronology Center, Special Publication No. 4, 71p.
- 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.
- Metsaranta, R.T. and Hamilton, M.A. 2020. A Precise U/Pb age for a north-trending mafic dike from the western flank of the Marathon swarm, East Bay area, northwestern Ontario; *in* Summary of Field Work and Other Activities, 2020, Ontario Geological Survey, Open File Report 6370, p.7-1 to 7-9.
- 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.
- Ontario Geological Survey 2017. Ontario airborne geophysical surveys, magnetic data, grid data (ASCII and Geosoft® formats), magnetic supergrids; Ontario Geological Survey, Geophysical Data Set 1037—Revised.
- 2021. Ontario drill hole database; Ontario Geological Survey, Ontario Drill Hole Database (September 2021 update), online database.
- Söderlund, U. and Johansson, L. 2002. A simple way to extract baddeleyite (ZrO₂); *Geochemistry, Geophysics, Geosystems*, v.3, no.2, 7p. doi.org/10.1029/2001GC000212

13. Project ON-19-004. Gold Fineness Across Ontario: An Update on the Gold Fingerprinting Project



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INTRODUCTION

The Gold Fingerprinting project is a collaborative effort between the Ontario Geological Survey (OGS), Metal Earth (Mineral Exploration Research Centre (MERC), Laurentian University) and the Royal Ontario Museum (ROM), which aims to better understand the microchemical signature of native gold from deposits across the globe, with a focus on deposits from Ontario. Previous research used proxies, like other associated minerals or elements, to characterize and describe gold deposits and their ore systems. However, with the advent of modern *in-situ* techniques, such as laser ablation inductively coupled plasma mass spectrometry (LA-ICP-MS) and atom probe tomography (APT), there is an opportunity to examine the geochemistry of gold itself, characterizing the type and variation of elements within native gold and its alloys (e.g., Guerra and Calligaro 2004; Watling, Scadding and Dixon 2009; Velasquez 2014; Gas'kov 2017; Hastie et al. 2020; Liu et al. 2021). The geochemistry of native gold has the potential to define the unique elemental attributes that vary depending on its genesis, source, depositional processes and time, thereby providing a new perspective on gold ore systems.

There are currently more than 6000 gold occurrences across Ontario (Ontario Geological Survey 2021), which include world-class camps such as Timmins, Kirkland Lake, Red Lake and Hemlo (Harris et al. 2006; Bateman, Ayer and Dubé 2008; Goldfarb and Groves 2015; Dubé and Mercier-Langevin 2020; Poulsen, Barber and Robert 2020) and, in 2019, Ontario led gold production in Canada with 2 370 600 ounces of gold produced (Natural Resources Canada 2019), making it a critical resource for the financial health of the province. Most of Ontario's gold deposits are located in greenstone belts within the Archean Superior Province and, most notably, within the well-endowed Abitibi greenstone belt (Gosselin and Dubé 2005; Monecke et al. 2017; Dubé and Mercier-Langevin 2020). Knowledge gained from the geochemistry of gold will refine exploration strategies as well as contribute to our understanding of the metallogeny and geodynamic evolution of greenstone belts, further enhancing Ontario as a global leader in gold production and cutting-edge research.

The present study constitutes the MSc thesis research of the senior author and is an update of the Gold Fingerprinting project as presented in Hastie et al. (2020). In this project, samples from significant Ontario deposits will be analyzed using a scanning electron microscope with an energy dispersive spectrometer (SEM-EDS), an electron probe microanalyzer (EPMA) and an LA-ICP-MS to determine the gold fineness (sometimes also known as “purity”), and major and trace element geochemistry of native gold. Further examination will be based on spatial and temporal variations according to geographic

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.13-1 to 13-9.*

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(e.g., northwestern Ontario) and geologic criteria (e.g., host rocks, metamorphic grade, crustal structures, etc.). Analytical results of this research will be included in an online Gold Fingerprinting database that will be freely available to the public (Hastie et al. 2020).

METHODS

Gold alloys are present in nature as a solid solution between gold, silver and copper and contain other trace metals as lattice impurities (Desborough 1970; Boyle 1979; Watling, Scadding and Dixon 2009), which can be uniformly distributed or display concentration or elemental zonation. Micro-inclusions or even superficial coatings, the latter imparted during sample preparation, previously have hindered establishing the true geochemistry of gold and its genesis (Chapman et al. 2009; Watling, Scadding and Dixon 2009; Hastie et al. 2020; Chapman et al. 2021; Liu et al. 2021).

The first phase of data acquisition in the project was performed with reflected light microscopy. The samples were mounted in epoxy resin pucks for a visual evaluation of the polishing process (surface coatings and contamination), inclusions, gold grain colour, grain size, associated minerals, and textures. Following optical microscopy and SEM–EDS analyses (not discussed in this article), a JEOL JXA-8530F EPMA equipped with 5 wavelength dispersive spectrometers at the OGS Geoscience Laboratories in Sudbury, Ontario, was used to provide quantitative analyses of the major and minor elements in the gold grains and to obtain internal standards for further analysis. The operating conditions for acquiring the elemental data were 20 kV accelerating voltage, 40 nA beam current, a probe diameter of 1 μm and an acquisition time (combined peak and background) of 110 s. Calibration standards used for quality control (QC) monitoring and evaluating overlap corrections were the Alfa Aesar pure metal standards for gold, silver and copper and the Micro-Analysis Consultants Ltd. (MAC) synthetic HgTe for mercury. For this reason, tellurium was also acquired for quality control. In addition, homogenous gold grains from the Preston Mine (Timmins Camp) were used as an in-house standard for long-term QC monitoring.

Ten spots were measured across and along each grain (where grain size permitted) to determine in-grain homogeneity, analyzing a total of 1543 points in all the samples. The average detection limits are as follows: 0.078 weight % Au, 0.063 weight % Ag, 0.017 weight % Cu, 0.059 weight % Hg and 0.032 weight % Te. Quality assurance and quality control (QA/QC) processing considered wavelength overlap, external and in-house standards and data accuracy. Values below the detection limit were set to zero in the figures and this data will be determined in the future using LA-ICP–MS, which has lower detection limits.

RESULTS

The analytical data presented include gold samples obtained from the Royal Ontario Museum (ROM), individuals, and companies. Typically, these are coarse to very-coarse gold grains primarily associated with quartz, carbonate, pyrite and chalcopyrite. Most of the samples have reports that detail their location and field relationships; however, only a general location is available for some samples. A total of 158 gold grain samples from 64 representative locations across Ontario were examined (Figure 13.1). To group samples geographically, they have been divided into 4 broad regions: northeastern, northwestern, central and southern Ontario (*see* Figure 13.1).

Northeastern Ontario has the most with 97 samples, followed by northwestern Ontario with 37 samples, central Ontario with 19 samples and southern Ontario with 5 samples. Gold fineness is defined to include not only silver content, but also the other minor elements present in the gold in weight % (i.e., $(\text{Au/all elements}) \times 1000$), and native gold is used herein for simplicity even though some data fall within the definition of electrum (i.e., containing >20 weight % Ag).

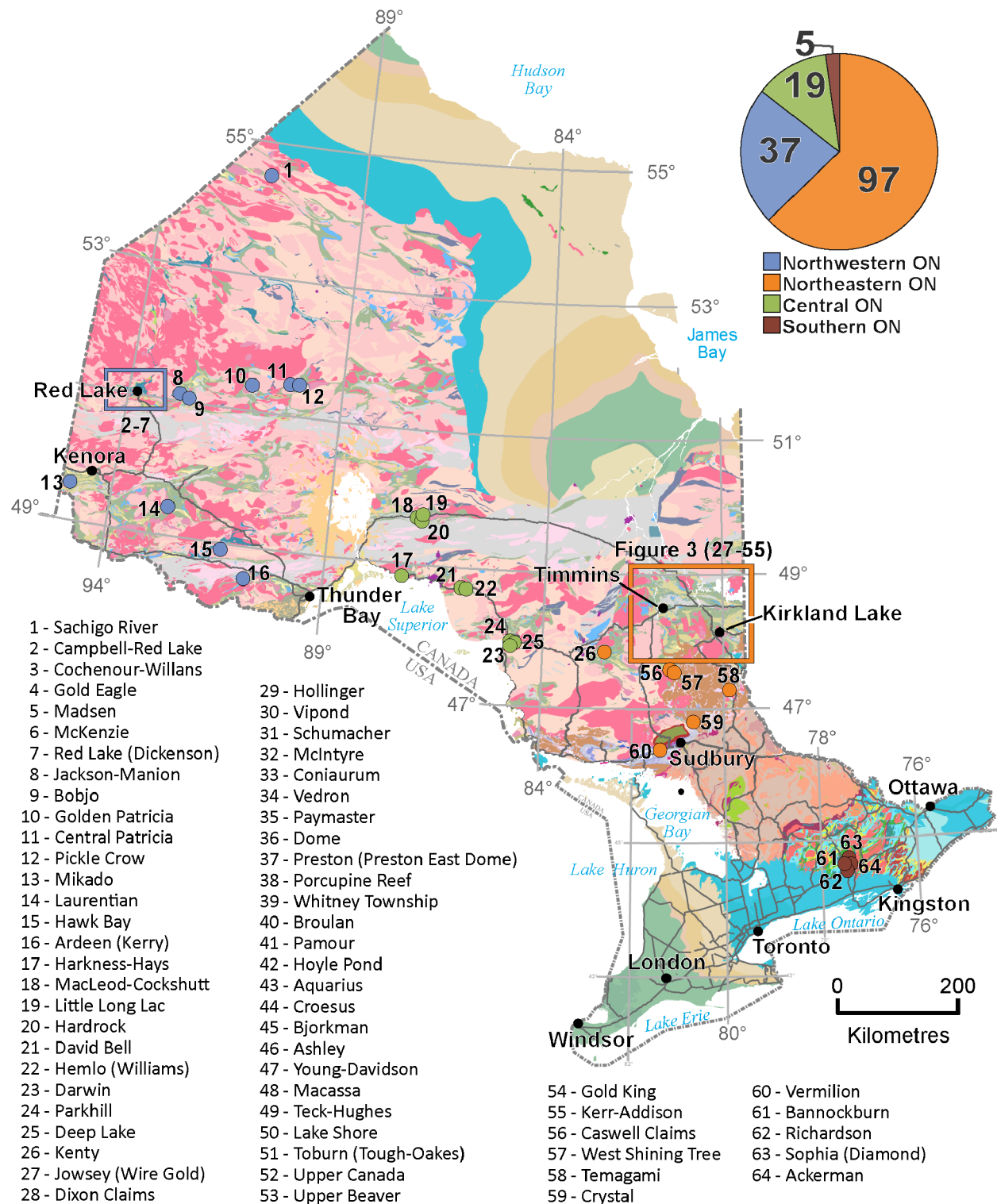


Figure 13.1. Geological map of Ontario, with simplified bedrock geology units, displaying the location of samples for which data are included in this report. The pie chart in the upper right of the figure shows the numbers of analyzed samples per geographical areas; the colours used in this chart are also used for the sample location dots. See Figure 13.3 for more detail about sample locations 27 to 55 in the area outlined in orange. See Ontario Geological Survey (2011) for a detailed legend for the geological units.

In general, the data display variations in gold fineness that range from a high of 993, to a low of 686. The content of gold ranges between 67.9 and 99.7 weight % Au, with a mean of 91.6 weight % Au; silver ranges from 0.5 to 30.9 weight % Ag, with a mean of 8.0 weight % Ag; copper ranges between 170 and 2810 ppm Cu with a mean of 470 ppm Cu; and mercury typically ranges from 580 to 10 500 ppm Hg, with a mean of 2200 ppm Hg; except at the Upper Beaver Mine where native gold has a mean mercury value of 3.9 weight % Hg. Minor to trace elements measured within the gold grains have a homogeneous distribution except for samples from the Toburn and Lake Shore mines, which display a different generation of gold occurring as veinlets with a lower fineness resulting from higher concentrations in mercury and silver.

To better visualize the EPMA data, ternary diagrams were constructed using gold, silver (Ag*10) and copper (Cu*250) as their vertices (Figure 13.2). The data indicate a 1:1 inverse relationship between gold and silver, whereas copper and gold increase up to 96 weight % Au where copper quickly decreases, matching a similar trend presented by Liu et al. (2021).

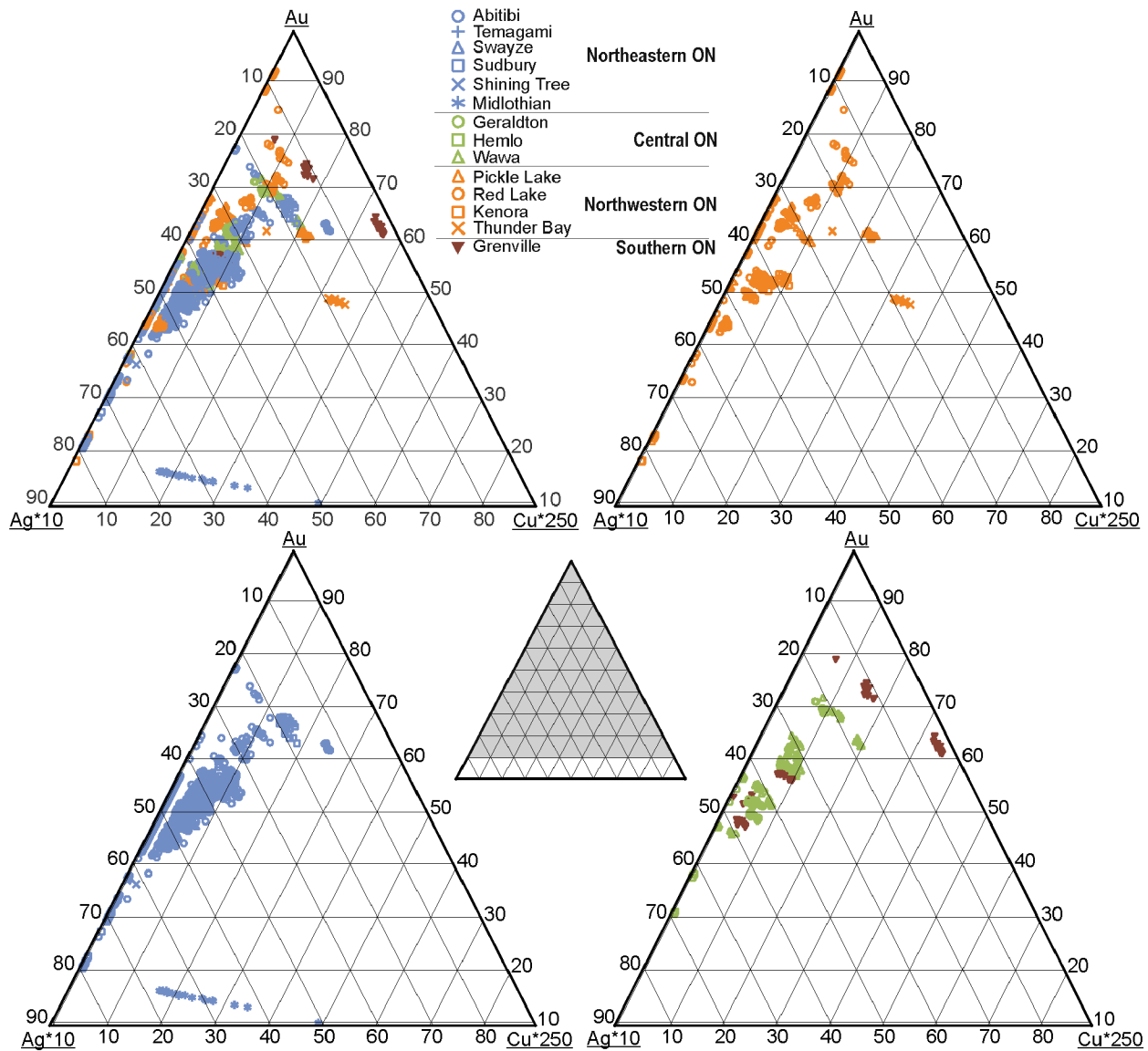


Figure 13.2. Gold (Au) – silver (Ag*10) –copper (Cu*250) ternary diagrams for the different geographic areas in Ontario. The upper left figure shows all the data. The upper right, lower left and lower right figures show the data for northwestern, northeastern, and central and southern Ontario, respectively. The data are grouped based on their geographical distribution and proximity to important gold camps.

Samples from northwestern Ontario have a mean gold fineness value of 924 and a median value of 931. There is a high dispersion of the data with a standard deviation of 53, which is well illustrated by differences between mines in the Kenora area versus mines in the Red Lake and Pickle Lake areas. The Kerry Mine stands out from the other mines in northwestern Ontario because of its higher copper concentration (2420 ppm Cu on average). Conversely, at the Mikado and Hawk Bay mines, the native gold is rich in silver (25.3–30.7 weight % Ag), and the former has mercury values that range between 2300 and 2500 ppm Hg.

Samples from central Ontario have a mean fineness value of 930 with a median value similar to northwestern Ontario and a standard deviation of 36, with the lowest fineness values recorded in native gold from the Hemlo area. The mines in the Geraldton and Wawa areas have very consistent fineness values.

In deposits from the Proterozoic Grenville Province in southern Ontario, the gold has a mean fineness of 952, a median of 941 and a standard deviation of 34. In this area, the Bannockburn and the Richardson mines have high gold and copper values, particularly the latter with an average of 2170 ppm Cu.

Northeastern Ontario has the most extensive data set, which display an average fineness of 907, a median of 917 and a standard deviation of 48. The lowest fineness values are in native gold from the Sudbury area (Vermilion) and in Midlothian Township near Matachewan (Bjorkman). Gold from the Vermilion nickel-copper-platinum group elements (Ni-Cu-PGE) mine is high in silver and has a mean fineness of 798. The Bjorkman occurrence has native gold intergrown with tetra-auricupride, a mean fineness of 701, 4600 ppm Cu and 2900 ppm Hg, thus displaying a different trend from much of the data in Figure 13.2.

The bulk of the data in northeastern Ontario is from the Abitibi greenstone belt and has been treated separately. Figure 13.3 shows the location of the gold mines and occurrences within the Abitibi greenstone belt included in this study, illustrating their average fineness by size and intensity of grey-scale circles. Samples from mines associated with the Porcupine–Destor fault zone (PDFZ) have an average fineness of 909 with a standard deviation of 25. Conversely, samples from mines associated with the Larder–Cadillac fault zone (LCFZ; sometimes referred to as the Larder Lake–Cadillac fault zone) have a mean fineness of 937, and a standard deviation of 17. The PDFZ samples have an average copper and mercury values of 359 ppm Cu and 1821 ppm Hg, respectively, whereas samples from the LCFZ have average copper and mercury values of 500 ppm Cu and 2168 ppm Hg, respectively. The Upper Beaver Mine constitutes a clear outlier and its copper and mercury values were not included in these averages.

Figure 13.4 displays data from the Abitibi greenstone belt on a gold–silver–copper ternary diagram. Although the data overlap, there is a clear difference between gold grains from samples associated with the PDFZ and the LCFZ; the former has higher gold and copper values, whereas the latter tend to have a lower gold to silver ratio and less copper and mercury. A single gold grain from the Croesus Mine near Matheson has a very high concentration of gold and off the trend of the other Croesus samples ($n=7$), as well as other PDFZ gold samples. Upon examining Figures 13.3 and 13.4, there appears to be no apparent relation between the deposit type or host rock with gold fineness.

CONCLUSIONS AND FUTURE WORK

In summary, native gold from the Red Lake camp has the highest fineness values, whereas the Mikado, Bjorkman and Vermilion gold grains have the lowest. The Kerry, Richardson and Upper Beaver mines have the highest copper values, with an average of 2400, 2170 and 1482 ppm Cu, respectively. Native gold from the Upper Beaver Mine has the highest mercury values of at 3.9 weight % Hg, whereas veinlets in gold from the Tough–Oakes and Lake Shore mines have values between 2.1 and 3.8 weight % Hg. In the Abitibi greenstone belt, gold grains from the Porcupine–Destor fault zone differ from those from the Larder–Cadillac fault zones, with the latter having higher fineness and copper values.

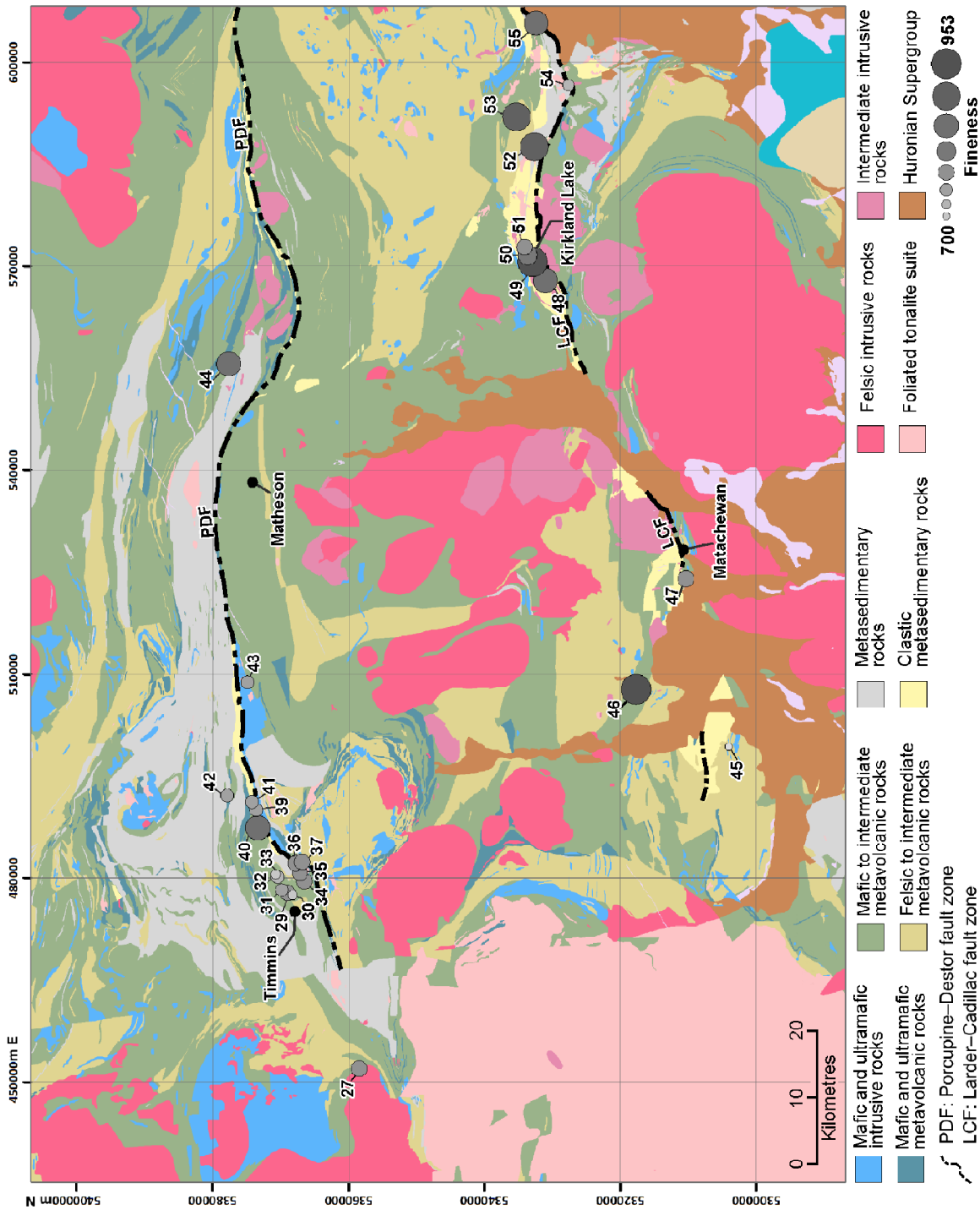


Figure 13.3. The Ontario portion of the Abitibi greenstone belt showing generalized rock types and the location of the PDFZ clearly with the EPMA results. Samples associated with the PDFZ clearly have a lower fitness than mines associated with the LCFZ. For the name of the mines, refer to the labelled numbers in Figure 13.1. Geology from Ontario Geological Survey (2011) and from Dubé and Mercier-Langevin (2020). The map co-ordinates are provided in Universal Transverse Mercator (UTM) using North American Datum (NAD) 1983 in Zone 17.

Future work will include the samples discussed herein and additional samples donated from industry and individuals. Additional data will be acquired through the EPMA, and new trace element data will be acquired using LA-ICP-MS; the latter will provide more robust data that includes other elements in order to fully fingerprint gold. All analytical data generated will be included in a global gold database that will be freely available (Hastie et al. 2020). The data will be analyzed spatially and with respect to geological criteria or associations to better constrain the genesis of gold ore systems, to aid exploration and to provide reference data for forensic geology, archaeology and other areas of knowledge where gold geochemistry will provide a valuable fingerprint.

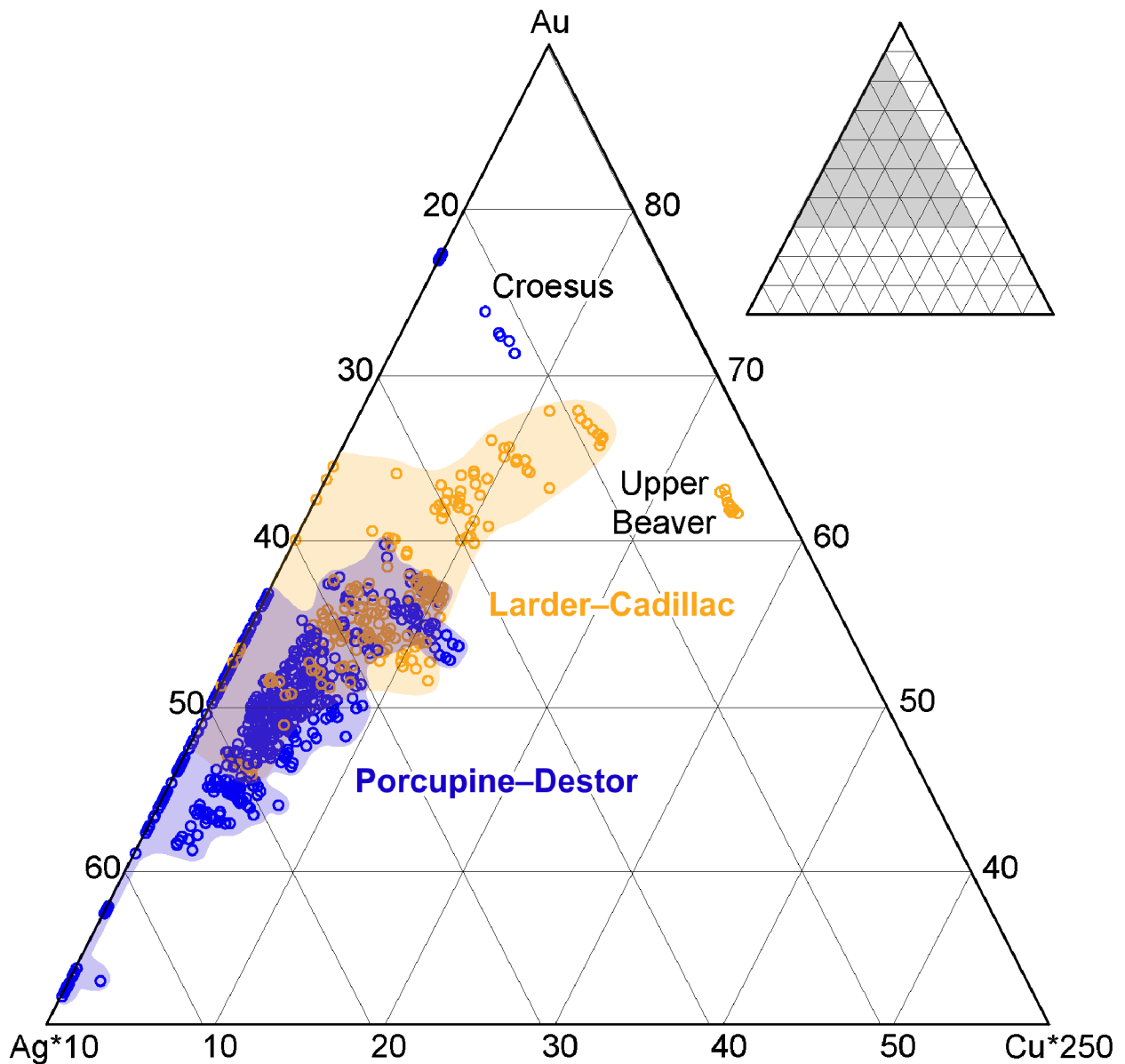


Figure 13.4. Gold (Au) – silver (Ag*10) –copper (Cu*250) ternary diagram showing the variation in the Au–Ag*10–Cu*250 ratios with respect to their location within the Porcupine–Destor or Larder–Cadillac faults.

ACKNOWLEDGMENTS

This project is part of a Master of Science thesis project by Julian Melo-Gómez at the Harquail School of Earth Sciences, Laurentian University, under the supervision of Drs. Harold Gibson and Evan Hastie. J.D.M-G. wrote the summary with contributions from all other authors. J.D.M-G. processed the EPMA data. J.D.M-G. interpreted the data with assistance from E.C.G.H. and H.L.G. E.C.G.H., H.L.G., K.T.T. and J.A.P. jointly conceived the study. The work is supported by the Ontario Geological Survey, the Royal Ontario Museum and the Metal Earth Initiative through the Mineral Exploration Research Centre and Harquail School of Earth Sciences at Laurentian University. Special thanks to Katherine Dunnell at the Royal Ontario Museum for her hard work organizing and sampling material from their collection. Assistance provided by Sandra Clarke and Dave Crabtree from the OGS Geoscience Laboratories is greatly appreciated, especially in the acquisition and quality control of the SEM and EPMA data presented here. Special thanks are also offered to companies and individuals for donating samples to the current data set shown above and for samples not yet analyzed. Companies: Canadian Gold Miner Corp., IAMGOLD Corp., Newmont Corp. and Transition Metals Corp. Individuals: Dorothy Campbell, Harold Gibson, Craig Green, Sheree Hinz, Tom Hart, Evan Hastie, Peter Karelse, Jeremy Richards and Ross Sherlock.

REFERENCES

- Bateman, R., Ayer, J.A. and Dubé, B. 2008. The Timmins-Porcupine gold camp, Ontario: Anatomy of an Archean greenstone belt and ontogeny of gold mineralization; *Economic Geology*, v.103, p.1285-1308.
- Boyle, R.W. 1979. The geochemistry of gold and its deposits; Geological Survey of Canada, Bulletin 280, 584p.
- Chapman, R.J., Banks, D.A., Styles, M.T., Walshaw, R.D., Piazzolo, S., Morgan, D.J., Grimshaw, M.R., Spence-Jones, C.P., Matthews, T.J. and Borovinskaya, O. 2021. Chemical and physical heterogeneity within native gold: Implications for the design of gold particle studies; *Mineralium Deposita*, v.56, p.1563-1588. doi.org/10.1007/s00126-020-01036-x
- Chapman, R.J., Leake, R.C., Bond, D.P.G., Stedra, V. and Fairgrieve, B. 2009. Chemical and mineralogical signatures of gold formed in oxidizing chloride hydrothermal systems and their significance within populations of placer gold grains collected during reconnaissance; *Economic Geology*, v.104, p.563-585.
- Desborough, G.A. 1970. Silver depletion indicated by microanalysis of gold from placer occurrences, western United States; *Economic Geology*, v.65, p.304-311.
- Dubé, B. and Mercier-Langevin, P. 2020. Gold deposits of the Archean Abitibi greenstone belt, Canada; *Society of Economic Geologists, Special Publication*, No.23, p.669-708.
- Gas'kov, I.V. 2017. Major impurity elements in native gold and their association with gold mineralization settings in deposits of Asian folded areas; *Russian Geology and Geophysics*, v.58, p.1080-1092.
- Goldfarb, R.J. and Groves, D.I. 2015. Orogenic gold: Common or evolving fluid and metal sources through time; *Lithos*, v.233, p.2-26.
- Gosselin, P. and Dubé, B. 2005. Gold deposits of Canada: Distribution, geological parameters and gold content; Geological Survey of Canada, Open File 4896, 105p.
- Guerra, M.F. and Calligaro, T. 2004. Gold traces to trace gold; *Journal of Archaeological Science*, v.31, p.1199-1208.
- Harris, J.R., Sanborn-Barrie, M., Panagapko, D.A., Skulski, T. and Parker, J.R. 2006. Gold prospectivity maps of the Red Lake greenstone belt: Application of GIS technology; *Canadian Journal of Earth Sciences*, v.43, p.865-893.

- 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 and Other Activities, 2020, Ontario Geological Survey, Open File Report 6370, p.10-1 to 10-10.
- Liu, H., Beaudoin, G., Makvandi, S., Jackson, S. and Huang, X. 2021. Multivariate statistical analysis of trace element compositions of native gold from orogenic gold deposits: Implication for mineral exploration; *Ore Geology Reviews*, v.131, paper 104061. doi.org/10.1016/j.oregeorev.2021.104061
- Monecke, T., Mercier-Langevin, P., Dubé, B. and Hannington, M. 2017. Archean base and precious metal deposits, southern Abitibi greenstone belt, Canada; *Reviews in Economic Geology*, v.19, p.1-5.
- Natural Resources Canada 2019. Canadian gold production, by region: Preliminary; www.nrcan.gc.ca/our-natural-resources/minerals-mining/minerals-metals-facts/gold-facts/20514#L2. [accessed September 28, 2021]
- Ontario Geological Survey 2011. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revision 1.
- 2021. Mineral Deposit Inventory; Ontario Geological Survey, Mineral Deposit Inventory (July 2021 update), online database.
- Poulsen, K.H., Barber, R. and Robert, F. 2020. Hemlo gold system, Superior Province, Canada; *Society of Economic Geologists, Special Publication, No.23*, p.81-100.
- Velasquez, A. 2014. Trace element analysis of native gold by laser ablation ICP-MS: A case study in greenstone-hosted quartz-carbonate vein ore deposits, Timmins, Ontario; unpublished MSc thesis, The University of British Columbia, Okanagan, British Columbia, 58p.
- Watling, R.J., Scadding, C.J. and Dixon, R. 2009. Gold – Identifying its provenance; Chapter 88A *in* Expert evidence: Law, practice, procedure and advocacy, 4th ed., Lawbook Company, Sydney, Australia, 76p.

14. Summary of Geophysical Projects and Activities



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INTRODUCTION

The Ontario Geological Survey (OGS) commissioned a helicopter-borne, time-domain electromagnetic (TDEM) and magnetometer survey over the Saganash Lake greenstone belt (Figure 14.1) which was completed in March of 2021. Two airborne gravity and magnetic data sets, donated by the Nuclear Waste Management Organization (NWMO), have been reprocessed and published under the names Mozhabong Lake and Namiegos Lake (*see* Figure 14.1).

Geophysical services, including imaging, data compilation interpretation and modelling were provided in support of bedrock geology mapping, groundwater and Resident Geologist programs. A scoping study and the development of workflows was performed for the collection, evaluation and dissemination of airborne geophysical digital assessment data.

SUPPORT FOR THE BEDROCK GEOLOGY MAPPING PROGRAM

In spite of reduced field work, geophysical support of the bedrock geology mapping program was provided for 6 projects. Support took the form of analysis of existing geophysical layers already provided for projects, the creation of suites of images for new projects and comparative reviews of geological maps with respect to geophysical data prior to publication.

Where airborne magnetic gradiometer data are available, enhanced high-resolution magnetic images were created using the pseudo-line interpolation method described last year (Rainsford, Biswas and Larsen 2020). Greater use was made of ternary magnetic imaging where composite images of the reduced-to-pole residual magnetic intensity (RMI), first vertical derivative of the pole-reduced RMI and second vertical derivative of the pole-reduced RMI were created by assigning them red, green and blue palettes, respectively. The ternary magnetic images are effective in displaying magnetic fabrics, low-amplitude responses and features in finer detail.

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

- Temagami area bedrock geology mapping project
- Thompson–Cobden townships bedrock geology mapping project
- Red Lake–Dixie geology compilation project
- North Caribou greenstone belt geology compilation project
- Iron Bridge–Blind River area bedrock geology mapping project
- Sudbury Basin geology map update

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.14-1 to 14-9.*

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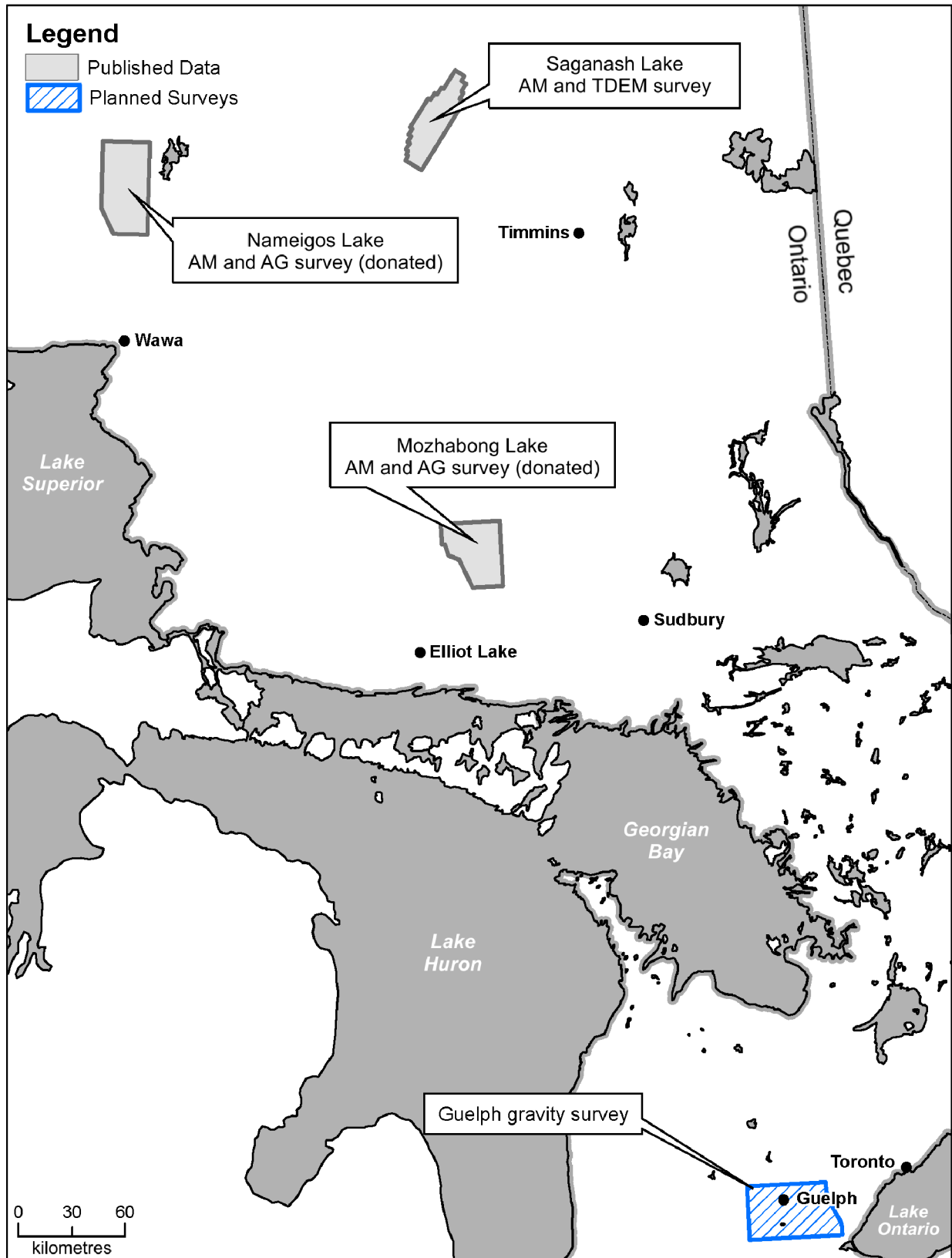


Figure 14.1. Locations of geophysical surveys published during 2020 and planned surveys. Abbreviations: AG, airborne gravity; AM, airborne magnetic; TDEM, time-domain electromagnetic.

Table 14.1. Summary of airborne geophysical data released by the Ontario Geological Survey in 2021.

Publication	Survey Name	Year of Survey	Survey Type	Line-Kilometres
GDS 1089	Saganash Lake area	2021	Airborne magnetic and electromagnetic	4848
GDS 1250	Nameigos Lake area	2015	Airborne magnetic and gravity	14 838
GDS 1251	Mozhabong Lake area	2016	Airborne magnetic and gravity	10 057

Abbreviation: GDS, Geophysical Data Set.

ACQUISITION OF NEW GROUND GRAVITY DATA

An approximately 3480 station ground gravity survey is planned in the Guelph area to support the Guelph three-dimensional (3-D) sediment mapping project (*see* Figure 14.1). The 100 m spaced stations will be distributed over 27 profiles along the roads in the region covering approximately 1450 km². The survey will complement existing ground gravity surveys in the Orangeville–Fergus, Kitchener–Waterloo Region, and Niagara Peninsula areas. The survey area is underlain by southwest-dipping bedrock of the Queenston Formation, above which are the Clinton Group–Cataract Group, Lockport Group and Salina Group. The sediment cover in the area varies from negligible in the east to 100 m in the southwest. The survey results, expected in early 2022, will be initially used to identify potential thalwegs and guide the placement of boreholes required to map and characterize subsurface sediments forming the regional and local aquifers and aquitards. Subsequently, the gravity data from the survey will be used to develop two-dimensional (2-D) models of sedimentary layers and underlying bedrock along select profiles to support the 3-D sediment mapping project in the Guelph area.

GEOPHYSICAL DATA RELEASES FOR 2021

Three geophysical data sets were published (Table 14.1) in 2021. The survey locations are shown in Figure 14.1. A helicopter-borne magnetic and TDEM survey was flown for the OGS over the Saganash Lake greenstone belt. The data acquisition was completed in March 2021 and the digital data (Ontario Geological Survey 2021a) and maps were released in October 2021. Preliminary interpretations of the survey results are discussed by Easton, Rainsford and Préfontaine (this volume, Article 6). The Nameigos Lake area and Mozhabong Lake area geophysical data sets (Ontario Geological Survey 2021b; Ontario Geological Survey 2021c) were generously donated by the Nuclear Waste Management Organization (NWMO). The donated data were reprocessed to conform with other OGS airborne geophysical data sets and prepared for publication in both map and digital formats.

SUPPORT FOR THE GROUNDWATER PROGRAM

The focus of this year's work to support the Niagara Peninsula 3-D sediment mapping project (Burt 2013) was to model the gravity data along Regional Road 20 (RR20) in the Fonthill area (Figure 14.2). The objective of the modelling was to characterize the depth and shape of the bedrock surface and, where possible, features within the overlying Quaternary sediments. The modelling was done using the results of a ground gravity survey, comprising 6828 stations, acquired in 2013 (Ontario Geological Survey 2014). Preliminary modelling results along the 14 km east-trending RR20 profile, are presented in Figure 14.3. The topographic feature known as Font Hill occupies the central portion of the profile (between distances of 3.9 km and 8 km), has an elevation of around 240 m asl compared to western and eastern portions where the ground elevation is approximately 180 m asl. It should be noted that seismic data are not available for this profile. Information from continuously cored borehole logs (Burt 2020a), 3-D Paleozoic geology model (Carter et al. 2019) and ongoing sediment modelling (A.K. Burt, Ontario Geological Survey, personal communication, 2021) have been used to constrain the gravity models along this profile. Boreholes BH06 and BH09 are located along the RR20 profile at profile distances of approximately 580 m and 8.7 km respectively. Boreholes BH30 and BH91 are located approximately 400 m and 1 km

respectively, to the south of the profile. Borehole BH02 is located approximately 2 km to the north of the profile (see Figure 14.2).

Gravity anomalies are caused by lateral density contrasts in the subsurface at various depths, from the near surface to the basement. For this study, the residual Bouguer gravity was calculated using a density of 2.1 g/cm³. The RR20 Bouguer gravity profile starts as a high in the west, is characterized by a wide gravity low centred at approximately 5.4 km profile distance, followed by a broad gravity high to the east and a gravity low at the eastern end (see Figure 14.3A). The maximum amplitude is approximately 1.2 mGal with a wavelength of 5 km. Using GM-SYS 2-D modelling software, the observed wavelengths and amplitudes of the gravity anomalies were reproduced using isolated bodies or layers with contrasting densities. The resulting model is just one possible representation of the subsurface geology. As gravity models are non-unique, multiple models fitting the data were created and assessed. The best model was chosen based on geological observations (i.e., surficial geology and boreholes) and is illustrated in Figure 14.3.

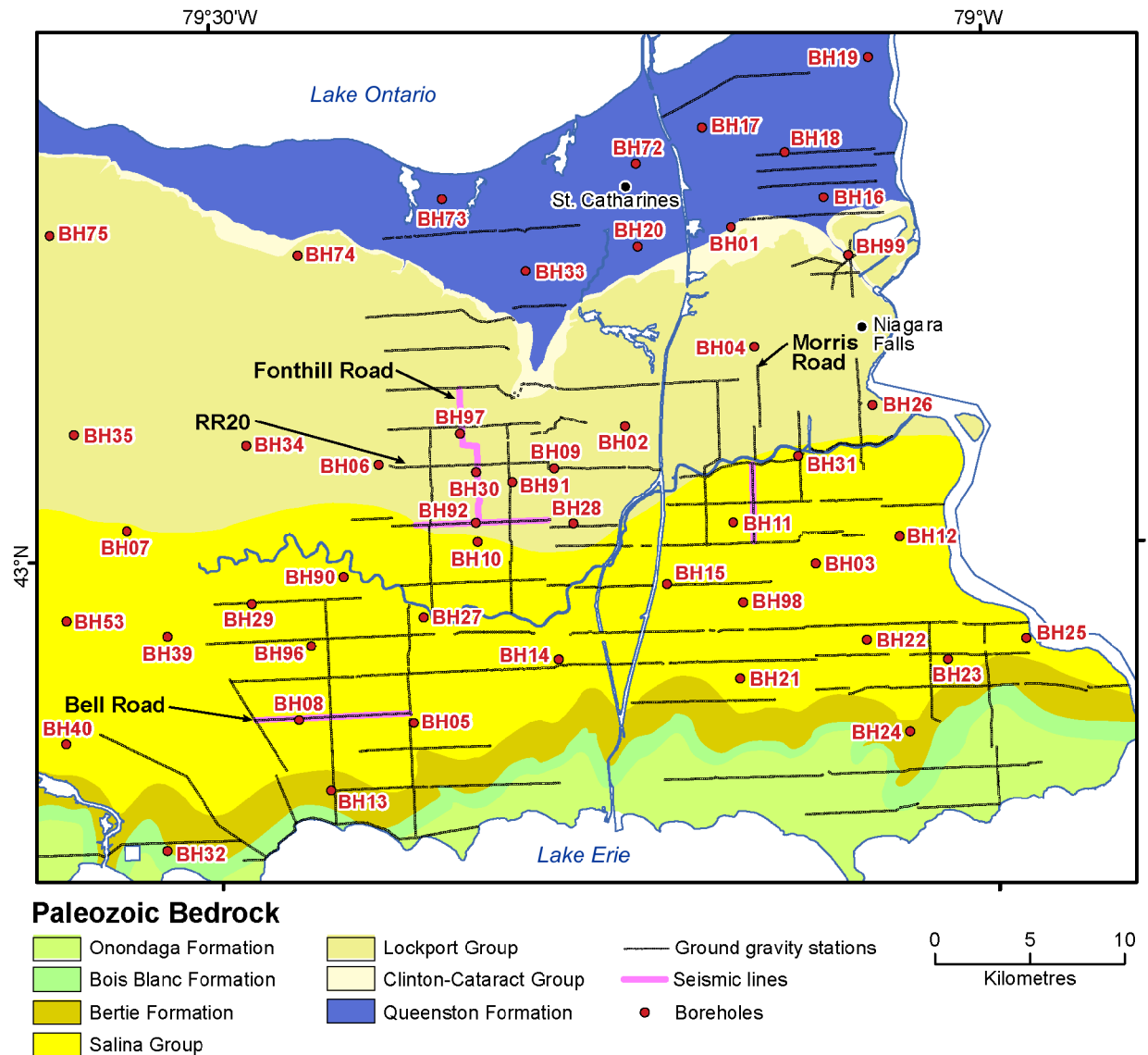


Figure 14.2. Location of the Niagara Peninsula 3-D sediment mapping project study area showing underlying Paleozoic bedrock (modified from Armstrong and Dodge 2007). A profile along Regional Road 20 (RR20) is discussed in the text. A profile along Morris Road was described by Rainsford, Biswas and Larsen (2020). A profile along Bell Road was described by Rainsford and Biswas (2018).

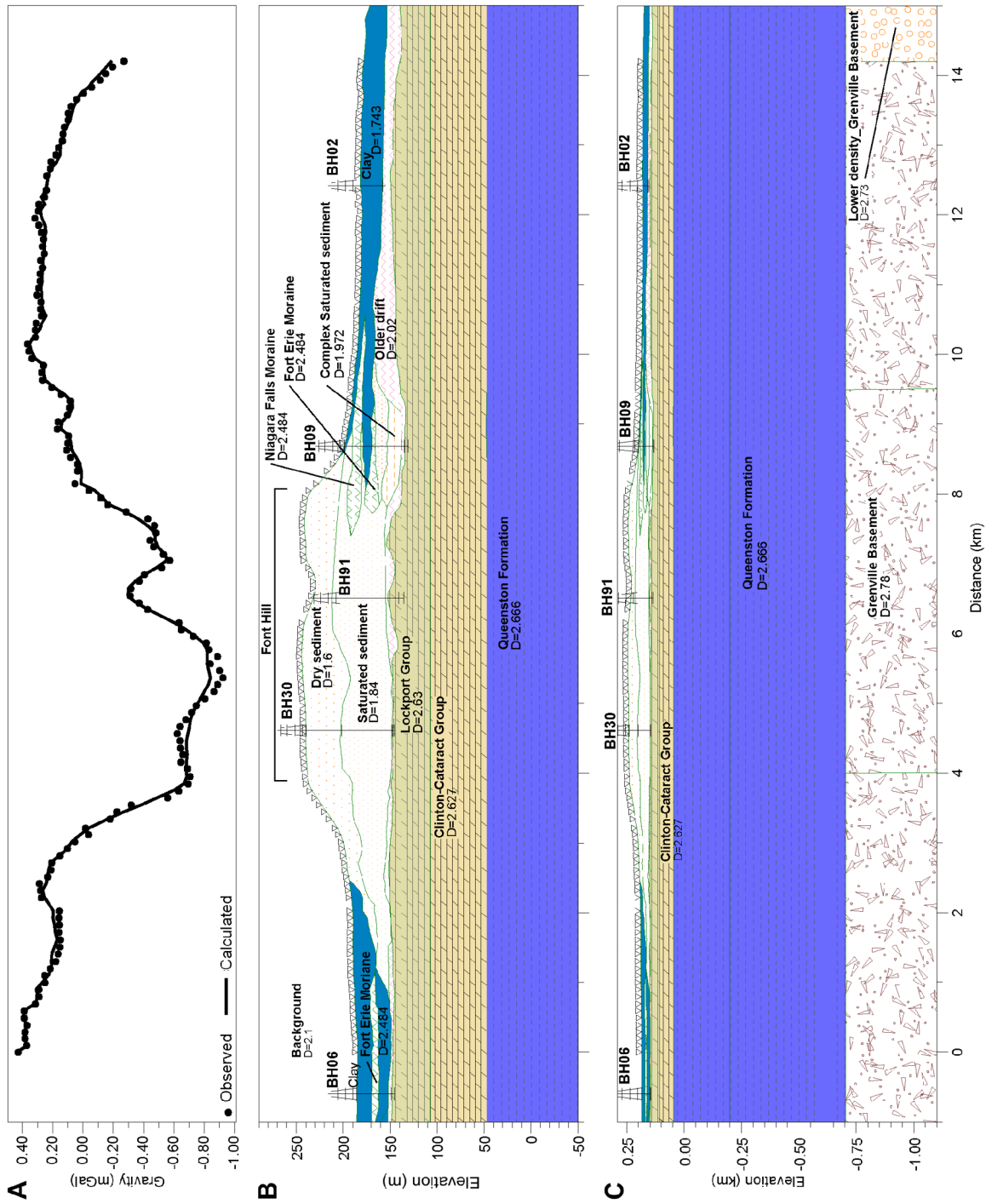


Figure 14.3. A) Top panel shows the observed and calculated residual Bouguer gravity profile along RR20. B) Shallow part of the modelled cross section of the profile. Note that the vertical scale indicating elevation is in metres. The horizontal axis is the same as for “ 0” . Mean Sea Level indicated by “ 0” . The densities of the lithologic units in g/cm³ are noted under the unit name label or descriptor as “ D= ” . Description of materials from the borehole logs is provided in Table 14.2. C) Deeper part of the modelled cross section showing inferred Grenville basement features. Note that the vertical scale is in kilometres.

Table 14.2. Simplified lithological units, descriptions and rock unit density used in the RR20 model.

	Unit	Summary Lithology ¹	Density ² (g/cm ³)
Overburden	Clay	Clayey silt to clay with some ice-rafted debris	1.743
	Dry sediment	Dry silt and sand	1.600
	Saturated sediment	Saturated silt and sand	1.840
	Moraine	Somewhat stony, silty to clayey diamicton (till)	2.484
	Complex saturated sediments	Interbedded sand, silt and clay	1.810 – 1.972
	Older drift	Overconsolidated silty to sandy till with beds of gravel	2.020
Bedrock	Lockport Group	Locally cherty and bituminous dolostone, limestone and shale	2.6303
	Clinton Group–Cataract Group	Shale, sandstone, dolostone and limestone	2.627
	Queenston Formation	Shale	2.666
	Grenville basement	N/A	2.730 – 2.780
	Upper crust	N/A	2.800
	Background	N/A	2.100

¹Abbreviation: N/A = not applicable.

²Densities of shallower rock types (<–900 m) from Ontario Stone, Sand and Gravel Association (2016, p.68-69).

³Densities for deeper rock types (>–900 m) are estimated for this region.

³Density of Lockport Group from Raven et al. (2011, p.135).

The ongoing Niagara Peninsula sediment model is based on measured sections, continuously cored boreholes and geological information obtained from water well records, geotechnical records and oil and gas records (Burt 2013, 2020a, 2020b). The density of the sediment layers and their corresponding descriptions are noted in Table 14.2. The silty to sandy Fonthill ice-contact fan-delta complex, located between 3.9 km and 8 km, forms a prominent hill (Font Hill) rising 60 m above the surrounding gently sloping clay plain (Burt 2020a, 2020b). Font Hill (topographic) corresponds with the central gravity low. The complex was deposited by meltwater in a large glacial lake ponded against the retreating Halton ice margin. This depositional history resulted in thick layers of low-density sand and gravel, which become thinner and finer grained away from the source, eventually transitioning to clay. The thick sand and gravel layers are largely responsible for the associated gravity low. On the eastern side of the Fonthill complex, borehole BH09 records a complex stratigraphy of relatively higher density clayey diamicton of the Fort Erie moraine interbedded with lower density lake clay and dry and saturated silt and sand. The varying thicknesses of these units are modelled to fit the corresponding higher gravity in the eastern part of RR20 profile (*see* Figure 14.3B). Farther to the east, the clay layer becomes predominant. Higher density sediments, corresponding with the Fort Erie moraine observed in borehole BH06, have been modelled to fit the gravity high in the western part of the RR20 profile. The base of the Quaternary sediment package is characterized by high-density older drift. This unit is thin in the west, becoming thicker in the east.

The Quaternary sediments are underlain by Silurian Lockport Group dolostone, Silurian Clinton Group–Cataract Group and Ordovician Queenston Formation shale (*see* Figure 14.3B). These bedrock units dip gently to the south (Armstrong 2017) and appear nearly horizontal along an east-west cross section. The modelled bedrock surface was constrained using bedrock intercepts in boreholes BH06 and BH09. The bedrock intercepts in boreholes BH30, BH91 and BH02, although they are located away from the traverse, were used as a guidance in modelling. The modelled bedrock surface is nearly horizontal at approximately 150 m asl in the west. The surface undulates between 152 m asl (borehole BH91) and 134 m asl (borehole BH09) in a central zone between 5.6 km and 10 km. The higher bedrock surface at borehole BH91 corresponds with a relative gravity high. In the east, a gentle broad bedrock high, centred around 12 km profile distance at 149 m asl, corresponds with a broad high in the gravity data.

The Grenville Province basement is approximately 880 m below the traverse (Ontario Geological Survey 2011). A lower density feature, indicative of heterogeneity in the Grenville basement, east of 14 km profile distance, was used to match the gravity low of the profile at the eastern end (*see* Figure 14.3C).

DIGITAL ASSESSMENT DATA COLLECTION

Assessment work reports and maps required to keep mining claims in good standing are currently accepted by the NDMNRF only in PDF format. Clients have been increasingly requesting the underlying digital data. In order to better serve stakeholders, the ministry is developing workflows to begin collecting digital data for airborne geophysical surveys filed for assessment. Experience gathered from this pilot project will be used design processes for the collection, evaluation and dissemination of digital data for all types of assessment work.

METHOD DEVELOPMENT: PSEUDO-LINE GRIDDING

Further work on the scripts to automate pseudo-line gridding of magnetic gradiometer data (Rainsford, Biswas and Larsen 2020) was done to make them easier to use and to ensure that they run on the latest version of Geosoft® Oasis montaj™ software. The use of these scripts was demonstrated to geophysical consultants and the code is available upon request on an “as is” basis. After applying the technique to 5 different OGS airborne magnetic gradiometer surveys, the improvement in resolution and imaging of oblique-to-flight line features over other commonly used gradient enhancement techniques is clearly demonstrated. As a result, new aeromagnetic gradiometer surveys commissioned by the OGS will require the use of pseudo-line gridding method (Hardwick 1999) for the interpolation of magnetic grids.

OTHER ACTIVITIES

In addition to supporting a diverse group of clients with a range of geophysical enquiries, at the request of the Northwest Territories (NWT) Geological Survey, a review of a compilation of aeromagnetic data for the NWT Cordillera was carried out prior to publication (Ugalde et al. 2021). Technical advice was provided to the Ontario Ministry of Agriculture, Food and Rural Affairs (OMAFRA) concerning the commissioning of an airborne radiometric survey to test the applicability of the technique for soil studies.

The OGS was invited to participate in Laurentian University’s modular GEOL 5956 Exploration Geophysics course with a presentation highlighting public-domain data available from the OGS.

The availability of geophysical and other geoscience data collected by the OGS can be viewed geographically and downloaded using the OGSEarth application (www.geologyontario.mndm.gov.on.ca/ogsearth.html). The OntarioGeophysics.KML (www.geologyontario.mndm.gov.on.ca/ogsearth.html#geophysical) file is a convenient tool for data discovery. The embedded links allow users to download geophysical data.

The Geophysical Survey Index (www.geologyontario.mndm.gov.on.ca/ogsearth.html#geophysical in GIS-compatible format) continues to be maintained and updated with each new release of geophysical data.

Free downloads of geophysical data are also available from the OGS online data warehouse—GeologyOntario (www.mndm.gov.on.ca/en/mines-and-minerals/applications/geologyontario). Hard-copy (paper) reports and maps, and physical media (CD or DVD) of digital data are also available for a nominal fee through the Publication Sales outlet:

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ACKNOWLEDGMENTS

Abigail Burt (Quaternary Geoscientist, Earth Resources and Geoscience Mapping Section) is thanked for her geological input regarding the gravity modelling project. Pat Gervais (Drafter, Earth Resources and Geoscience Mapping Section) is thanked for his contributions on the figures.

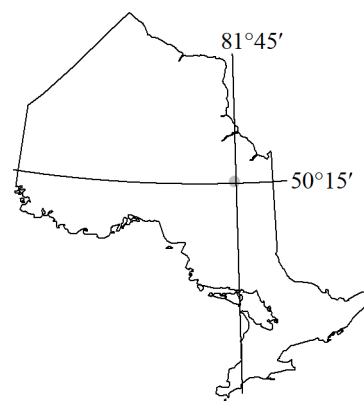
REFERENCES

- Armstrong, D.K. 2017. Paleozoic geology of the Welland–Fort Erie area, southern Ontario; Ontario Geological Survey, Preliminary Map P.3811, scale 1:50 000.
- Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 219.
- Burt, A.K. 2013. The Niagara Peninsula study: A new three-dimensional Quaternary geology mapping project; *in* Summary of Field Work and Other Activities, 2013, Ontario Geological Survey, Open File Report 6290, p.38-1 to 38-21.
- 2020a. Results of the 2014–2017 drilling programs on the Niagara Peninsula: Graphic logs, descriptions and analytical data; Ontario Geological Survey, Miscellaneous Release—Data 383.
- 2020b. The Niagara Peninsula 3-D Sediment Mapping Project: From data acquisition to modelling; abstract *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.5.
- Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Freckelton, C., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L. and Yeung, K.H. 2019. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Ontario Geological Survey, Groundwater Resources Study 19 / Geological Survey of Canada, Open File 8618. doi.org/10.4095/315045
- Hardwick, C.D. 1999. Gradient-enhanced total field gridding; abstract *in* 69th Annual International Meeting, Society of Exploration Geophysicists, Technical Program Expanded Abstracts 1999, p.381-384.
- Ontario Geological Survey 2011. Regional structure and isopach maps of potential hydrocarbon-bearing strata for southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 276.
- 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.
- 2021a. Ontario airborne geophysical surveys, magnetic and electromagnetic data, grid and profile data (ASCII and Geosoft® formats) and vector data, Saganash Lake area, Ontario Geological Survey, Geophysical Data Set 1089.
- 2021b. Ontario airborne geophysical surveys, magnetic and gravimetric data, grid and profile data (ASCII and Geosoft® formats) and vector data, Nameigos Lake area; Ontario Geological Survey, Geophysical Data Set 1250.
- 2021c. Ontario airborne geophysical surveys, magnetic and gravimetric data, grid and profile data (ASCII and Geosoft® formats) and vector data, Mozhabong Lake area; Ontario Geological Survey, Geophysical Data Set 1251.
- Ontario Stone, Sand and Gravel Association (OSSGA) 2016. Materials reference guide; Ontario Stone, Sand and Gravel Association, Mississauga, Ontario, 78p.
- Rainsford, D.R.B. and Biswas, S. 2018. Summary of geophysical projects and activities; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.16-1 to 16-10.
- Rainsford, D.R.B., Biswas, S. and Larsen, T.O. 2020. Summary of geophysical projects and activities; *in* Summary of Field Work and Other Activities, 2020, Ontario Geological Survey, Open File Report 6370, p.11-1 to 11-10.

Raven, K., McCreath, D., Jackson, R., Clark, I., Heagle, D., Sterling, S. and Melaney, M. 2011. OPG's Deep Geologic Repository for low & intermediate level waste: Descriptive geosphere site model, prepared for Ontario Power Generation by Intera Engineering Ltd. (now Geofirma Engineering Ltd.); NWMO DGR-TR-2011-24, 435p., available from https://ceaa-acee.gc.ca/050/documents_staticpost/17520/49820/site_model.pdf. [accessed September 22, 2021] [note 1: this is a direct link to the PDF file.] [note 2: not available from www.nwmo.ca/en/Reports/]

Ugalde, H., Bourke, L., Fischer, B.J. and Mirza, A. 2021. A compilation of aeromagnetic data for the Northwest Territories Cordillera; Northwest Territories Geological Survey, NWT Open File 2020-06.

15. Updates on Drill-Core Logging in Southern James Bay Lowland, Far North of Ontario



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INTRODUCTION

The Ontario Geological Survey (OGS) received 3 diamond-drill cores donated by VR Resources Limited after a drilling program, conducted by the company in late 2020, to explore the mineral potential of the Hecla–Kilmer carbonatite–alkalic intrusive suite located between the Mattagami and Abitibi rivers in the Moose River Basin within the James Bay Lowland, northern Ontario (50°19′37.79″N, 81°52′14.38″W) (Figure 15.1; Table 15.1). The drill cores each contain approximately 40 m of Quaternary sediments consisting of tills and a sub till, organic, nonglacial lacustrine deposit (*see* Figure 15.1). The drill sites are not far from the Missinaibi River and Adam Creek bank exposures, where the sub till nonglacial Missinaibi Formation was defined (*see* Figure 15.1) (Skinner 1973; Terasmae and Hughes 1960). Although sub till nonglacial deposits of this formation were observed at many sites along the Moose River and its tributaries, e.g., the Mattagami, Abitibi, and Missinaibi rivers, they have rarely been reported in the interfluvies in this region (Telford 1982; Telford et al. 1991; Smith 1992). As such, these drill cores provide a rare opportunity to examine and compare the surficial deposits with those reported previously for better understanding the recent geological history and providing a sound stratigraphical framework to support the OGS ongoing Far North terrain mapping project (e.g., Barnett and Yeung 2010; Bajc, Lee and Yeung 2014; Gao et al. 2019; Gao and Yeung 2020).

The drill sites are in the flat, low-relief lowland covered with boreal forest and extensive intervening wetlands (Farley-Gill 1980). Based on the photos provided (M. Gunning, VR Resources Limited, personal communication, 2020), the local vegetation at the drill sites consists of black spruce (*Picea mariana*), with occasional tamarack (*Larix laricina*). The Quaternary deposits in this region are mostly 50 to 100 m thick but can reach 150 m and thicker at a few localities (Long 2000).

DRILL-CORE RECORDS

The 3 drill cores, approximately 280 to 460 m apart, have good core recovery (>80%) below 6 m depth; above this depth, the core recovery is poor (*see* Figure 15.1; Photos 15.1 and 15.2). The sub till organic lacustrine deposit is seen in drill-core HK20-001 at depths between 9 to 12 m (noncorrected depth from borehole dip and hereafter). Based on texture, pebble lithology and colour, 3 major lithostratigraphic units were recognized above the bedrock, in an ascending order: (I) a reddish till, (II) a grey till, and (III) the sub till organic lacustrine deposit. The uppermost interval, which includes till deposits but with poor core recovery, is collectively referred to as unit IV (*see* Figure 15.1).

Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.15-1 to 15-9.

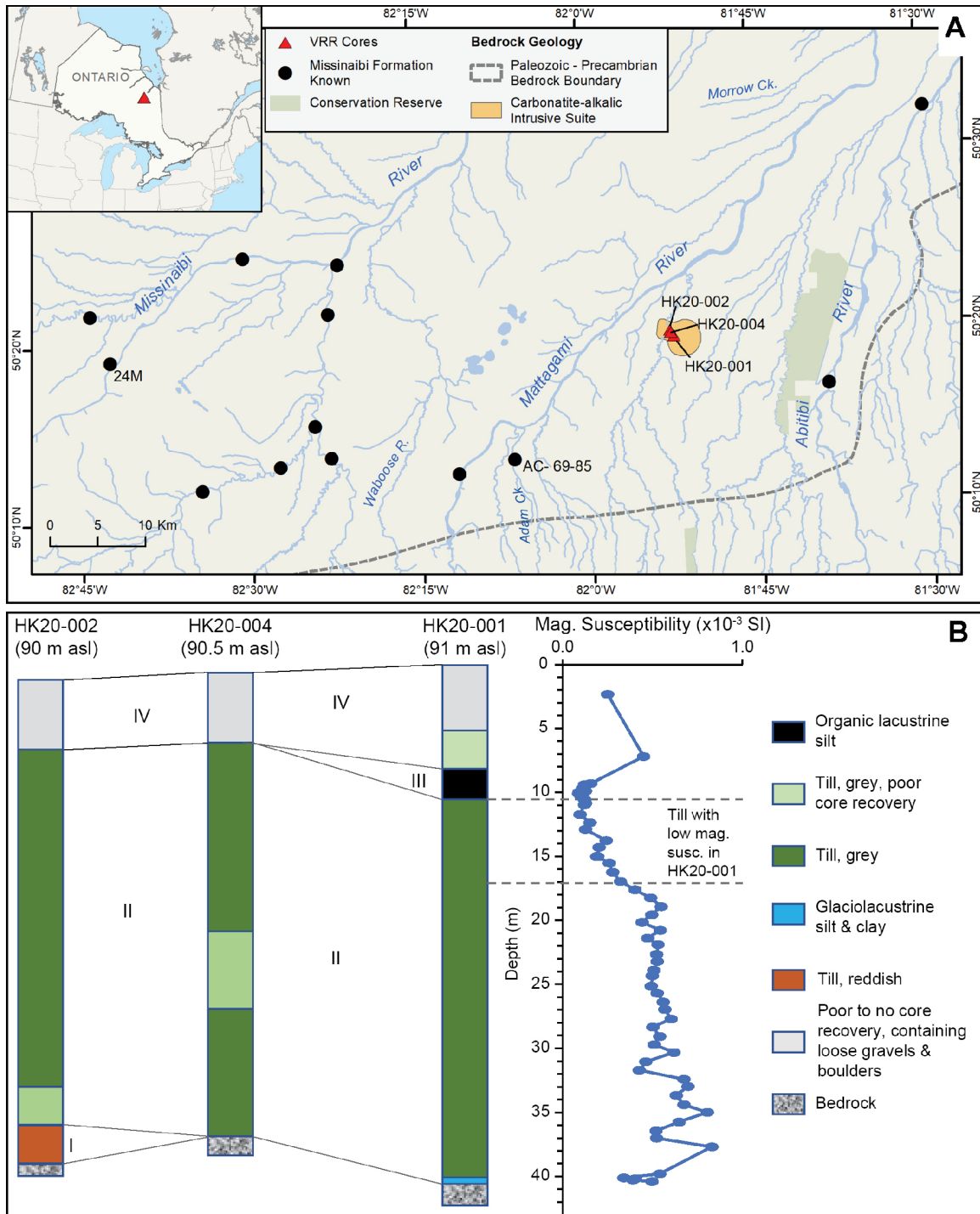


Figure 15.1. Location map and drill-core records of the 2020 drilling program by VR Resources Limited (“VRR” in figure legend), James Bay Lowland, northern Ontario. **A)** Location of the drill cores as indicated by small red triangles with drill-core number. Solid black dots are the major sites where subtill nonglacial deposits of the Missinaibi Formation were reported previously; those marked with 24M and AC-69-85 on the Missinaibi River and Adam Creek, respectively, are the key sites for defining this formation. Oval area with orange colour is the Hecla–Kilmer carbonatite–alkalic intrusion and dashed grey line, the Paleozoic–Precambrian bedrock boundary (Ontario Geological Survey 2006). Inset is the index map showing the drill-core locations in Ontario. **B)** Drill-core logs, with the surface elevation indicated as m asl (metres above sea level) in parentheses below the drill-core number. The subtill organic lacustrine silt of unit III is correlated with the Missinaibi Formation. Refer to main text for discussions on this and other units. The magnetic susceptibility was derived from borehole HK20-001. Note the depths are true depths after borehole dip correction.

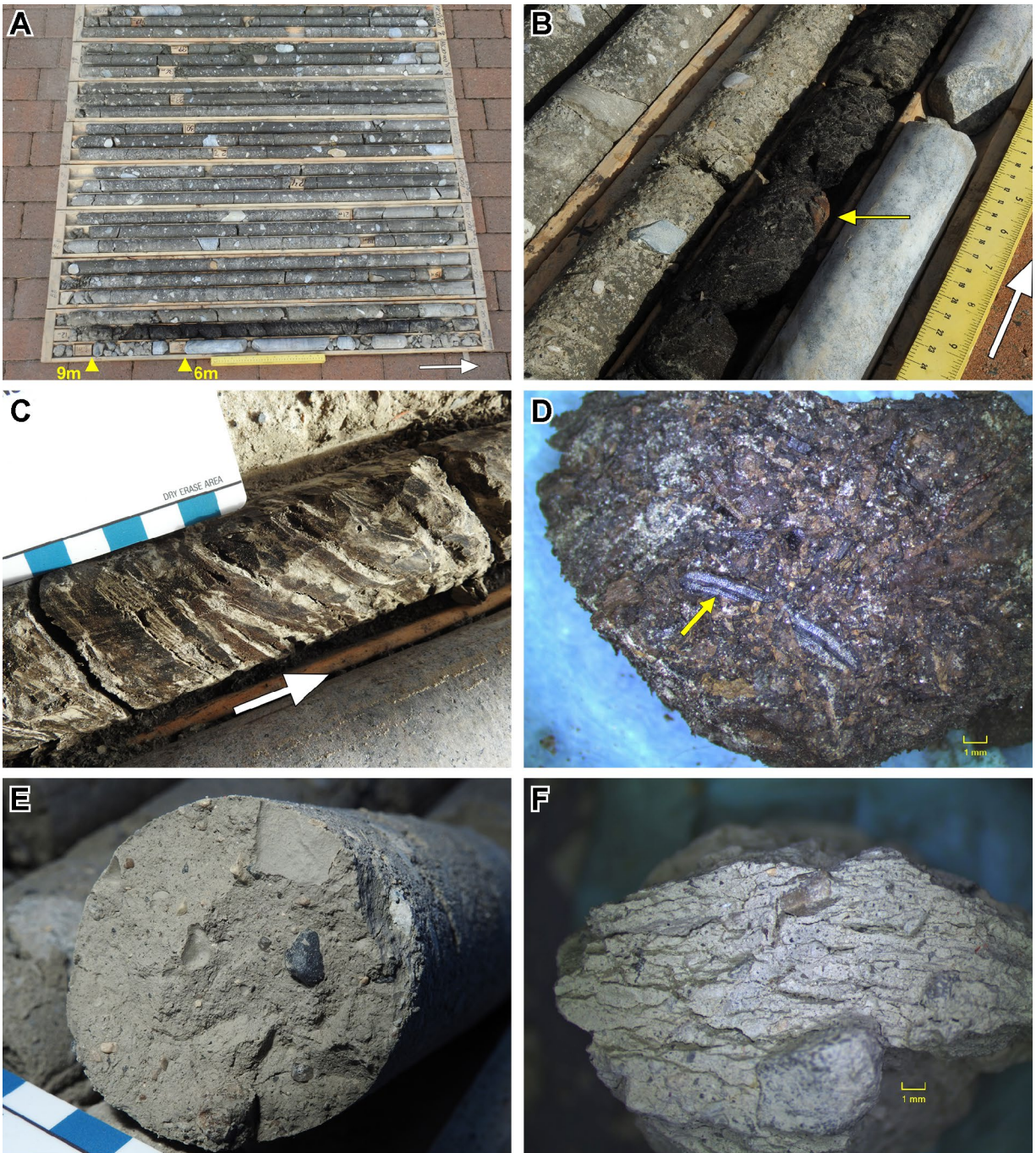


Photo 15.1. Photos from drill-core HK20-001. White arrows indicate up-core direction. Core boxes are 1.5 m long. **A)** Drill-core HK20-001, consisting predominantly of grey till. In the upper part of the core (base of photo), a dark-toned organic lacustrine deposit occurs at 9 to 12 m depth (unit III), which is overlain by a till which is poorly recovered, at 6 to 9 m depth (between yellow triangles) (lower part of unit IV). Note the 2 large granitic boulders above 6 m depth. **B)** Close-up view of the peaty lower part of the organic lacustrine deposit. Note a piece of wood (spruce or tamarack), as indicated by a yellow arrow. Scale in centimetres and inches. **C)** Enlarged view of the upper part of the organic lacustrine deposit, consisting of laminated, brownish organic mud and pale, fine sand and silt. Scale in centimetres. **D)** Peat material containing predominantly partly decomposed plant debris with occasional, well-preserved spruce needles (arrow) in the lower part of the lacustrine deposit. **E)** A core segment at 25 m depth, showing the highly compact, structureless silty grey till (unit II). Scale in centimetres. **F)** Till fragments, or clasts, exist in the upper part of the core at 0 to 9 m depth, where core recovery is poor (unit IV). Photo shows such a till fragment, which is a calcareous silty diamicton with well-developed joints or fissility. Refer to Figure 15.1 for the lithostratigraphic units mentioned.



Photo 15.2. Photos from drill-cores HK20-002 (A to E) and HK20-004 (F). White arrows indicate up-core direction. Core boxes are 1.5 m long. **A)** Drill-core HK20-002, consisting of a thick grey till (unit II) underlain by a red till up to 3 m thick (unit I). The uppermost 6 m of the core has poor recovery (above the yellow triangle). The contact between the red till and underlying greenish shale bedrock is at 39 m depth (yellow triangle). **B)** Close-up view of the sharp contact between the red till and greenish shale bedrock (yellow arrow). Note the presence of surface mud coating renders the red till to appear less reddish in colour. **C)** The sharp upper contact of the red till (yellow arrow) at 36 m depth. The overlying grey till has a poor core recovery at the interval immediately above this contact (36–33 m depth). **D)** Enlarged view of the red till (unit I) in a core segment at 36.1 m depth, which is a calcareous, highly compact, structureless silty diamiction. The light-toned, large pebble on the lower left is a Paleozoic limestone. Scale in centimetres. **E)** Red to reddish brown arkosic sandstone clasts in the red till, which were picked from 2 to 0.125 mm fraction of a washed sample. **F)** Drill-core HK20-004, consisting almost entirely of the grey till (unit II). It has poor core recovery above 6 m depth (yellow triangle). Its sharp contact with the greenish brown shale bedrock is at 37 m depth (yellow triangle). Refer to Figure 15.1 for the lithostratigraphic units mentioned.

Table 15.1. Summary of drill-core information.

Borehole Number	Hole Type	Hole Size	Depth Drilled (m) ^a	Overburden Depth (m) ^a	Core OGS Received	Northing ^b (m)	Easting ^b (m)	Elevation (m asl)	Azimuth (°)	Dip (°)	Drilling Started	Drilling Completed
HK20-001	DD	NQ	351	45	0–45 m	5575334	438017	91	15	–64	09/26/2020	09/30/2020
HK20-002	DD	NQ	606	39.3	0–40.7 m	5575968	437627	90	165	–75	10/01/2020	10/07/2020
HK20-004	DD	NQ	609	37.4	0–37.8 m	5575698	437688	90.5	335	–78	10/13/2020	10/18/2020

^a Not true depth because of borehole dip.

^b Universal Transverse Mercator (UTM) location co-ordinates provided using World Geodetic System 1984 (WGS84) in Zone 17N.

Table 15.2. Summary of pebble counts.

Borehole	Sample No.	Depth (m)*	Total clasts **	% Carbonate, Paleozoic	% Crystalline, Precambrian	% Greywacke, Proterozoic	% Red sandstone, Paleozoic	% Other ***	% Total	Lithostratigraphic Unit
HK20-001	-03	3.0	240	61.3	22.1	16.7	0.0	0.0	100	IV, grey till
HK20-001	-37	11.9	162	61.1	25.3	13.6	0.0	0.0	100	II, grey till ****
HK20-001	-39	12.8	163	61.3	33.1	5.5	0.0	0.0	100	II, grey till ****
HK20-001	-52	21.8	158	67.1	24.7	7.6	0.0	0.6	100	II, grey till
HK20-001	-58	25.8	196	71.4	17.3	8.2	2.6	0.5	100	II, grey till
HK20-001	-65	30.0	204	62.3	26.5	8.3	1.0	2.0	100	II, grey till
HK20-001	-71	34.5	237	71.3	17.3	8.0	2.1	1.3	100	II, grey till
HK20-001	-77	38.9	205	62.4	29.8	7.8	0.0	0.0	100	II, grey till
HK20-001	-82	44.3	216	63.4	25.5	9.7	0.5	0.9	100	II, grey till
HK02-002	-04	30.0	145	62.1	31.0	4.1	0.0	2.8	100	II, grey till
HK02-002	-03	36.1	214	45.8	40.7	3.7	7.5	2.3	100	I, red till

* True depth after borehole dip correction.

** Clast size 2 to 9.5 mm.

*** Other includes ironstone, coal and unknown.

**** Samples within the interval where low magnetic susceptibility was detected in till. Refer to Figure 15.1 for the chart of this geophysical property.

Unit I, which occurs in only HK20-002, is a red, calcareous, silt-rich till up to 3 m thick. The till is highly compact and has a massive structure without any joints or fissile structures (Photo 15.2D). It overlies a greenish shale bedrock and has a sharp upper contact with the overlying grey till (Photos 15.2A to 15.2C). This till contains a sizable amount of red to reddish brown sandstone clasts (Table 15.2). The red clasts are noncalcareous and contain subrounded to subangular feldspar grains, including some quartz (Photo 15.2E). In addition, abundant Precambrian crystalline rock clasts occur in this till (*see* Table 15.2).

Unit II is a grey, calcareous, silt-rich till, with a thickness up to 31 m (*see* Photos 15.1 and 15.2). Like the underlying red till, its high compaction and lack of fissile structures are the likely reasons for its excellent core recovery (Photo 15.1E). Two small intervals of poor core recovery likely record the presence of less consolidated till materials within this unit (*see* Figure 15.1). A glaciolacustrine silty clay, only seen in HK20-001, occurs at the base of this till with a thickness of 0.5 m (*see* Figure 15.1). It has a massive structure and contains many debris clasts and coarse sand grains, probably of ice-rafting origin in a glacial lake. Three samples from this deposit were analyzed for palynological study, but none of them contains countable pollen and spores. The grey till has, in general, high magnetic susceptibility, as measured on HK20-001. However, low magnetic susceptibility was found consistently in the upper 7 m of this till immediately below the overlying organic lacustrine deposit of unit III, which also has a similar low response in the magnetic susceptibility profile (*see* Figure 15.1).

Unit III is the sub till organic lacustrine deposit composed predominantly of silt and clayey silt with sand and pebbly sand in its basal and topmost parts (Photo 15.1C). Peat-rich layers and lenses with flattened wood and other plant macrofossils, e.g., spruce needles, are common in the lower half of the sequence (Photo 15.1D), whereas its upper half contains mainly fine-grained, disseminated organic material (Photo 15.1C). The recorded length for this interval is approximately 3 m (9–12 m depth), but only ~1.5 m (50%) sediment was recovered in the core (Photo 15.1A). Because the core obtained shows an intact, continuous sedimentary sequence without signs of any significant core loss, it is likely that the uppermost part of the original sequence was not recovered owing to the presence of less compact, sandy material. Core loss may have also happened in its sand-rich basal part. About 30 samples are being analyzed for pollen. The preliminary result indicates a predominance of spruce and pine (*Pinus banksiana* and *P. strobus*), with abundant sphagnum spores. Other trees are present but in low frequency, e.g., birch (*Betula*), alder (*Alnus*) and poplar (*Populus*).

Unit IV is the interval with poor core recovery from ground surface down to 6 m depth and, in HK20-001, to 9 m depth. Although the recovered material contains mainly loose pebbles and boulders, fragments of grey-coloured silty till, up to a few centimetres in size, are present (see Photos 15.1A, 15.2A and 15.2F). For instance, in HK20-001, the lower part of this interval (6–9 m depth) comprises, in addition to gravels, several such till fragments, or clasts, up to 5 cm in size overlying the organic lacustrine deposit of unit III. Till clasts are also present in the upper part of this interval (0–6 m depth) where large boulders predominate (see Photo 15.1A). The till clasts examined all show well-developed fissility and are very friable, readily becoming disintegrated into small slabs during handling and sampling, the likely reason for the poor core recovery (see Photo 15.1F). Other less compact sediments, such as the late- to post-glacial glaciolacustrine and glaciomarine deposits as revealed in the adjacent riverbanks (Skinner 1973), may also have existed in this interval and played a role in the poor core recovery.

STRATIGRAPHICAL CORRELATIONS

The sub till organic lacustrine deposit of unit III indicates ice-free conditions under which boreal forest grew in this region, as indicated by pollen and plant macrofossils (see Photos 15.1B and D). The pollen assemblage, although preliminary, appears similar to those derived from both the modern surface soil and the deposits of the Missinaibi Formation in the James Bay Lowland, suggesting a climate probably not unlike today (e.g., Terasmae and Hughes 1960; Skinner 1973; Farley-Gill 1980; Allard et al. 2012; Gao et al. 2020). Two wood samples were submitted for radiocarbon age determination and the results indicate an age beyond the detection limit, i.e., older than 50 ka (samples UOC-14016 and UOC-14017). This minimum age plus its stratigraphical position, i.e., between tills, suggests that this nonglacial deposit can probably be correlated with the Last Interglacial (Marine Isotope Stage (MIS) 5e) Missinaibi Formation, which was defined in the Missinaibi and other nearby river valleys (see Figure 15.1) (Skinner 1973). Specifically, based on the lithology, this nonglacial deposit appears to match the lower, organic-rich part of the Lacustrine Member of this formation (Skinner 1973).

If the correlation to the Missinaibi Formation is accepted, the till units below the organic lacustrine deposit provide a record of Illinoian and earlier glacial events. Skinner (1973) recognized, in the nearby river valleys, 3 calcareous tills underlying the Missinaibi Formation which are mostly grey in colour and separated in places by glacial fluviolacustrine deposits. Till fabrics and striated boulders in the tills generally indicate ice flows to the southwest. Because of the little variations in till compositions, he interpreted the tills and intervening deposits being a result of temporary oscillations of a single ice sheet during the Illinoian Stage. In comparison, the grey till of the current study (Unit II) can probably be correlated with that suite of glacial deposits he studied. The preponderance of Paleozoic carbonate clasts in the grey till (see Table 15.2) indicates a major source area within the Paleozoic bedrock area, consistent, in general, with the ice-flow direction suggested by Skinner (1973).

The low magnetic susceptibility in the upper part of the grey till results from low concentrations of ferromagnetic minerals, e.g., magnetite (*see* Figure 15.1). This would suggest a different source area and, therefore, a different till unit. Conversely, a lack of compositional differences observed in pebble lithologies across the boundary of this geophysical anomaly suggests both facies are probably part of the same till (*see* Table 15.2). Skinner (1973) noticed the absence of carbonate material in a substrate below the Lacustrine Member of the Missinaibi Formation and hence the presence of strong pedological reduction, or gleying. Under strong reduction conditions, iron oxides, e.g., magnetite, can be altered geochemically, resulting in weak magnetic susceptibility in sediments such as those deposited in deep lakes (e.g., Gao et al. 2020). However, substrates subjected to strong pedogenic weathering usually do not exceed 1 m depth as Skinner (1973) observed for this region. The till interval with low magnetic susceptibility has a thickness of 7 m (*see* Figure 15.1). Although a late diagenesis mechanism is possible, the thickness of this interval appears inconsistent with a pedogenic process. The carbonate material is abundant throughout (*see* Table 15.2) and there are no signs for significant decrease in its concentration within this interval. Therefore, the lack of removal of carbonate material in the till also negates such a mechanism. It is hoped that magnetic susceptibility to be measured on the remaining drill-cores HK20-002 and -004 provide clues for better understanding of this geophysical anomaly.

The red till of unit I differs from the grey till of unit II in that it contains much more Precambrian crystalline rock and Paleozoic red sandstone clasts (*see* Table 15.2). The drill sites are not far from the Paleozoic–Precambrian bedrock boundary to the east and south (*see* Figure 15.1) and the significant proportions of crystalline rock clasts suggest a source area in the Precambrian terrain. The red clasts appear to resemble the reddish arkosic sandstone of the early Devonian Sextant Formation in the southern Moose River Basin (Sanford and Norris 1975). Although sporadic outcrops have been observed in areas north of the drill sites (Sandford and Norris 1975), significant occurrence of this formation is only seen approximately 80 km east-northeast of the drill sites, at the southern edge of the Moose River Basin where it overlies the Precambrian bedrock (Sandford and Norris 1975; Johnson et al. 1992). These lines of evidence together suggest an ice flow moving toward the west-southwest. The red till probably developed in the Illinoian but in an earlier phase than the overlying grey till. Alternatively, it may have developed in a glacial stage predating the Illinoian. The current data available are not sufficient to allow preference of a particular stratigraphical correlation over the other.

Above the sub-till organic lacustrine deposit, at least one till occurs in unit IV (*see* Figure 15.1). Except for its well-developed fissility (*see* Photo 15.1F), the till from this interval appears to have similar texture and pebble lithologies as the grey till of unit II (*see* Table 15.2). In the James Bay Lowland and its vicinity, 2 or more tills are common above the Missinaibi Formation (McDonald 1969; Skinner 1973; Allard et al. 2012; Dubé-Loubert et al. 2013; Gao et al. 2020; Thorleifson, Wyatt and Warman 1993; Roy 1998; Dredge and McMartin 2011; Gauthier et al. 2019). In the nearby Adam Creek, the Adam and Kipling tills of the Wisconsin Stage were recognized above the Missinaibi Formation, which are separated by occasional glacial fluviolacustrine silt and sand collectively referred to as the Friday Creek sediments (Skinner 1973). The till material found in unit IV is probably correlative to either the Adam or Kipling tills. Above the Kipling till, late- and post-glacial glaciolacustrine and glaciomarine deposits occur beneath the surface peat (Skinner 1973). However, these deposits are not recovered in the drill cores.

SUMMARY AND PROJECT STATUS

Three drill cores in the interfluvium between the Mattagami and Abitibi rivers in the Moose River Basin revealed an organic nonglacial lacustrine deposit between tills. The sub-till nonglacial deposit indicates ice-free conditions under which boreal forest grew in this region. Radiocarbon age determinations on wood samples indicate a minimum age greater than 50 ka. This nonglacial deposit can probably be correlated with the Missinaibi Formation of the Last Interglacial (MIS 5e) which was defined

from the nearby riverbank exposures. Below this nonglacial deposit, a younger grey till and an older red till occur, probably deposited during the Illinoian or earlier. The grey till resembles those described previously from the nearby riverbanks, which were probably emplaced by an ice sheet moving to the southwest as Skinner (1973) suggested. The red till was likely deposited by an ice flowing toward the west-southwest because of its abundant Precambrian crystalline rock clasts and a sizeable amount of red sandstone pebbles derived from the early Devonian Sextant Formation located to the east-northeast at the southern edge of the Moose River Basin. Above the nonglacial deposit, the core recovery is poor. But at least one till has been recognized, which is probably correlative to either the Adam or Kipling tills of the Wisconsinan reported previously from the nearby riverbank sections. Core logging and sampling is ongoing. Samples collected will be submitted for geochemistry and other laboratory analyses for characterization of the deposits.

ACKNOWLEDGMENTS

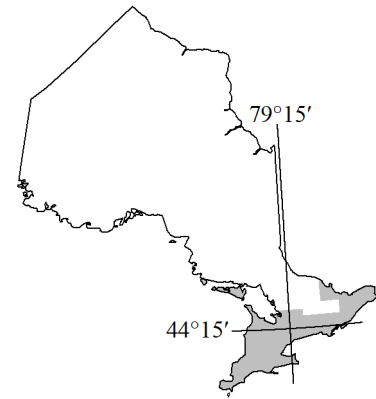
VR Resources Limited donated the drill cores. Special thanks are extended to Michael Gunning, President and CEO of the company, who provided the information and many comments on the drill cores. Saurav Biswas (OGS) assisted in measuring magnetic susceptibility. André E. Lalonde, AMS Laboratory of the University of Ottawa, undertook the radiocarbon dating. Julien Bonin (OGS) drafted the figures. Abigail Burt and Riley Mulligan (OGS) reviewed the manuscript with edits and helpful comments.

REFERENCES

- Allard, G., Roy, M., Ghale, B., Richard, P.J.H., Larouche, A.C., Veillette, J.J. and Parent, M. 2012. Constraining the age of the last interglacial-glacial transition in the Hudson Bay lowlands (Canada) using U-Th dating of buried wood; *Quaternary Geochronology*, v.7, no.1, p.37-47.
- Bajc, A.F., Lee, V.L. and Yeung, K.H. 2014. Field studies in support of terrain mapping and aggregate resource assessment, James Bay Lowland, Ontario; *in* Summary of Field Work and Other Activities, 2014, Ontario Geological Survey, Open File Report 6300, p.23-1 to 23-9.
- 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.
- Dredge, L.A. and McMartin, I. 2011. Glacial stratigraphy of northern and central Manitoba; Geological Survey of Canada, Bulletin 600, 35p.
- Dubé-Loubert, H., Roy, M., Allard, G., Lamothe, M. and Veillette, J.J. 2013. Glacial and nonglacial events in the eastern James Bay lowlands, Canada; *Canadian Journal of Earth Sciences*, v.50, p.379-396.
- Farley-Gill, L.D. 1980. Contemporary pollen spectra in the James Bay Lowland, Canada, and comparison with other forest tundra assemblages; *Géographie physique et Quaternaire*, v.343, p.321–334.
- 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, paper 106590. doi.org/10.1016/j.quascirev.2020.106590
- Gao, C. and Yeung, K.H. 2020. Far North terrain mapping in the Pickle Lake–Cat Lake area, northwestern Ontario: Preliminary indicator mineral results; *in* Summary of Field Work and Other Activities, 2020, Ontario Geological Survey, Open File Report 6370, p.12-1 to 12-13.
- 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.

- 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.
- Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* *Geology of Ontario*, Ontario Geological Survey, Special Volume 4, Part 2, p.907-1010.
- Long, D.G.F. 2000. Cretaceous fluvial strata in the Moose River Basin of Ontario, Canada, as a source of kaolin for paper and ceramic industries; *Applied Clay Science*, v.16, p.97-115.
- McDonald, B.C. 1969. Glacial and interglacial stratigraphy, Hudson Bay Lowland; Geological Survey of Canada Paper 68-53, p.78-99.
- Ontario Geological Survey 2006. 1:250 000 scale bedrock geology of Ontario; Ontario Geological Survey, Miscellaneous Release—Data 126 – Revised.
- Roy, M. 1998. Pleistocene stratigraphy of the lower Nelson River area: Implications for the evolution of the Hudson Bay Lowland of Manitoba, Canada; unpublished MSc thesis, University of Quebec, Montreal, Quebec, 220p.
- Sanford, B.V. and Norris, A.W. 1975. Devonian stratigraphy of the Hudson Platform; Geological Survey of Canada, Memoir 379, Part 1, 124p.
- Skinner, R.G. 1973. Quaternary stratigraphy of the Moose River Basin, Ontario; Geological Survey of Canada, Bulletin 225, 77p.
- Smith, S.L. 1992. Quaternary stratigraphic drilling transect, Timmins to the Moose River Basin, Ontario; Geological Survey of Canada, Bulletin 415, 103p.
- Telford, P.G. 1982. Mesozoic stratigraphy of the Moose River Basin; *in* *Mesozoic Geology and Mineral Potential of the Moose River Basin*; Ontario Geological Survey, Study 21, p.21-50.
- Telford, P.G., Long, D.G.F., Norris, G., Zippi, P. and Griffis, R. 1991. Mesozoic geology and lignite potential of the Moose River Basin; Ontario Geological Survey, Open File Report 5777, 185p.
- 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.

16. Project SO-21-001. Progress on the Development of a New Stratigraphic Framework for the Paleozoic Geology of Southern Ontario



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INTRODUCTION

This article reports on the proposed next steps resulting from the past 6 years of collaborative studies between the Ontario Geological Survey (OGS), the Geological Survey of Canada and the staff of the Oil, Gas and Salt Resources Library, London, to create the first three-dimensional (3-D) Paleozoic bedrock model for south-central and southwestern Ontario using the Leapfrog[®] Works program (Brunton et al. 2017; Carter et al. 2019, Carter et al. 2020; Brunton and Brintnell 2020; Carter et al. 2021; Figure 16.1). The bulk of this earlier work, carried out between 2015 and 2021 (Phases 1 and 2 of Ontario Geological Survey studies), involved examining formational-rank units and developing criteria for picking formation tops for parts of the Devonian, Silurian and Upper Ordovician successions. More than 30 000 formation tops spanning almost 8000 oil and gas and other cored bedrock wells were determined to help constrain the regional extent of Paleozoic strata, mostly in southwestern Ontario.

This regional subsurface study exposed many discrepancies in the existing stratigraphic nomenclature, many of which were addressed during the development of the 3-D model. Although the Paleozoic stratigraphy of Ontario has been well studied for more than 175 years, many inconsistencies between surface and subsurface terminology still exist. Furthermore, rock units with the same stratigraphic name may have different lithologic and/or paleontologic characteristics and subdivisions depending on their geographic location, thereby creating ambiguity. In addition, over the years, some terms originally used as chronostratigraphic terms (e.g., Black River, Trenton, Beekmantown) have been adopted for lithostratigraphic units, adding further confusion and making it difficult to reconcile nomenclature between older and more recent literature. Finally, the results of many more recent stratigraphic studies by academic researchers, federal, and provincial or state geological surveys have yet to be incorporated into the Paleozoic stratigraphic framework used by the OGS. Recent ongoing OGS mapping initiatives in the Cambrian and Ordovician stratigraphic succession of eastern Ontario (Ottawa graben and Kingston areas: Béland Otis 2017, 2018, 2019; Perth area: Easton 2015, 2016), including alkali-reactivity assessments (Hahn and MacDonald 2018) and updating of the southern Ontario karst map (Brunton 2019), has revealed that several Upper Ordovician stratigraphic units can be correlated across the Frontenac Arch and extend into southwestern Ontario. Therefore, the authors are in the process of updating the Cambrian and Ordovician stratigraphic nomenclature of southern Ontario, which will be incorporated into a revised lithostratigraphic chart associated with the 3-D model of Paleozoic geology of south-central and southwestern Ontario.

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.16-1 to 16-9.*

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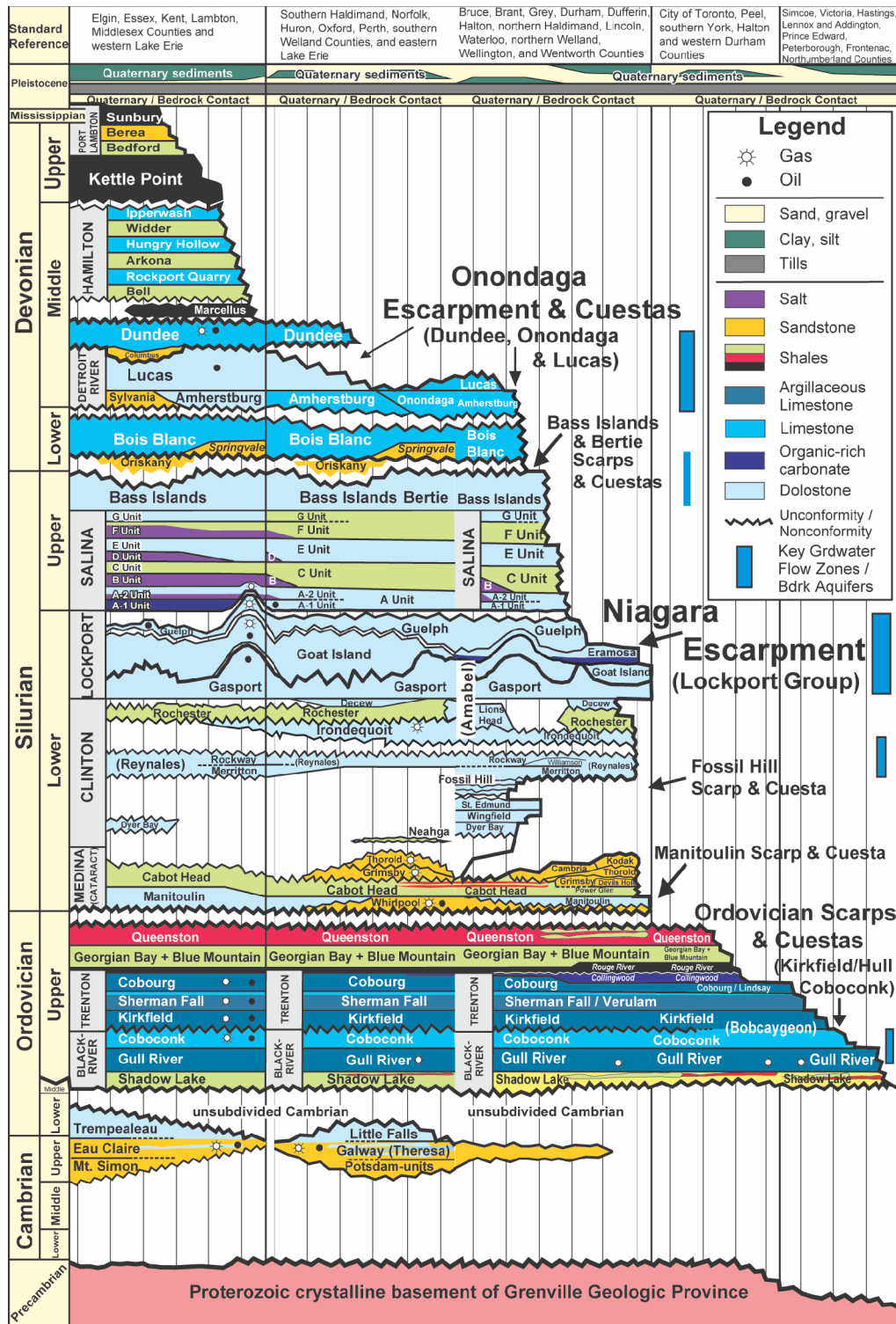


Figure 16.1. Current terminology of Paleozoic strata for south-central and southwestern Ontario (see Brunton and Brintnell 2020). The Phanerozoic bedrock topography is depicted by the erosional line (uppermost, thickened, black zig-zag line), from lower right to upper left, of stepped karstic cuestas (key escarpments labelled) that reside above the Grenville geologic province crystalline rocks, from Lake Simcoe–Frontenac Arch area to Windsor area (northeast to southwest; see geographic regions at top of figure). The remaining horizontal black zig-zag lines reflect unconformities, or sequence boundaries. The line thicknesses signify inferred missing time interval (note Cambrian, Lower to Middle Ordovician and Lower Silurian gaps in sedimentation). The relative thicknesses of rock units are not to scale.

The main goals of this project include the 1) delineation and updating of top and bottom descriptions and the criteria used to define Paleozoic bedrock formational and group rank rock units; 2) identification of type and reference sections for formational and group rank rock units; 3) standardization of the Paleozoic lithostratigraphic chart and creation of a seamless Paleozoic bedrock map legend for southern Ontario; and 4) eventual creation of a revised lexicon of Paleozoic geology for southern Ontario (cf. Winder 1961), with a listing of type and reference sections and a listing of revised and/or abandoned units in accordance with the North American Stratigraphic Code (NACSN 2021).

We wish to produce a draft revised lithostratigraphic chart by the end of 2022, to assist in ongoing field mapping projects of the lower Paleozoic of eastern Ontario and the subsurface of southwestern Ontario. This work will involve field investigations in the spring and/or summer of 2022 to examine key stratigraphic sections in Ontario for comparison with their type section descriptions in order to provide lithologic descriptions that support any redefining of formational rank contacts.

In the meantime, the authors are reviewing all historical literature concerning Paleozoic lithologic descriptions, formational and group rank definitions, relative ages of rock units, incorporation of U/Pb zircon ages from bentonite beds, and using geochemical information (e.g., carbon and oxygen isotopes) that may help with regional correlation. The results of this effort will be a defensible and predictive stratigraphic framework across southern Ontario utilizing both local and regional rock units across southern Ontario. The authors have decided to start with the oldest Paleozoic units because these strata require more attention and were not addressed during the initial phases of the 3-D Leapfrog® Works modelling endeavours.

To date, the Cambrian to Ordovician units have been studied, and the focus over the past few months has been on the Black River and Trenton groups, focusing on the Gull River and Bobcaygeon formations from south-central (Liberty 1969; Carson 1981a; Armstrong 2000) and eastern Ontario (Williams 1991; Armstrong and Dodge 2007) and corresponding stratigraphic sections in New York State and Quebec (see discussions and references in Béland Otis 2017, 2018, 2019; Figure 16.2). The next section describes some, but not all, of the stratigraphic nomenclatural issues related to the Cambrian and Ordovician stratigraphy of Ontario.

Subsurface Ontario (Sanford 1961, 1969)		South-Central Ontario (Armstrong 2000)			Kingston–Napanee Area (Liberty 1969; Carson 1981b)			Eastern Ontario (Williams 1991)					
Group	Formation	Group	Formation	Member	Group	Formation	Member	Group	Formation	Member			
Trenton	Kirkfield	Simcoe	Bobcaygeon	upper	Simcoe	Bobcaygeon	upper	Ottawa	Bobcaygeon	upper			
				middle			lower			middle			
lower	lower			lower									
Black River	Coboconk			Gull River			upper			Gull River	upper	Gull River	upper
	Gull River						lower				middle		lower
							lower				lower		lower
Shadow Lake	Shadow Lake	Shadow Lake	Shadow Lake	Shadow Lake	Shadow Lake	Shadow Lake							

Figure 16.2. Summary of OGS published nomenclature currently in use for the stratigraphic interval spanning from the Shadow Lake through to the Bobcaygeon formations. See text for discussion.

CAMBRIAN AND ORDOVICIAN STRATIGRAPHIC ISSUES

Discussion

Cambrian and Early to Middle Ordovician rocks are absent throughout most of Ontario, except for parts of eastern Ontario and the deeper subsurface of southwestern Ontario. The oldest Paleozoic units, within the Potsdam Group, primarily comprise quartz-rich sandstones and conglomerates. The OGS currently recognizes only 2 units: the conglomerates of the Covey Hill Formation and the overlying quartz arenites of the Nepean Formation. However, Lowe et al. (2017) recently suggested that the American nomenclature should take precedence and that the Potsdam Group in Ontario be subdivided into the Ausable, Hannawa Falls and Keeseville formations. The feasibility of that suggestion remains to be tested, especially in the Perth area, where the Covey Hill Formation is conglomerate-dominated (not sandstone-dominated as in Quebec and New York) and where its deposition may have been controlled by Neoproterozoic to early Paleozoic faults (cf. Easton 2016). Lowe et al. (2017) also suggested use of the term “Altona Member” (a mudstone-dominated sequence in the eastern part of Lowe’s study area) located near the base of the Ausable Formation. They also adopted the Rivière Aux Outardes Member of Clark (1966), which is present in the northern part of the Ottawa graben (a failed rift) and is a dolomitic bioturbated sandstone that interfingers with the Keeseville Formation.

The Potsdam Group is overlain by the Beekmantown Group, which consists mostly of calcareous sandstones and dolostones (cf. Williams 1991). Williams (1991) used a two-fold division of the Beekmantown Group, which was revised by Bernstein (1992). Williams’ (1991) oldest unit in the Beekmantown Group is the March Formation. Bernstein (1992) has argued that the Theresa Formation of New York State should take precedence. Bernstein (1992) also replaced Wilson’s (1946) and Williams’ (1991) Oxford Formation with the Beauharnois and Carillon formations and further subdivided the Beauharnois into the Ogdensburg and Huntington members (see discussion and references in Bernstein 1992).

The Rockcliffe Formation of Williams (1991), is subdivided into a lower and upper member and overlies the Beekmantown Group. The sequence is dominated by interbedded sandstones and noncalcareous shales; however, the upper member contains dolostone and limestone beds that were referred to as the St. Martin Formation by Wilson (1946). Additionally, Salad Hersi and Dix (1997) proposed the use of the Hog’s Back Formation for this upper interval.

The nomenclature of Upper Ordovician sedimentary rocks in eastern and south-central Ontario varies both geographically and between the outcrop belts and the subsurface. In south-central Ontario, these strata are named the Simcoe Group (Liberty 1969), whereas in eastern Ontario, they are referred to as the Ottawa Group (Wilson 1946). In the subsurface of southwestern Ontario, they are referred to as the Black River and Trenton groups (Sanford 1961). The Simcoe and Ottawa groups are both subdivided into the Shadow Lake, Gull River, Bobcaygeon, Verulam and Lindsay formations (Liberty 1969; Williams 1991; Armstrong 2000). In the subsurface, the Black River Group encompasses the Shadow Lake, Gull River and Coboconk formations, whereas the Trenton Group consists of the Kirkfield, Sherman Fall and Cobourg formations (see Figure 16.2). Despite the differences in terminology between eastern and south-central Ontario and between the subsurface and outcrop belts, many units are of broadly equivalent age, with similar faunas, and were deposited under similar conditions, thus sharing similar lithologic attributes.

The oldest unit in south-central Ontario is the relatively thin (average of 6 m) siliciclastic-dominated Shadow Lake Formation, which uncomfortably overlies Proterozoic Grenville Province rocks (Johnson et al. 1992). The Shadow Lake Formation has been used in 2 different contexts. In much of south-central Ontario, it has been used to describe any siliciclastic rocks present between the Precambrian basement and the overlying Paleozoic limestones (cf. Di Prisco and Springer 1991). In this context, it could vary in age from Cambrian to middle Ordovician, as the unit is typically devoid of any biostratigraphic constraints. The Shadow Lake Formation also crops out in eastern Ontario, where it disconformably

overlies the Rockcliffe Formation and has been considered the equivalent of the lower Pamela Formation of New York State (Wilson 1932; Liberty 1955; Williams 1991). Salad Hersi and Dix (1997) abandoned the Shadow Lake Formation, which correlates broadly with the upper member of their Hog's Back Formation (a unit that cannot be correlated on a subregional basis). Thus, in eastern Ontario, it appears that the Shadow Lake Formation better fits within part of the Pamela Formation (Cushing 1908; Wilson 1932, 1936; Kay 1937, 1942, 1968; Okulitch 1939; Liberty 1955). Resolving these different usages will require further work.

In south-central Ontario (Lake Simcoe area), the member designations and defined contacts of the Gull River Formation are problematic (*see* Okulitch 1939; Liberty 1969; Armstrong 2000; Sanford 1993), and they cannot be easily traced to the Kingston area (*see* Liberty 1969; Carson 1981a, 1981b, 1982a, 1982b) or the Ottawa graben (Williams 1991). In Quebec and in the United States, the Gull River Formation corresponds to most of the Black River Group. The term "Black River Group" is also used to describe equivalent subsurface strata in southwestern Ontario and is subdivided into the Shadow Lake, Gull River and Coboconk formations (Sanford 1961).

Descriptions of the lower member of the Gull River Formation are relatively consistent from south-central Ontario to Ottawa, and in broad terms it can be described as thin- to medium-bedded, alternating dark grey to brownish grey limestone and some calcareous to noncalcareous, light greenish grey dolomitic mudstone or dolomudstones with interbeds of dark grey to green shale (generally noncalcareous). Vugs filled with pink calcite, thin quartz sandstone interbeds, evaporite casts, intraclasts and bird's-eye texture are frequently identified in the Gull River Formation and ostracods, nautiloids, gastropods and stromatolites are among the more common faunal elements. The greenish dolomudstones and interbedded green shale form the middle member of the Gull River Formation in the Kingston area, and thus, the combined lower and middle members in Kingston are equivalent to the lower member of the Gull River Formation in the Ottawa graben (*see* Figure 16.2). The lower Gull River Formation is also referred to as the Pamela Formation (e.g., McFarlane 1992; Salad Hersi and Dix 1999).

Descriptions of the upper Gull River Formation are more varied geographically. In the Ottawa graben, it consists of thin- to medium-tabular beds of medium- to dark brownish-grey mudstone to packstone with some interbeds of dark grey to black thin calcareous shale (Williams 1991). The unit commonly is light bluish grey weathering, with bird's-eye textures, and possesses mostly gastropods, bivalves, ostracods, and tetradiid (coral) colonies increasing in abundance toward the top of the formation. In the Kingston area, the upper Gull River Formation contains stromatolitic bioherms, ooid beds, intraclast-bearing beds and variably thick shale interbeds (McFarlane 1992). The upper Gull River Formation has also been named the Lowville Formation in eastern Ontario and in adjacent jurisdictions (e.g., Wilson 1946; Salad Hersi and Dix 1999; Globensky 1987; Walker 1973; Cameron and Mangion 1977; MacFarlane 1992).

Current Activities

Current activities involve establishing a standardized nomenclature to apply to the stratigraphic interval from the upper Gull River Formation to the base of the Verulam Formation, which straddles the Black River–Trenton group boundary and the entirety of the Bobcaygeon Formation. The Bobcaygeon Formation follows a three-fold subdivision in south-central Ontario (Armstrong 2000), a two-fold subdivision in the Kingston–Napane area (Carson 1981b), and a three-fold subdivision in the Ottawa Graben (Williams 1991) (*see* Figure 16.2). Furthermore, in the subsurface in southwestern Ontario, a different nomenclature is used, with the Bobcaygeon Formation referred to as the Coboconk Formation of the Black River Group (equivalent to the lower Bobcaygeon Formation) and the Kirkfield Formation of the Trenton Group (equivalent to the middle and upper members of the Bobcaygeon Formation; *see* Sanford 1993; Brunton et al. 2017).

Recent work by Paton and Brett (2020) in south-central Ontario applied the Coboconk–Kirkfield terminology to the Bobcaygeon Formation in the Lake Simcoe area. Near Napanee and Kingston, the lower Bobcaygeon Formation has also been referred to as the Selby Formation (McFarlane 1992; *see* James et al. 2020) based on the Trenton Group nomenclature from New York State.

In eastern Ontario, Williams (1991) based the stratigraphic subdivisions of Bobcaygeon Formation on shale content rather than grain size and faunal content, the criteria Liberty (1969) proposed for the Lake Simcoe area. The lower member of the Bobcaygeon Formation in eastern Ontario corresponds to the upper Gull River Formation of south-central Ontario, as defined by Liberty (1969), and the previously defined Leray, Rockland and Hull beds of Wilson (1946). The middle and upper members of the Bobcaygeon Formation correspond respectively to the lower and upper members of the Hull Formation (cf. Sinclair 1954; Uyeno 1974).

Advancements in the field of chemostratigraphy has allowed for some improvements in regional correlation, but care must be taken in areas where significant cut-downs or disconformities are recognized. The terminology of the Black River and Trenton groups and corresponding stratigraphic subdivisions have historical precedence over the Simcoe Group terminology currently in use by the OGS and can be applied across various jurisdictions (Vermont, New York State, Quebec, Pennsylvania, Ohio and Ontario). Additional field work to refine existing type sections and possibly define new type sections, in addition to lithochemical and chemostratigraphic sampling, and core logging, are planned to develop a predictive and consistent stratigraphic nomenclature to assist in various mapping initiatives by the OGS and for the wide variety of end-users of the Paleozoic bedrock data.

ACKNOWLEDGMENTS

The authors wish to acknowledge the able field assistance by Brittany Pegg, Alison Jerome and Carolyn Hatton. Thanks go to the National Capital Commission, the City of Ottawa, the Geological Survey of Canada, Golder Associates Ltd., quarry owners and operators (Karson Group, Thomas Cavanagh Construction Ltd, H&H Construction Inc., The Miller Group, WRC Construction) for granting access and allowing sample collection on their properties. The authors wish to thank all ERGMS colleagues for technical support, as well as staff of the OGS Geoscience Laboratories, Publications Services and the John B. Gammon Geoscience Library for their ongoing help throughout this project.

REFERENCES

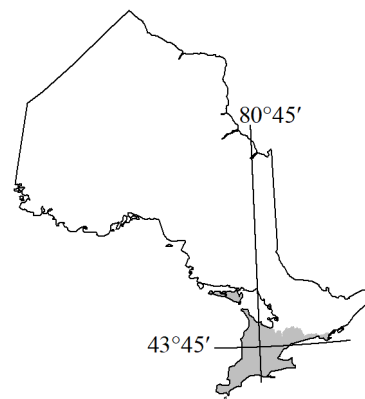
- Armstrong, D.K. 2000. Paleozoic geology of the northern Lake Simcoe area, south-central Ontario; Ontario Geological Survey, Open File Report 6011, 43p.
- Armstrong, D.K. and Dodge, J.E.P. 2007. Paleozoic geology of southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 219.
- Béland 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 20-10.
- Bernstein, L. 1992. A revised lithostratigraphy of the Lower–Middle Ordovician Beekmantown Group, St. Lawrence Lowlands, Quebec and Ontario; Canadian Journal of Earth Sciences, v.29, p.2677-2694.

- 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. and Brintnell, C. 2020. Early Silurian sequence stratigraphy and geological controls on karstic bedrock groundwater flow zones, Niagara Escarpment region and the subsurface of southwestern Ontario; Ontario Geological Survey, Groundwater Resources Study 13.
- Brunton, F.R., Carter, T., Logan, C., Clark, J., Yeung, K., Fortner, L., Freckelton, C., Sutherland, L. and Russell, H.A.J. 2017. Lithostratigraphic compilation of Phanerozoic bedrock units and 3D geological model of southern Ontario; abstract *in* Regional-scale Groundwater Geoscience in Southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House, Guelph, Ontario, March 1–2, 2017, Geological Survey of Canada, Open File 8212, p.3. doi.org/10.4095/299750
- 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. Preliminary report on the Paleozoic geology of the Peterborough–Campbellford area, southern Ontario; Ontario Geological Survey, Open File Report 5331, 84p.
- 1981b. Paleozoic geology of the Kingston area, southern Ontario; Ontario Geological Survey, Miscellaneous Paper 100, p.134-136.
- 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.
- Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Freckelton, C., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L. and Yeung, K.H. 2019. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Ontario Geological Survey, Groundwater Resources Study 19 / Geological Survey of Canada, Open File 8618. doi.org/10.4095/315045
- Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L. and Yeung, K.H. 2020. Three-dimensional geological modelling of the Paleozoic bedrock of southern Ontario: Status update; *in* Southern Ontario Groundwater Project 2014–2019: Summary Report, Geological Survey of Canada, Open File 8536, p.7-21. doi.org/10.4095/321079
- Carter, T.R., Logan, C.E., Clark, J.K., Russell, H.A.J., Brunton, F.R., Cachunjua, A., D’Arienzo, M., Freckelton, C., Rzyszcak, H., Sun, S. and Yeung, K.H. 2021. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Geological Survey of Canada, Open File 8795, (ed. version 2), 103p. doi.org/10.4095/328297
- Clark, T.H. 1966. Châteauguay area; Châteauguay, Huntingdon, Beauharnois, Napierville and St. Jean counties; Québec Department of Natural Resources, Geological Report 122, 63p.
- Cushing, H.P. 1908. Lower portion of the Paleozoic section in northwestern New York; *Geological Society of America Bulletin*, v.19, p.155-176.
- Di Prisco, G. and Springer, J.S. 1991. The Precambrian-Paleozoic unconformity and related mineralization in southeastern Ontario; Ontario Geological Survey, Open File Report 5751, 122p.
- Easton, R.M. 2015. Precambrian and Paleozoic geology of the Perth area, Grenville Province; *in* Summary of Field Work and Other Activities, 2015; Ontario Geological Survey, Open File Report 6313, p. 18-1 to 18-13.
- 2016. Precambrian and Paleozoic geology of the Perth area, Grenville Province; *in* Summary of Field Work and Other Activities, 2016; Ontario Geological Survey, Open File Report 6323, p.17-1 to 17-13.

- Globensky, Y. 1987. Géologie des Basses–Terres du St-Laurent; Ministère de l'Énergie et des Ressources du Québec, MM 85-02, 63p.
- Hahn, K.E. and MacDonald C.A. 2018. Identification and mapping of alkali–carbonate reactive layers in the Gull River Formation, near Kingston, Ontario; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.23-1 to 23-9.
- James, N.P., Narbonne, G.M. and Armstrong, D.K. 2020. Aragonite depositional facies in a Late Ordovician calcite sea, Eastern Laurentia; *Sedimentology*, v.67, p.3513-3532.
- Johnson, M.D., Armstrong, D.K., Sanford, B.V., Telford, P.G. and Rutka, M.A. 1992. Paleozoic and Mesozoic geology of Ontario; *in* Geology of Ontario, Ontario Geological Survey, Special Volume 4, Part 2, p.907-1008.
- Kay, G.M. 1937. Stratigraphy of the Trenton Group; *Geological Society of America Bulletin*, v.48, p.233-302.
- 1942. Ottawa–Bonnetche Graben and Lake Ontario homocline; *Geological Society of America Bulletin*, v.53, p.585-646.
- 1968. Ordovician formations in northwestern New York; *Le Naturaliste Canadien*, v.95, p.1373-1378.
- Liberty, B.A. 1955. Stratigraphic studies of the Ordovician system in Central Ontario; *Geological Association of Canada, Proceedings*, v.7, p.137-147.
- 1969. Palaeozoic geology of the Lake Simcoe area, Ontario; *Geological Survey of Canada, Memoir 355*, 201p.
- 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 MSc thesis, Queen's University, Kingston, Ontario, 181p.
- North American Commission on Stratigraphic Nomenclature (NACSN) 2021. North American Stratigraphic Code, 2021 Edition; *Stratigraphy*, v.18, no.3, p.153-204.
- Okulitch, V.J. 1939. The Ordovician section at Coboconk, Ontario; *Royal Canadian Institute, Transactions*, v.33, p.319-339.
- Paton, T.R. and Brett, C.E. 2020. Revised stratigraphy of the middle Simcoe Group (Ordovician, upper Sandbian–Katian) in its type area: An integrated approach; *Canadian Journal of Earth Sciences*, v.57, p.184-198.
- Salad Hersi, O. and Dix, G.R. 1997. Hog's Back Formation: A new (Middle Ordovician) stratigraphic unit, Ottawa Embayment, eastern Ontario, Canada; *Canadian Journal of Earth Sciences*, v.34, p.588-597.
- 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.
- Sanford, B.V. 1961. Subsurface stratigraphy of Ordovician rocks in southwestern Ontario; *Geological Survey of Canada, Paper 60-26*, 54p.
- 1969. Geology, Toronto–Windsor area; *Geological Survey of Canada, Map 1263A*, scale 1:250 000.
- 1993. Stratigraphic and structural framework of Upper Middle Ordovician rocks in the Head Lake–Burleigh Falls area of south-central Ontario; *Géographie Physique et Quaternaire*, v.47, no.3, p.253-268.
- Sinclair, G.W. 1954. The age of the Ordovician Kirkfield Formation in Ontario; *Ohio Journal of Science*, v.54, p.31-41.

- Uyeno, T.T. 1974. Conodonts of the Hull Formation, Ottawa Group (Middle Ordovician), of the Ottawa–Hull area, Ontario and Quebec; Geological Survey of Canada, Bulletin 248, 31p.
- Walker, K.R. 1973: Stratigraphy and environmental sedimentology of Middle Ordovician Black River Group in the type area, New York State; New York State Museum and Science Service, Bulletin 419, 43p.
- 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. 1932. Notes on the Pamela Member of the Black River Formation of the Ottawa Valley; American Journal of Science, v.24, p.135-146.
- 1936. Contributions to the study of the Ordovician of Ontario and Quebec – Part I, A synopsis of the Ordovician of Ontario and western Quebec and the related succession in New York; Geological Survey of Canada, Memoir 202, p.1-20.
- 1946. Geology of the Ottawa–St Lawrence Lowland, Ontario and Quebec; Geological Survey of Canada, Memoir 241, 66p.
- Winder, C.G. 1961. Lexicon of Paleozoic names in southwestern Ontario; University of Toronto Press, Toronto, Ontario, 121p.

17. Project SO-21-002. Stratigraphy and Sedimentology of Upper Ordovician Strata, with Emphasis on Collingwood and Rouge River Members, Southern Ontario and Manitoulin Island: Project Introduction



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INTRODUCTION

The Paleozoic stratigraphy of Ontario has been well studied for more than 100 years; however, many inconsistencies remain between surface and subsurface stratigraphic nomenclature. Rock units with the same stratigraphic name have different lithologic and/or paleontologic characteristics and subdivisions depending on their geographic location, thus creating ambiguity.

One of the main goals of this study will be to focus on improving formation-rank top pick criteria for the Upper Ordovician (Middle to Upper Katian: 452 to 445 Ma) succession in southern Ontario, including, in ascending order, 1) the Collingwood Member of the Cobourg Formation and how it relates to the Utica Formation of northeastern United States, regionally, 2) the Rouge River Member of the Blue Mountain Formation and 3) Georgian Bay Formation. At present no systematic formation-rank picks or stratigraphic nomenclature have been agreed upon for these Upper Ordovician strata in Ontario. This work will build upon the past 6 years of collaborative studies between the Ontario Geological Survey (OGS), Geological Survey of Canada and staff of the Oil, Gas & Salt Resources Library, London, to create the first three-dimensional (3-D), Paleozoic bedrock Leapfrog[®] Works model for south-central and southwestern Ontario (Brunton et al. 2017; Carter et al. 2019; Carter et al. 2020; Brunton and Brintnell 2020; Carter et al. 2021; *see* Figure 16.1 (this volume)).

As seen in the core repositories of the Oil, Gas and Salt Resources Library and the Ontario Geological Survey, thousands of wells penetrate the Upper Ordovician succession across southern Ontario and Manitoulin Island. Among these, approximately 22 wells have cored intervals through all of the study's target formations and members. Recent studies by Béland Otis (2012, 2015a, 2015b) have provided formation picks for 65 out of 128 cored holes that target the Collingwood Member.

OBJECTIVES

The main objectives of this study are to characterize formation-rank picks, building upon previous work, and provide quality assurance and quality control (QA/QC) criteria for key Upper Ordovician regional-cored wells. COVID-19 pandemic restrictions meant that a planned 2021 field season consisted

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.17-1 to 17-3.*

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mostly of a review of the stratigraphic and sedimentologic literature and a compilation of data for the wells and cores that will be examined in the winter of 2021–2022.

This project will include a more detailed examination of the Collingwood and Rouge River stratigraphic interval, in both the subsurface and outcrop. It is hoped that this will provide descriptive characteristics of the units that will enable correlation of the relatively thin cratonic wedge present in Ontario (Collingwood Member and Rouge River Member) with the much thicker Utica Formation and its coeval formations in other jurisdictions (cf. Brett and Baird 2002; Baird and Brett 2002) and build upon the regional characterization of these units by the OGS (Béland Otis 2012, 2015a, 2015b). The study will also attempt to undertake a sedimentological and sequence stratigraphic approach to assessing the interplay between regional tectonic influences relative to sedimentation processes, in addition to carrying out more detailed studies of the organic-rich units (cf. Rancourt 2009; Sweeney 2014; Hamblin 2018). This stratigraphic information will be integrated into the 3-D Leapfrog® Works model of the Paleozoic bedrock for southern Ontario (cf. Carter et al. 2019; Carter et al. 2020) and the development of a revised lithostratigraphic chart for southern Ontario (*see* this volume, Article 16). Upper Ordovician strata in southern Ontario record drastic climate changes, from greenhouse to ice-house climate conditions (Finnegan et al. 2011). Oceanic anoxia during global warming resulted in massive organic carbon burial and accumulation of organic-rich deposits (e.g., black shale), leading to a major depletion of atmospheric CO₂, global cooling, culminating in the latest Ordovician (Hirnantian: 445.2 to 443.8 Ma) glaciation and mass extinctions.

RESEARCH METHODS

Quality assurance of the formation-top picks will combine lithofacies descriptions of rock core and cuttings relative to geophysical well logs (gamma-ray, neutron, density) combined with measuring key outcrop sections. This approach will involve lithostratigraphy, chemostratigraphy, optical petrography, and scanning-electron microscopy (SEM) of shale and carbonate-rich deposits. The fluctuations in the intensity of marine anoxia will be assessed using paleontological (e.g., brachiopod and trilobite occurrences), petrographic (e.g., organic contents, erosional surfaces), and sulphur isotope profiles through the succession. This approach will help refine formational-rank picks and stratigraphic correlations of key sedimentary rock units and reconstructions of the depositional environments of the respective units.

ACKNOWLEDGMENTS

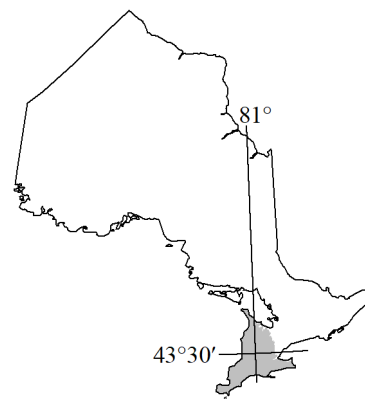
This research forms part of an MSc thesis study at the University of Western Ontario. We wish to thank staff at the Oil, Gas and Salt Resources Library in London, Ontario, for their help in compiling key cored wells to be examined in this study. Rhys Paterson and Shuo Sun are thanked for their help concerning the assessment of the subsurface data available at the core library.

REFERENCES

- Baird, G.C. and Brett, C.E. 2002. Indian Castle Shale: Late synorogenic siliciclastic succession in an evolving Middle to Late Ordovician foreland basin, eastern New York State; *Physics and Chemistry of the Earth*, v.27, p.203-230.
- Béland Otis, C. 2012. Preliminary results: Potential Ordovician shale gas units in southern Ontario; *in* Summary of Field Work and Other Activities, 2012; Ontario Geological Survey, Open File Report 6280, p.29-1 to 29-12.

- 2015a. Upper Ordovician organic-rich mudstones of southern Ontario: Drilling project results; Ontario Geological Survey, Open File Report 6312, 59p.
- 2015b. Geological, geochemical and geophysical data from the Ordovician shales drilling program and the regional sampling program, southern Ontario; Ontario Geological Survey, Miscellaneous Release—Data 326.
- Brett, C.E. and Baird, G.C. 2002. Revised stratigraphy of the Trenton Group in its type area, central New York: Sedimentology and tectonics of a Middle Ordovician shelf-to-basin succession; *Physics and Chemistry of the Earth*, v.27, p.231-263.
- Brunton, F.R. and Brintnell, C. 2020. Early Silurian sequence stratigraphy and geological controls on karstic bedrock groundwater flow zones, Niagara Escarpment Region and the subsurface of southwestern Ontario; Ontario Geological Survey, Groundwater Resources Study 13.
- Brunton, F.R., Carter, T., Logan, C., Clark, J., Yeung, K., Fortner, L., Freckelton, C., Sutherland, L. and Russell, H.A.J. 2017. Lithostratigraphic compilation of Phanerozoic bedrock units and 3D geological model of southern Ontario; abstract *in* Regional-scale Groundwater Geoscience in Southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House, Guelph, Ontario, March 1–2, 2017, Geological Survey of Canada, Open File 8212, p.3. doi.org/10.4095/299750
- Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Freckelton, C., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L. and Yeung, K.H. 2019. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Ontario Geological Survey, Groundwater Resources Study 19 / Geological Survey of Canada, Open File 8618. doi.org/10.4095/315045
- Carter, T.R., Brunton, F.R., Clark, J.K., Fortner, L., Logan, C.E., Russell, H.A.J., Somers, M., Sutherland, L. and Yeung, K.H. 2020. Three-dimensional geological modelling of the Paleozoic bedrock of southern Ontario: Status update; *in* Southern Ontario Groundwater Project 2014–2019: Summary Report; Geological Survey of Canada, Open File 8536, p.7-21. doi.org/10.4095/321079
- Carter, T.R., Logan, C.E., Clark, J.K., Russell, H.A.J., Brunton, F.R., Cachunhua, A., D’Arienzo, M., Freckelton, C., Rzyszcak, H., Sun, S. and Yeung, K.H. 2021. A three-dimensional geological model of the Paleozoic bedrock of southern Ontario; Geological Survey of Canada, Open File 8795 (ed. version 2), 103p. doi.org/10.4095/328297
- Finnegan, S., Bergmann, K., Eiler, D.S., Jones, D.A., Eisenman, I., Hughes, N.C., Tripartti, A.K. and Fischer, W.W. 2011. The magnitude and duration of Late Ordovician–Early Silurian glaciation; *Science*, v.331, p.903-906.
- Hamblin, A.P. 2018. Stratigraphic architecture, sedimentology, and resource potential of the Upper Ordovician Nottawasaga Group of southwestern Ontario, surface and subsurface: Tectonics and sequence stratigraphy in the distal Appalachian Foreland; Geological Survey of Canada, Open File 8153, 86p.
- Rancourt, C.C. 2009. “Collingwood” strata in south-central Ontario - A petrophysical chemostratigraphic approach to comparison and correlation using geophysical borehole logs; unpublished MSc thesis, University of Toronto, Toronto, Ontario, 65p.
- Sweeney, S.N. 2014. Allostratigraphy of the Upper Ordovician Blue Mountain Formation, southwestern Ontario, Canada; unpublished MSc thesis, The University of Western Ontario, London, Ontario, 301p.

18. Project SO-20-001. Subsurface Correlation of the Silurian Clinton and Medina Groups, Southwestern Ontario



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INTRODUCTION

This report summarizes observations made from examining subsurface cores through select formations of the early Silurian Clinton and Medina groups under eastern and central Lake Erie and onshore in southwestern Ontario (*see* Paterson et al. 2020). This study forms part of an MSc thesis by the senior author at The University of Western Ontario and is supported by several agencies, including the Ontario Geological Survey and the Oil, Gas and Salt Resources Library in London, Ontario, through the Mitacs Accelerate Program at The University of Western Ontario (for details, *see* “Acknowledgments”).

The Clinton and Medina groups comprise siliciclastic (sandstone and shale) and minor carbonate sedimentary rocks that crop out and subcrop along the Niagara Escarpment and occur in the subsurface across parts of southwestern Ontario. Although stratigraphic studies of Silurian strata began in the Niagara region more than 150 years ago (Williams 1919; Bolton 1953, 1957, 1965; Sanford 1969; Brett et al. 1995), there is still much detailed work to be done regarding characterization of formational top picks and lithofacies descriptions of key rock units (*see* discussion in Paterson et al. 2020; Figure 18.1). The Clinton and Medina groups comprise various formations, which, in descending order, include Clinton Group: DeCew, Rochester, Irondequoit, Rockway, Williamson, Merritton, Reynales, Neagha formations; and Medina Group: Kodak, Cambria, Thorold, Grimsby, Devils Hole, Ball’s Falls, Power Glen, Cabot Head and Whirlpool formations (for the evolution of stratigraphic nomenclature, refer to Telford 1978; Johnson et al. 1992; Brett et al. 1995; Brunton et al. 2017; Brett, Brunton and Calkin 2018; Brunton and Brintnell 2020; *see* Figure 18.1). The Grimsby, Thorold and Whirlpool formations are important natural gas reservoirs that occur both onshore and offshore in southwestern Ontario (most of the larger active natural gas pools occur under Lake Erie; Figure 18.2).

The Ordovician–Silurian boundary occurs within this stratigraphic interval, but the precise position of the boundary is currently being re-evaluated (Schröer et al. 2016). The interplay between forebulge migration phases (short-lived tectonic activity) and paleoclimatic and paleogeographic conditions (glaciations, global sea-level changes, marine invertebrate mass extinctions) associated with this boundary interval resulted in complex and rapidly changing depositional environments on the far-field side of the Appalachian foreland basin of Laurentia (now southwestern Ontario; Brett, Goodman and LoDuca 1990; Brett et al. 1995; Ettensohn and Brett 2002; Ettensohn et al. 2002; Ettensohn 2008; Brunton et al. 2012; Jin et al. 2013; Jin, Zhan and Wu 2018).

Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.18-1 to 18-9.

Because of the logistical restrictions placed on field work as a result of the COVID-19 pandemic, this study focussed primarily on the subsurface, and included the examination of 47 cores situated from the subsurface of Lake Erie to onshore areas of southwestern Ontario, focussing on the Medina Group. Some of the formations in this succession do not have adequate type section descriptions and, therefore, confusion exists in relating the vertical changes in lithofacies to the geophysical log signatures in the boreholes. This study aims to improve the regional lithostratigraphy of these units in the subsurface of southwestern Ontario by combining detailed core logging and drill-cuttings descriptions, with field observations of select outcrops. The study will involve the integration of geophysical log data with core description and analyses of key cores.

PREVIOUS WORK

The historical development of the stratigraphic nomenclature for the lower Silurian siliciclastic succession in southwestern Ontario is both confusing and complex (*see* Winder 1961; Beards 1967; Martini 1971, 1974a, 1974b; Martini and Salas 1983; Martini and Kwong 1985; Rickard 1975; Telford 1978; Duke and Brusse 1987; Brett et al. 1995; Armstrong and Carter 2010; Cramer et al. 2011. Armstrong and Carter (2006, 2010) represent the many previous attempts in more than 4 decades to update Beards' (1967) doctoral work to merge outcrop stratigraphic nomenclature with subsurface nomenclature. A total of 1635 wells have been drilled in Lake Erie in the 53 years since 1967.

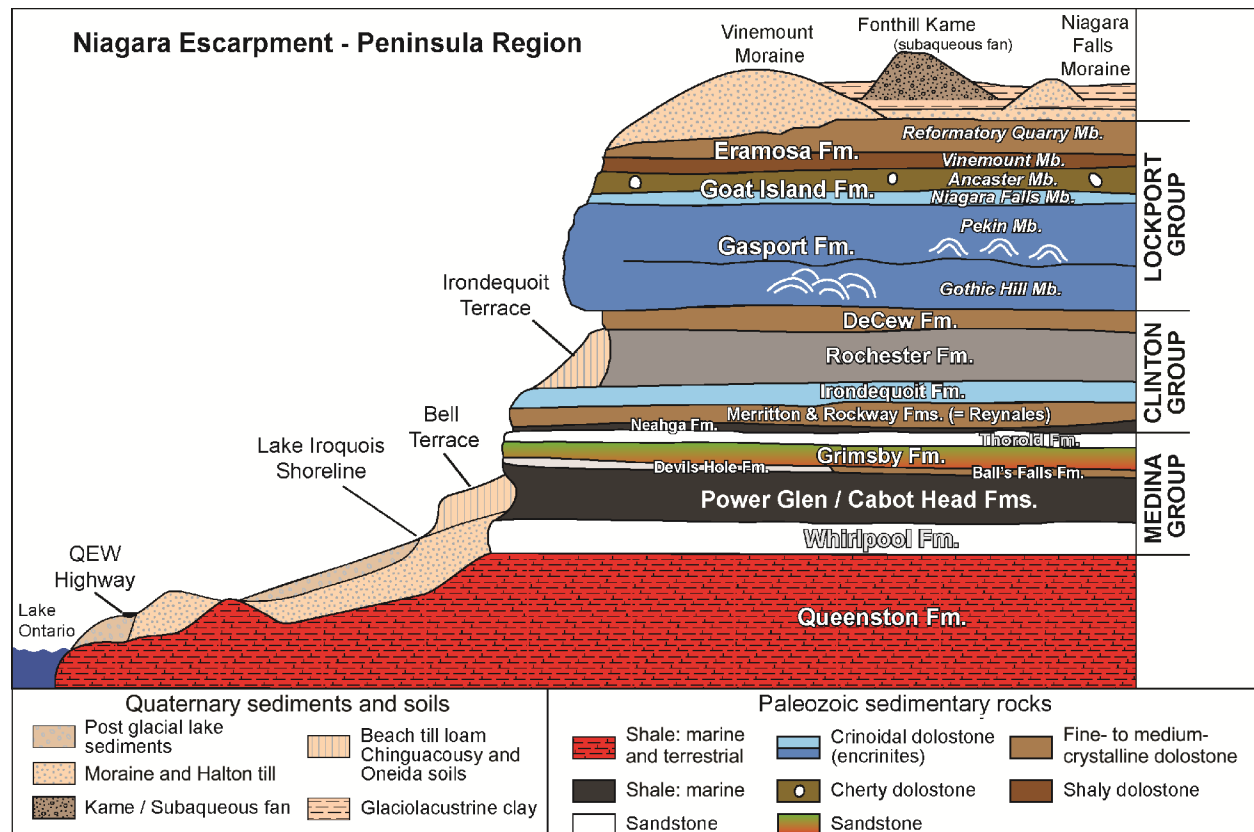


Figure 18.1. Upper Ordovician and early Silurian Paleozoic stratigraphy and simplified Quaternary geology of the Niagara Peninsula region, southwestern Ontario (*modified from* Haynes 2000; Brunton and Brintnell 2020).

GEOLOGICAL SETTING

The bedrock geology of southern Ontario comprises upwards of 1400 m of Paleozoic sedimentary strata that range from upper Cambrian to Carboniferous (Mississippian) (Johnson et al. 1992; Armstrong and Carter 2010). Present-day southern Ontario was positioned in subtropical latitudes during the depositional and erosional history of the Clinton and Medina successions (Johnson et al. 1992; Jin et al. 2013; Jin, Zhan and Wu 2018).

The depositional environment during the early Silurian consisted of shallow epeiric seas and deltaic environments, reflecting diverse environments from nonmarine sandstones to marine shales and shallow marine carbonates (Brett et al. 1995; Brunton and Brintnell 2020). This succession accumulated on the far-field side of the Appalachian foreland basin within a regionally extensive ramp on the Laurentia craton that was subjected to sea-level drawdown during the Late Ordovician and early Silurian glacial and interglacial phases, and episodic forebulge migration tectophases and associated sea-level fluctuations (Brett, Goodman and LoDuca 1990; Cheel 1991; Brett et al. 1995; Brunton et al. 2012; Brunton and

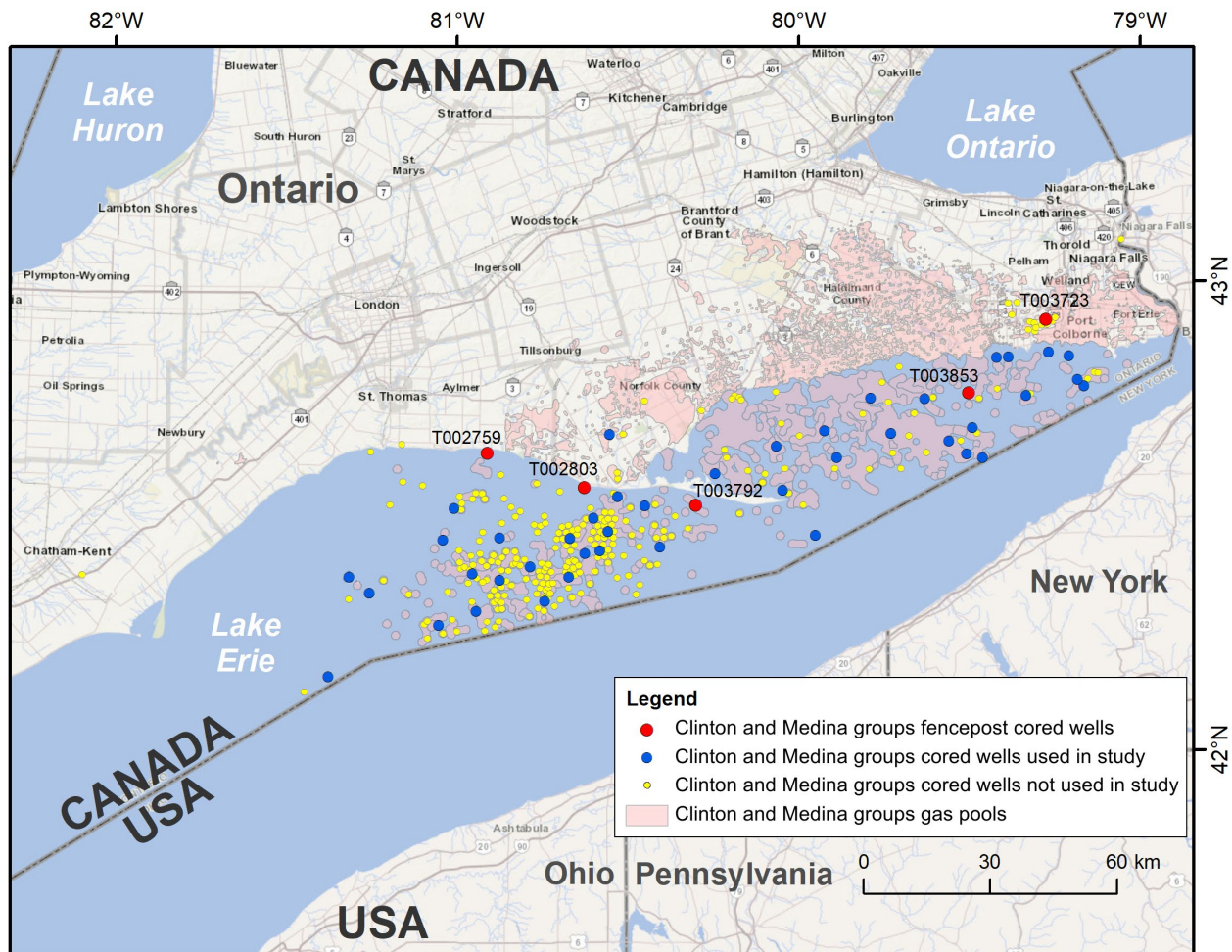


Figure 18.2. Distribution map of a) fencepost wells with core (red dots), priority and secondary wells with core (blue dots) and porosity and/or permeability data within the Clinton and Medina groups used in this study (wells listed in Table 18.1); b) all exploration and development wells (yellow dots) within the Clinton and Medina groups, as identified in the Ontario Petroleum Data System; and c) Clinton and Medina groups gas pools (pale pink fill) (data from Oil, Gas and Salt Resources Library, London, Ontario). More than 10 000 oil and gas wells (not all indicated) penetrate parts of the lower Silurian strata in southwestern Ontario.

Brintnell 2020). Geographically, the northern flank of the Appalachian foreland basin is present in southern Ontario, with many of the strata of the Clinton and Medina groups showing thinning and pinch outs (representing subregional disconformities) from east-central Lake Erie into southwestern Ontario (Martini 1971, 1974a, 1974b; Duke and Brusse 1987; Brett, Goodman and LoDuca 1990; Cheel 1991; Brett et al. 1995; Brunton et al. 2012; Brunton et al. 2017; Brunton and Brintnell 2020).

PRELIMINARY RESULTS

This study involved the logging and photographing of 23 priority cored wells and 24 select secondary cored wells from the more than 260 cored wells that penetrate the Clinton and Medina groups succession, in order to undertake more detailed lithofacies analyses and for the development of quality assurance and quality control (QA/QC) criteria to classify formational rank picks on the surrounding wells that have only geophysical logs and/or drill cuttings records (*see* Figure 18.2; Table 18.1). Emphasis was placed on selecting cored wells spaced across the study area to assess variations in lithofacies and establish a stratigraphic architecture. Research has focussed on detailed logging of rock type, sedimentary structures, fauna and diagenetic alteration in the cores.

The lithological descriptions of cores, including the examination of geophysical well logs, have aided in the descriptions of Medina Group formational rank units. Five cores have been selected as reference cores, as they have the most complete section of the rock units (*see* Table 18.1). From east to west, these are

Core 173, Consumers' 32271, Wainfleet 2-2-III, Licence # T003723

Core 229, Anschutz, Haldimand Lake Erie 22-S-4, Licence # T003853

Core 371, Anschutz, Norfolk Lake Erie 92-N-3, Licence # T003792

Core 1001, Consumers'- Amoco 13102, Norfolk Lake Erie 96-D-1, Licence # T002803

Core 999, Consumers'- Pan Am 13057, Elgin Lake Erie 56-E-3, Licence # T002759

Medina Group

QUEENSTON FORMATION

The Queenston–Whirlpool formation contact interval is best developed in Core 173, which is regarded as the reference core section for this contact in this study area. Here, the top of the Queenston Formation is picked at 221.13 m. Starting at this depth, the Queenston Formation is marked by a reddish brown or maroon to green, extremely fissile shale, and is referred to as Unit 1 in this study. The top of the Queenston Formation may be a reddish to maroon fissile shale or have a thin green shale displaying a sharp and disconformable contact with the overlying quartzose sandstones of the Whirlpool Formation. The top unit of the formation can be traced regionally from Core 173 to Core 1001 as a reddish brown or maroon to green, fissile shale. To the east, Unit 1 changes from shale to a thick, light grey to green dolomudstone facies (e.g., in Cores 999 and 1001).

WHIRLPOOL FORMATION

The Whirlpool–Queenston contact interval is best developed in Core 229, which is regarded as the reference core section for this contact. The Whirlpool Formation is characterized by a white or grey to tan, fine- to medium-sand–grade quartzose sandstone with dark and/or light grey shale interbeds and laminae. As noted by previous authors (e.g., Martini and Salas 1983), the Whirlpool Formation can be subdivided into an Upper and Lower unit, representing a shallow water nearshore

Table 18.1. Priority and secondary wells selected for subsurface stratigraphic study of Clinton and Medina groups under eastern and central Lake Erie and onshore in southwestern Ontario (see Figure 18.2 (blue dots) for generalized well locations). Priority reference (fencepost) cores are indicated in bold. Photographed cores have been logged and formation contacts compared to picks summarized in Form 7 records in the Oil, Gas and Salt Resources Library, London, Ontario.

	Licence No.	Name	Core No.	Photos?	Latitude (°N)	Longitude (°W)
Priority Cores	T002940	Shawnee UBR N.Walsingham 2-10-VII	103	Yes	42.689917	-80.560778
	T003011	CPOG Haldimand No.1, Lake Erie 131-G-4	146	Yes	42.471973	-79.969498
	T003723	Consumers' 32271, Wainfleet 2-2-III	173	Yes	42.924577	-79.292114
	T003853	Anschutz, Lake Erie 22-S-4	229	Yes	42.770766	-79.520797
	T002401	Consumers' Pan Am 13022, Lake Erie 155-Y-3	292	Yes	42.335377	-80.749466
	T003582	Consumers' 13217, Lake Erie 120-H-3	317	Yes	42.470922	-80.878161
	T003433	Consumers' 13164, Lake Erie 157-M-2	337	Yes	42.380302	-80.878113
	T003792	Anschutz, Lake Erie 92-N-3	371	Yes	42.537794	-80.312474
	T004008	Place Anschutz, Lake Erie 19-X-1	683	Yes	42.762577	-79.803898
	T004805	Anschutz #4, Lake Erie 162-T-4	694	Yes	42.353103	-81.253852
	T005582	Consumers' 13755, Lake Erie 220-W-4	766	Yes	42.174185	-81.371415
	T005858	Pembina #4, Lake Erie 67-F-4	774	Yes	42.636778	-79.904361
	T002523	Consumers' Pan Am 13036, Lake Erie 118-M-2	808	Yes	42.465602	-81.042642
	T002521	Consumers' Pan Am 13044, Lake Erie 123-R-2	809	Yes	42.437189	-80.633263
	T002721	Consumers' Pan Am 13062, Lake Erie 124-D-3	848	Yes	42.483383	-80.566509
	T006572	Pembina #2, Lake Erie 65-E-2	916	Yes	42.662697	-80.078964
	T002759	Consumers' Pan Am 13057, Lake Erie 56-E-3	999	Yes	42.65088	-80.913745
	T002803	Consumers' Amoco 13102, Lake Erie 96-D-1	1001	Yes	42.577272	-80.634566
	T007738	Pembina, Lake Erie 24-V-1	1012	Yes	42.763228	-79.353905
	T007753	Pembina, Lake Erie 39-Y-3	1013	Yes	42.669174	-79.580631
T008269	Pembina East, Lake Erie 26-S-1B	1039	Yes	42.78042	-79.1869	
T008155	Pembina, Lake Erie 72-O-1	1040	Yes	42.63237	-79.483887	
T002777	Consumers' Amoco 13100, Lake Erie 126-P-2	1064	Yes	42.449409	-80.41642	
Select Secondary Cores	T003834	Anschutz, Lake Erie 89-D-3	106	Yes	42.56838	-80.061757
	T003814	Anschutz Welland 7-Y, Lake Erie 7-Y-1	107	Yes	42.846169	-79.404242
	T003414	Consumers' 13153, Lake Erie 122-J-3	273	Yes	42.468895	-80.676011
	T003217	Consumers' 13089, Lake Erie 123-T-1	306	Yes	42.441889	-80.590103
	T003409	Consumers' 13148, Lake Erie 96-V-1	341	Yes	42.512008	-80.608841
	T003829	Consumers' 13291, Lake Erie 155-J-3	386	Yes	42.387148	-80.679604
	T003439	Consumers' 13170, Lake Erie 94-M-3	438	Yes	42.537895	-80.45919
	T003955	Anschutz, Lake Erie 6-R-4	656	Yes	42.854226	-79.287293
	T003957	Anschutz, Lake Erie 5-X-2	677	Yes	42.845836	-79.228746
	T003989	Anschutz, Lake Erie 8-V-1	679	Yes	42.845714	-79.437181
	T004792	Anschutz #3, Lake Erie 162-G-3	695	Yes	42.386795	-81.31257
	T005864	Pembina #3, Lake Erie 41-P-3	773	Yes	42.686767	-79.74629
	T002615	Consumers' Pan Am 13018, Lake Erie 183-N-4	802	Yes	42.283688	-81.054033
	T001436	M & M Lake Erie No.750-56, Lake Erie 44-S-1	831	Yes	42.694529	-79.938541
	T002564	Consumers' Pan Am 13035, Lake Erie 101-K-3	834	Yes	42.533992	-81.009307
	T002418	Consumers' Pan Am 13023, Lake Erie 156-C-1	836	Yes	42.408383	-80.79152
	T006794	Pembina #4, Lake Erie 62-T-4	914	Yes	42.604927	-80.256462
	T003274	Consumers' 13138, Lake Erie 158-H-1	977	Yes	42.393652	-80.957607
	T007602	Telesis 13922, Lake Erie 95-H-4	1011	Yes	42.55808	-80.539007
	T008266	Pembina East, Lake Erie 26-M-1A	1037	Yes	42.794753	-79.204095
T008286	Pembina East, Lake Erie 39-T-2	1038	Yes	42.696169	-79.512053	
T008113	Pembina, Lake Erie 21-X-2	1041	Yes	42.759555	-79.647645	
T008122	Pembina, Lake Erie 71-I-3	1043	Yes	42.640506	-79.53019	
T008522	Pembina Central, Lake Erie 184-I-2	1062	Yes	42.313939	-80.947083	

marine environment and a braided fluvial environment, respectively. Core 371 (from 465.12 m to 469.09 m) best displays these facies relationships. The most distinguishing factor identifying the Whirlpool–Queenston contact is the colour change from the red or grey or green shale of the Queenston Formation to the white sandstone of the Whirlpool Formation. In Core 229, the marked shift in gamma-ray response reflects these changes in lithofacies, showcasing a transition downward from white, fine- to medium-sand–grade quartzose sandstone to shale-rich lithofacies of the Queenston Formation. Although the Whirlpool Formation typically overlies the Queenston Formation in the study area, there are locations in southwestern Ontario where the Manitoulin Formation disconformably overlies the Queenston Formation. The Whirlpool Formation can be traced laterally over much of the study area. A thin sandy remnant persists into central Lake Erie and pinches out on the northwestern margin of the study area.

MANITOULIN FORMATION

The Manitoulin Formation lower contact interval is best developed in Core 1001. Gamma-ray logs are useful to delineate the contact in surrounding wells. Core 1001 is regarded as the reference core section for this contact. The Manitoulin Formation is a dolomitic carbonate unit, with minor grey or green shale beds that grade into overlying Cabot Head formational rock units. In the literature, the contact with the underlying Whirlpool Formation has been described as gradational when both units are present, consequently the need for the geophysical logs in order to delineate the contact. In Core 371, there is a sharp, erosive lower Manitoulin contact with the Whirlpool sandstone at 467.26 m depth. In Core 1001, the Manitoulin Formation contact with the Whirlpool Formation is gradational, displaying a colour change from reddish brown to light and dark grey and a lithofacies change from interbedded shale and sandstone to mottled dolostone at a depth of 463.90 m. A bioturbated sandy shale unit at this contact may be the last remnants of the Whirlpool Formation.

CABOT HEAD FORMATION

The Cabot Head Formation lower contact interval is best developed in Cores 1001 and 999. The formation can be traced laterally and regionally from Lake Erie to the Bruce Peninsula and Manitoulin Island. The typical definition of the Cabot Head Formation in Lake Erie is expressed differently than where the Cabot Head is exposed on the Bruce Peninsula and Manitoulin Island. Consequently, the description and definition of the Cabot Head in this study area will need to be modified to include the presence of formational units, such as the Devils Hole, Power Glen, and the Artpark phosphate bed, present in the eastern portion of the study area. Examples of these equivalent formations can be seen in Core 173, among others in that area. There are many depositional cycles within the Cabot Head Formation. Lithofacies vary from dark grey to green to tan to reddish maroon shale beds interbedded with fossiliferous packstone and/or grainstone carbonate beds and sandstone, the latter of which are predominantly grey to reddish maroon. These beds can be traced laterally throughout the study area. It is challenging to pick a formational top when using only drill cuttings and gamma-ray logs because the sandstone, siltstone, carbonate beds and interbedded shales were observed to recur for many metres in some of the cored holes.

GRIMSBY FORMATION

The Grimsby Formation upper contact is best developed in Core 173, which is regarded as the reference core section for this formation. The formation consists of red, grey–white, and green, fine- to medium-sand–grade sandstones that are interbedded with silt and shale partings. The contact from Grimsby to Thorold formation lithofacies is difficult to pick because of the similarities between the 2 formations, and although colour change is used as a defining feature, it cannot be solely used. In Core 173, a vertical change is observed from pale gray-green sandstones of the overlying Thorold Formation to

interbedded gray and maroon shales and sandstones of the underlying Grimsby Formation. In other fencepost (priority reference) cores, the Grimsby Formation contact displays massive reddish-brown, fine- to medium-sand-grade sandstone with very little shale present, but with portions of the sandstone white in irregular blotches. This contact is difficult to pick regionally because of the extreme variability of the lithofacies, including colour change.

THOROLD FORMATION

The Thorold Formation lower contact interval is best developed in Core 173. This formation is characterized by grey to green to white, fine- to medium-sand-grade, massive quartz sandstone beds with silty to shale partings and laminae. In other areas, the Thorold Formation can be confused with the Grimsby Formation because of their similar colours and siliciclastic characteristics. The boundary between the Thorold Formation and the overlying Clinton Group (*see* Figure 18.1) units is complex, as any of 4 different units, such as the Neagha, Rockway, Merritton and Reynales formations, could be present at the contact. In Core 173, the transition from shale to white, massive, fine-sand-grade quartz sandstone is evident at 187.76 m depth. Core 229 displays a sharp contact between the dark grey Neagha Formation shales and pale green-grey Thorold Formation sandstones at 289.50 m depth. Farther west an uppermost boundary between the Thorold and a potential Rockway and/or Merritton formational interval can also be characterized by the presence of fossils, such as pentamerid brachiopod shells and black chert nodules, along with a colour change from a grey-green-white shale and sandstone unit to a white-tan-grey-pinkish dolomitic unit and represents a disconformity.

ACKNOWLEDGMENTS

This study forms part of an MSc thesis by the senior author at The University of Western Ontario and is supported by several agencies: the Ontario Geological Survey (OGS); a Natural Sciences and Engineering Research Council (NSERC) grant to Dr. Jisuo Jin at The University of Western Ontario, London, Ontario; the Ontario Petroleum Institute (OPI); and the Oil, Gas and Salt Resources Library in London, Ontario, through the Mitacs Accelerate Program at The University of Western Ontario. This article fulfills part of the requirements for the Mitacs Accelerate Program. The authors thank Jordan Clark (Manager of Oil, Gas and Salt Resources Library) for co-ordinating access to the library, digital records, and core handling and photography.

REFERENCES

- Armstrong, D.K. and Carter, T.R. 2006. An updated guide to the subsurface Paleozoic stratigraphy of southern Ontario; Ontario Geological Survey, Open File Report 6191, 214p.
- 2010. The subsurface Paleozoic stratigraphy of southern Ontario; Ontario Geological Survey, Special Volume 7, 301p.
- Beards, R.J. 1967. Guide to the subsurface Palaeozoic stratigraphy of southern Ontario; Ontario Department of Energy Resources Management, Paper 67-2, 19p.
- Bolton, T.E. 1953. Silurian formations of the Niagara Escarpment in Ontario; Geological Survey of Canada, Paper 53-23, 19p.
- 1957. Silurian stratigraphy and paleontology of the Niagara Escarpment in Ontario; Geological Survey of Canada, Memoir 289, 145p.

- 1965. Pre-Guelph, Silurian formations of the Niagara Peninsula, Ontario; *in* Geology of Central Ontario, Michigan Basin Geological Society, Field Trip Guidebook, p.55-80.
- Brett, C.E., Brunton, F.R. and Calkin, P.E. 2018. Sequence stratigraphy and paleontology of the classic Upper Ordovician–Silurian succession in Niagara County, New York – with supplement on Quaternary geology of western New York; Association of Earth Science Editors, 52nd Annual Meeting, September 26–29, 2018, Niagara Falls, New York, Field Trip Guidebook, 191p.
- Brett, C.E., Goodman, W.M. and LoDuca, S.T. 1990. Sequences, cycles, and basin dynamics in the Silurian of the Appalachian Foreland Basin; *Sedimentary Geology*, v.69, p.191-244.
- Brett, C.E., Tepper, D.H., Goodman, W., LoDuca, S.T. and Eckert, B.-Y. 1995. Revised stratigraphy and correlations of the Niagaran Provincial Series (Medina, Clinton and Lockport groups) in the type area of western New York; United States Geological Survey, Bulletin 2086, 66p.
- Brunton, F.R. and Brintnell, C. 2020. Early Silurian sequence stratigraphy and geological controls on karstic bedrock groundwater flow zones, Niagara Escarpment region and the subsurface of southwestern Ontario; Ontario Geological Survey, Groundwater Resources Study 13.
- Brunton, F.R., Brintnell, C., Jin, J. and Bancroft, A.M. 2012. Stratigraphic architecture of the Lockport Group in Ontario and Michigan – A new interpretation of Early Silurian “basin geometries” and “Guelph pinnacle reefs”; *in* Proceedings, Ontario Petroleum Institute, 51st Annual Conference, Niagara Falls, Ontario, v.51, Technical Paper 8, p.1-37.
- Brunton, F.R., Carter, T., Logan, C., Clark, J., Yeung, K., Fortner, L., Freckelton, C., Sutherland, L. and Russell, H.A.J. 2017. Lithostratigraphic compilation of Phanerozoic bedrock units and 3D geological model of southern Ontario; abstract *in* Regional-scale Groundwater Geoscience in Southern Ontario: An Ontario Geological Survey, Geological Survey of Canada, and Conservation Ontario Geoscientists Open House, Guelph, Ontario, March 1–2, 2017, Geological Survey of Canada, Open File 8212, p.3. doi:10.4095/299759
- Cheel, R.J. ed. 1991. Sedimentology and depositional environments of Silurian strata of the Niagara Escarpment, Ontario and New York; Geological Association of Canada–Mineralogical Association of Canada–Society of Economic Geologists, Joint Annual Meeting, Toronto 1991, Field Trip B4 Guidebook, 99p.
- Cramer, B.D., Brett, C.E., Melchin, M.J., Männik, P., Kleffner, M.A., McLaughlin, P.I., Loydell, D.K., Munnecke, A., Jeppsson, L., Corradini, C., Brunton, F.R. and Saltzman, M.R. 2011. Revised correlation of Silurian Provincial Series of North America with global and regional chronostratigraphic units and $\delta^{13}\text{C}_{\text{carb}}$ chemostratigraphy; *Lethaia*, v.44, p.185-202.
- Duke, W.L. and Brusse, W.C. 1987. Cyclicity and channels in the upper members of the Medina Formation in the Niagara Gorge; *in* Sedimentology, Stratigraphy and Ichnology of the Lower Silurian Medina Formation in New York and Ontario, Eastern Section of the Society of Economic Paleontologists and Mineralogists, Guidebook for the 1987 Annual Field Trip, p.46-65.
- Ettensohn, F.R. 2008. The Appalachian foreland basin in eastern United States; Chapter 4 *in* The sedimentary basins of the United States and Canada, Elsevier, Amsterdam, *Sedimentary Basins of the World*, v.5, p.105-179.
- Ettensohn, F.R. and Brett, C.E. 2002. Stratigraphic evidence from the Appalachian Basin for continuation of the Taconian orogeny into Early Silurian time; *Physics and Chemistry of the Earth*, v.27, p.279-288.
- Ettensohn, F.R., Hohman, J.C., Kulp, M.A. and Rast, N. 2002. Evidence and implications of possible far-field responses to Taconian Orogeny: Middle–Late Ordovician Lexington Platform and Sebree Trough, east-central United States; *Southeastern Geology*, v.41, p.1-36.
- Haynes, S.J. 2000. Geology and Wine 2. A geological foundation for terroirs and potential sub-appellations of Niagara Peninsula wines, Ontario, Canada; *Geoscience Canada*, v.27, p.67-87.

- Jin, J., Harper, D.A.T., Cocks, R.M., McCausland, P.J.A., Rasmussen, C.M.O. and Sheehan, P.M. 2013. Precisely locating the Ordovician equator in Laurentia; *Geology*, v.41, p.107-110.
- Jin, J., Zhan, R. and Wu, R. 2018. Equatorial cold-water tongue in the Late Ordovician; *Geology*, v.46, p.759-762.
- 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.
- Martini, I.P. 1971. Regional analysis of sedimentology of Medina Formation (Silurian), Ontario and New York; *American Association of Petroleum Geologists Bulletin*, v.55, p.1249-1261.
- 1974a. Deltaic and shallow marine Lower Silurian sediments of the Niagara Escarpment between Hamilton, Ont. and Rochester, N.Y. – A field guide; *Maritime Sediments*, v.10, no.2, p.52-66.
- 1974b. Environments of deposition of the Medina (Grimsby) Formation, and exploration for hydrocarbons; *in* *Proceedings, Ontario Petroleum Institute, 13th Annual Conference*, London, Ontario, v.13, Technical Paper 7, 18p.
- Martini, I.P. and Kwong, J.K.P. 1985. Depositional characteristics and resources potential of the Whirlpool Sandstone, Lower Silurian, Ontario; Ontario Geological Survey, Open File Report 5549, 69p.
- Martini, I.P. and Salas, C. 1983. Depositional characteristics of the Whirlpool Sandstone, Lower Silurian, Ontario; Ontario Geological Survey, Open File Report 5363, 124p.
- Paterson, R.H., Brunton, F.R., Jin, J., Phillips, A.R., Yeung, K.H. 2020. Subsurface correlation of the Silurian Clinton and Medina groups, southwestern Ontario; *in* *Summary of Field Work and Other Activities, 2020*, Ontario Geological Survey, Open File Report 6370, p.15-1 to 15-9.
- Rickard, L.V. 1975. Correlation of the Silurian and Devonian rocks in New York State; *New York State Museum and Science Service, Map and Chart Series no.24*, 16p.
- Sanford, B.V. 1969. Silurian of southwestern Ontario; *in* *Proceedings, Ontario Petroleum Institute, 8th Annual Conference*, Toronto, Ontario, v.8, Technical Paper 5, 44p.
- Schröer, L., Vandenbroucke, T.R.A., Hints, O., Steeman, T., Verniers, J., Brett, C.E., Cramer, B.D. and McLaughlin, P.I. 2016. A Late Ordovician age for the Whirlpool and Power Glen formations, New York; *Canadian Journal of Earth Sciences*, v.53, p.739-747.
- Telford, P.G. 1978. Silurian stratigraphy of the Niagara Escarpment, Niagara Falls to the Bruce Peninsula; *in* *Toronto '78 Field Trips Guidebook*, Geological Society of America–Geological Association of Canada–Mineralogical Association of Canada, Joint Annual Meeting, p.28-42.
- Williams, M.Y. 1919. The Silurian geology and faunas of Ontario Peninsula, and Manitoulin and adjacent islands; *Geological Survey of Canada, Memoir 111*, 195p.
- Winder, G.C. 1961. *Lexicon of Paleozoic names in southwestern Ontario*; University of Toronto Press, Toronto, Ontario, 121p.

19. Project Unit 07-025. Ambient Groundwater Geochemical Database Compilations for Ontario, 2021–2022: Summary of Available Data and Forthcoming Publications



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INTRODUCTION

The Ambient Groundwater Geochemistry Project is an ongoing project of groundwater collection and analysis carried out by the Ontario Geological Survey (OGS), the purpose of which is to characterize groundwater chemistry in accessible areas of the province. The project began in 2007 and field work has been carried out in every subsequent year except 2020 and 2021. In addition to primary data collection to support groundwater geochemical mapping, there have been numerous add-on and related studies, which involved additional sample collection using similar field protocols. These studies were of 3 types: 1) academic theses, 2) collaborations with other agencies and 3) regional aquifer mapping studies that also used outcomes from the OGS three-dimensional Quaternary aquifer mapping studies. Most of the add-on work was following-up on particular themes or phenomena that were discovered as part of the primary mapping phases of the project (Figure 14.1), which ended in 2014 in southern Ontario (Hamilton 2015), and in 2018 in northeastern Ontario (Dell and Francis 2018).

The purpose of this article is to describe the information that will be made available in 2 forthcoming data publications: 1) Miscellaneous Release—Data 283 – Revision 2 (Hamilton, in press), a revision and update of Hamilton (2015) and 2) a completely new publication that comprises results from 2016, 2017 and 2018 field seasons in northeastern Ontario.

OBJECTIVES

The objectives of the Ambient Groundwater Geochemistry Project are described in Hamilton, Brauneder and Mellor (2007) and Hamilton and Brauneder (2008), and are to

- characterize baseline groundwater geochemistry of the major rock and overburden units in southern Ontario (subject to accessibility),
- relate water chemistry to aquifer chemistry, and
- support the determination of groundwater flow and aquifer conditions.

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.19-1 to 19-9.*

CONTRIBUTING STUDIES

The Ambient Groundwater Geochemistry Project has so far had 11 field seasons of sample collection as part of its primary geochemical mapping function (*see* Figure 14.1). The various projects and important milestones were as follows:

- Hamilton, Brauner and Mellor 2007. London area (Project Unit 07-25¹)
- Hamilton and Brauner 2008. Grand Bend and Lake Huron region
- Hamilton and Freckelton 2009. Grey and Bruce counties and area
- Hamilton, Freckelton and Mariotti 2010. Niagara Peninsula and Guelph areas
- Hamilton 2011. Publication of MRD 283, *Ambient Groundwater Geochemistry Data for Southwestern Ontario, 2007–2010*

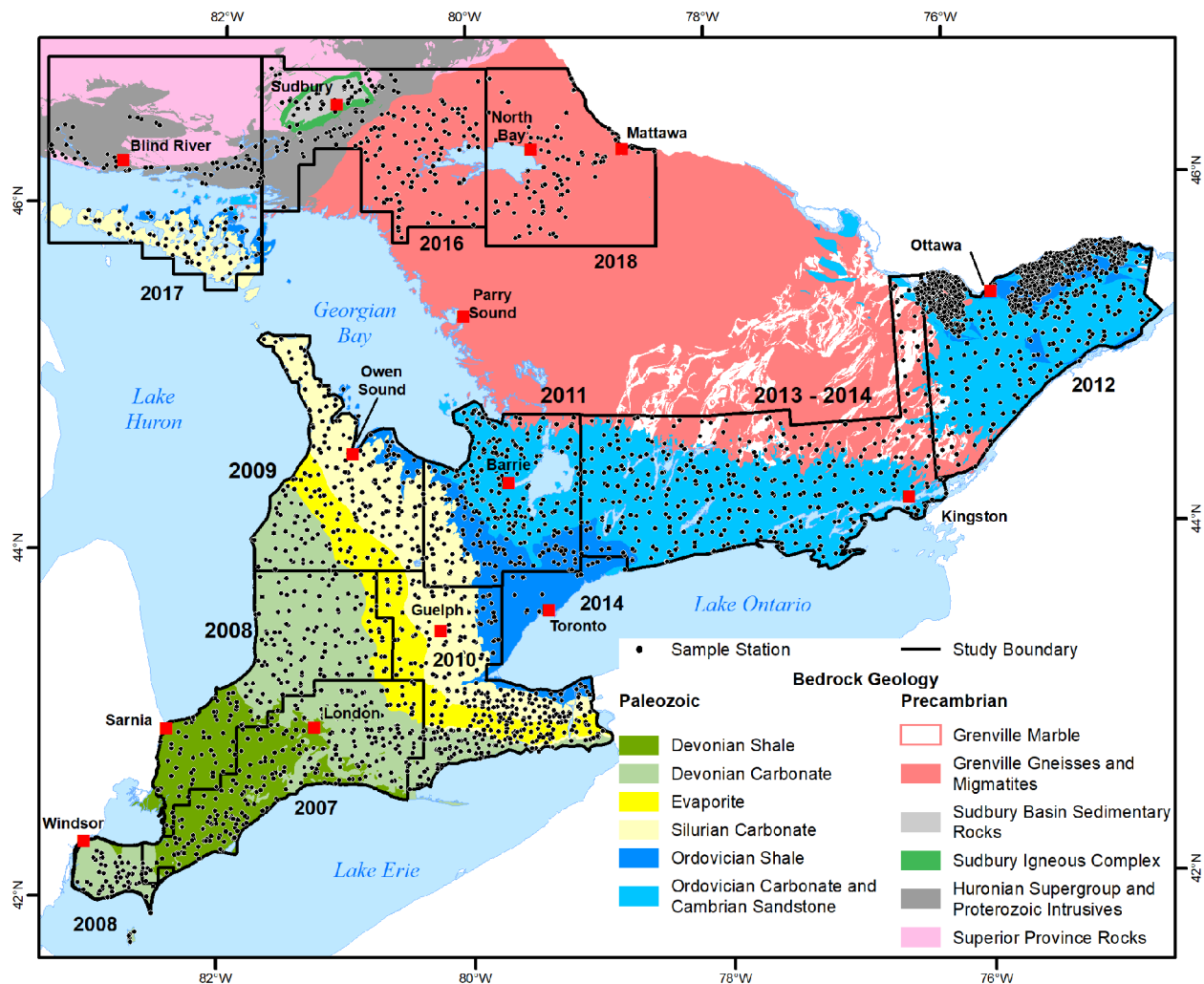


Figure 14.1. Primary geochemical mapping phases of the Ambient Groundwater Geochemistry Project, by year. The southern group will be published as MRD 283—Revision 2 (Hamilton, in press); the northern group of project areas will be published as a new, separate publication for northeastern Ontario.

¹ Note: These “Project Unit” or “Project” numbers are used for OGS internal tracking purposes only, but previous publications may have included reference to these numbers.

- Hamilton et al. 2011. Aurora and Orillia area
- Freckelton and Hamilton 2012. Ottawa and St. Lawrence Rivers area
- Freckelton and Hamilton 2013. Kingston and Peterborough area
- 2014 Pan-southern Ontario gap filling and wrap-up of southern Ontario
- Hamilton 2015. Publication of MRD 283—Revised, *Ambient Groundwater Geochemistry Data for Southern Ontario, 2007–2014*
- Dell, Fudge and Hamilton 2016. Sudbury area (Project NE-16-001)
- Dell, Francis and Hamilton 2017. Manitoulin Island and North Shore areas (Project NE-17-004)
- Dell and Francis 2018. North Bay area (Project NE-18-004)

The 3 studies since 2016 provide the entirety of the data for a new forthcoming publication of the northeastern Ontario Ambient Groundwater Geochemistry database (K.M. Dell, personal communication, September 30, 2021). Prior to the publication of that data, a revision to the southern Ontario component of the Ambient Groundwater Geochemistry database (MRD 283—Revised: Hamilton 2015) will be published (Hamilton, in press); this will be the second revision since the original publication of the data in 2011

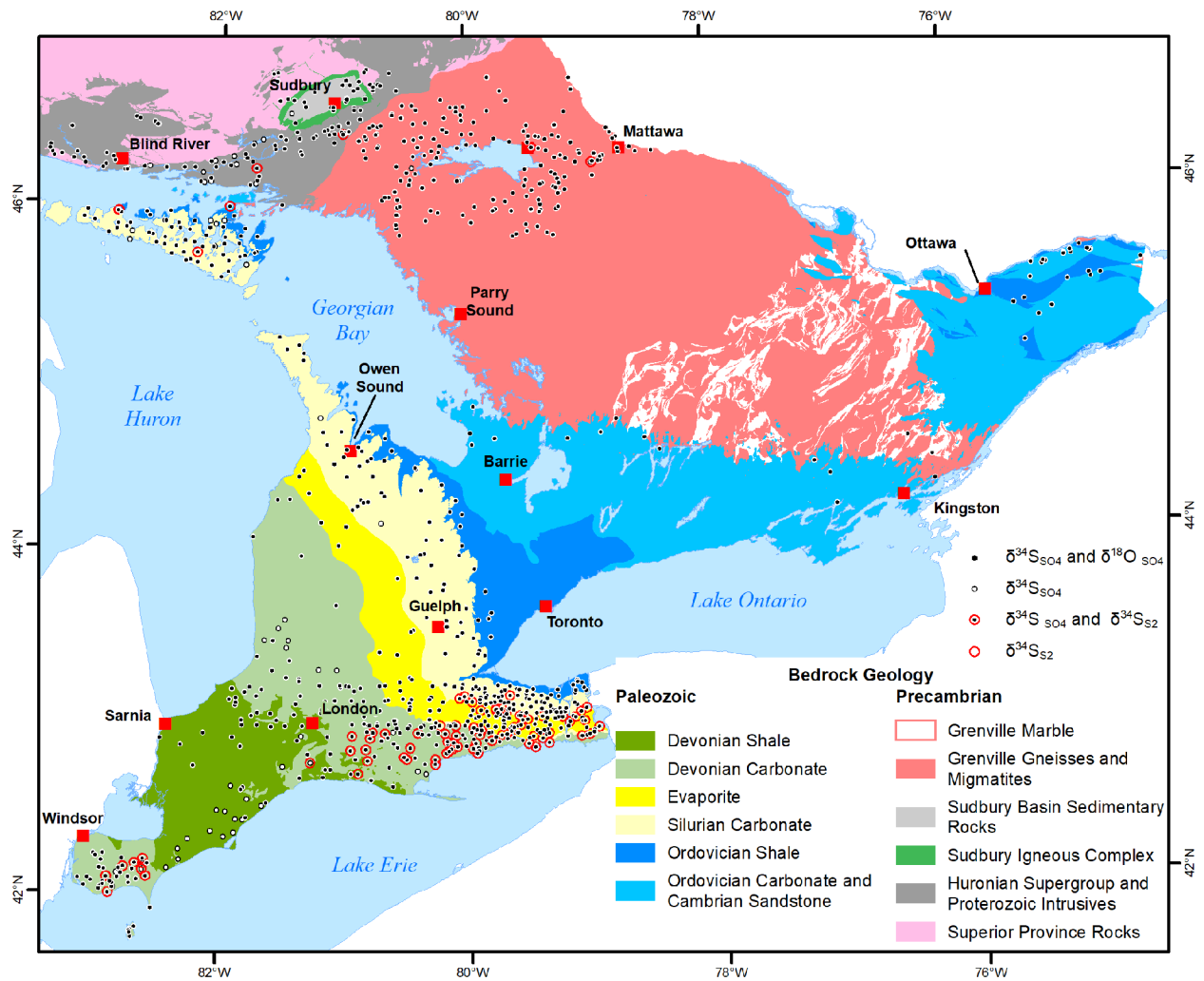


Figure 14.2. Station locations for sulphur isotopic data gathered as part of various add-on projects or from re-analysis of archived samples.

(as MRD 283). The data for the second revision originated from a number of collaborative add-on projects, including graduate theses and an OGS multi-disciplinary study (Priebe et al. 2018; Priebe et al. 2019). The other studies comprise the following:

- Mellor 2008. Bedrock lithologies effect on bulk groundwater chemistry in southwestern Ontario (thesis)
- Freckelton, Hamilton and Longstaffe 2010 (and Freckelton 2013). Breathing well zone of southwestern Ontario (Project Unit 10-027)
- Morton et al. 2013 (and Morton 2015). Development of an aquifer mapping tool, City of Clarence–Rockland (Project Unit 13-027)
- McIntosh et al. 2014 (and Hamilton et al. 2015). Controls on methane occurrences in shallow aquifers in southwestern Ontario
- Di Iorio, Lemieux and Hamilton 2015. Township of Alfred and Plantagenet groundwater study (Project Unit 15-016)
- McEwan et al. 2015 (and Smal 2017). Highly mineralized groundwater on the Niagara Peninsula (Project Unit 15-017)

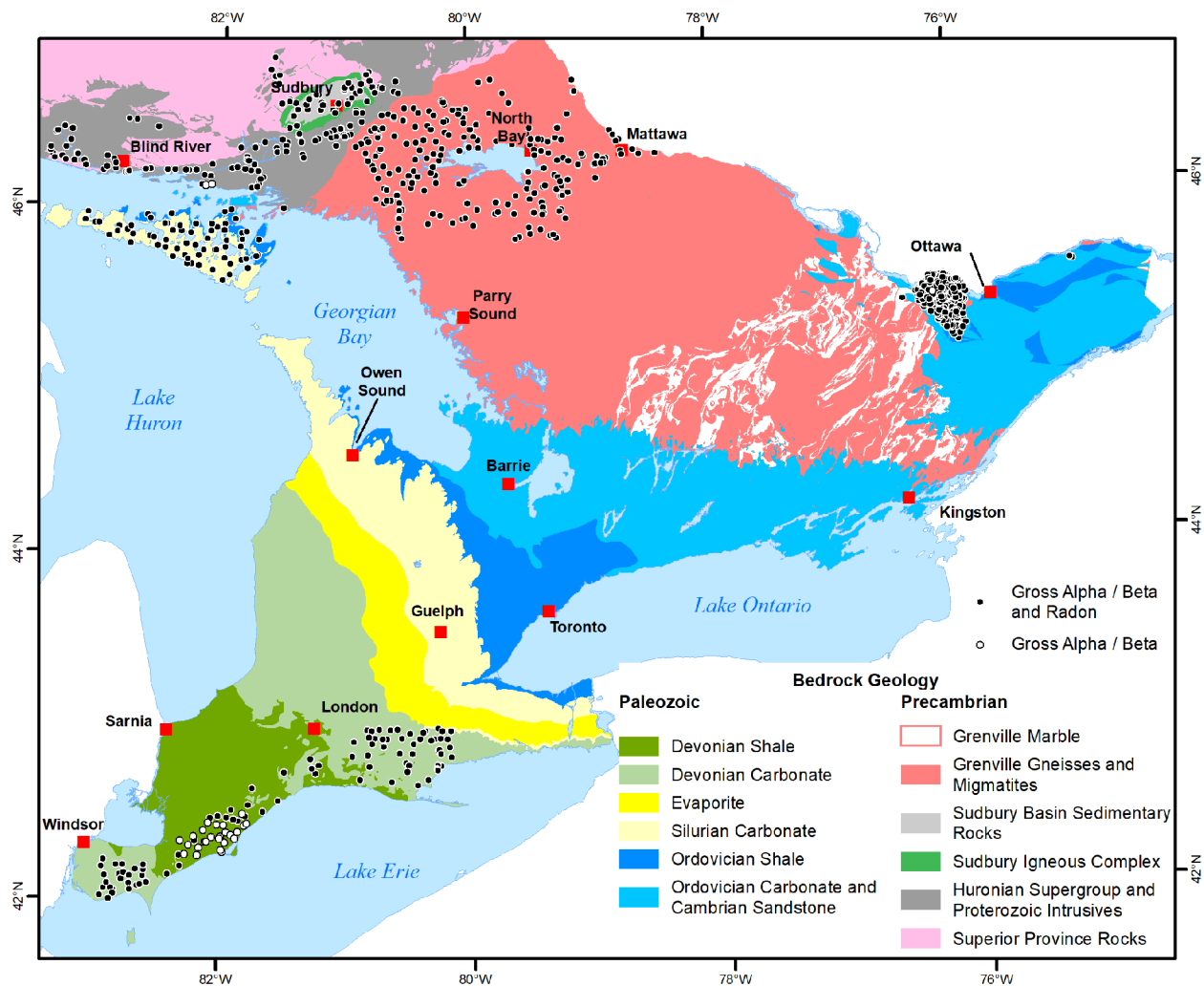


Figure 14.3. Station locations for radionuclide parameters analyzed as part of various add-on projects.

- Lemieux et al. 2016 (and Lemieux, Clark and Hamilton 2017, 2019; Lemieux 2018; Lemieux, Hamilton and Clark 2019). Methane and halogens in groundwater in southeastern Ontario
- Rogerson et al. 2016 (and Rogerson 2018). Groundwater as a source of high iodine levels in milk from dairy herds in eastern Ontario
- Di Iorio et al. 2017. East Ottawa–Champlain Township groundwater study (Project SO-17-004)
- Matheson, Hamilton and Kyser 2018 (and Matheson 2011). Groundwater salinization on the Niagara Peninsula
- Priebe 2019. Mapping groundwater systems in karstic carbonate bedrock
- Di Iorio et al. 2019. West Ottawa groundwater study (Project SO-19-004)

DATA SETS IN FORTHCOMING PUBLICATIONS

The format and almost all of the data fields will be the same in both the new northeastern Ontario publication (Dell, in preparation) and in MRD 283—Revision 2 (Hamilton, in press). However, there are new fields in both these databases that were not present in the earlier versions of the MRD.

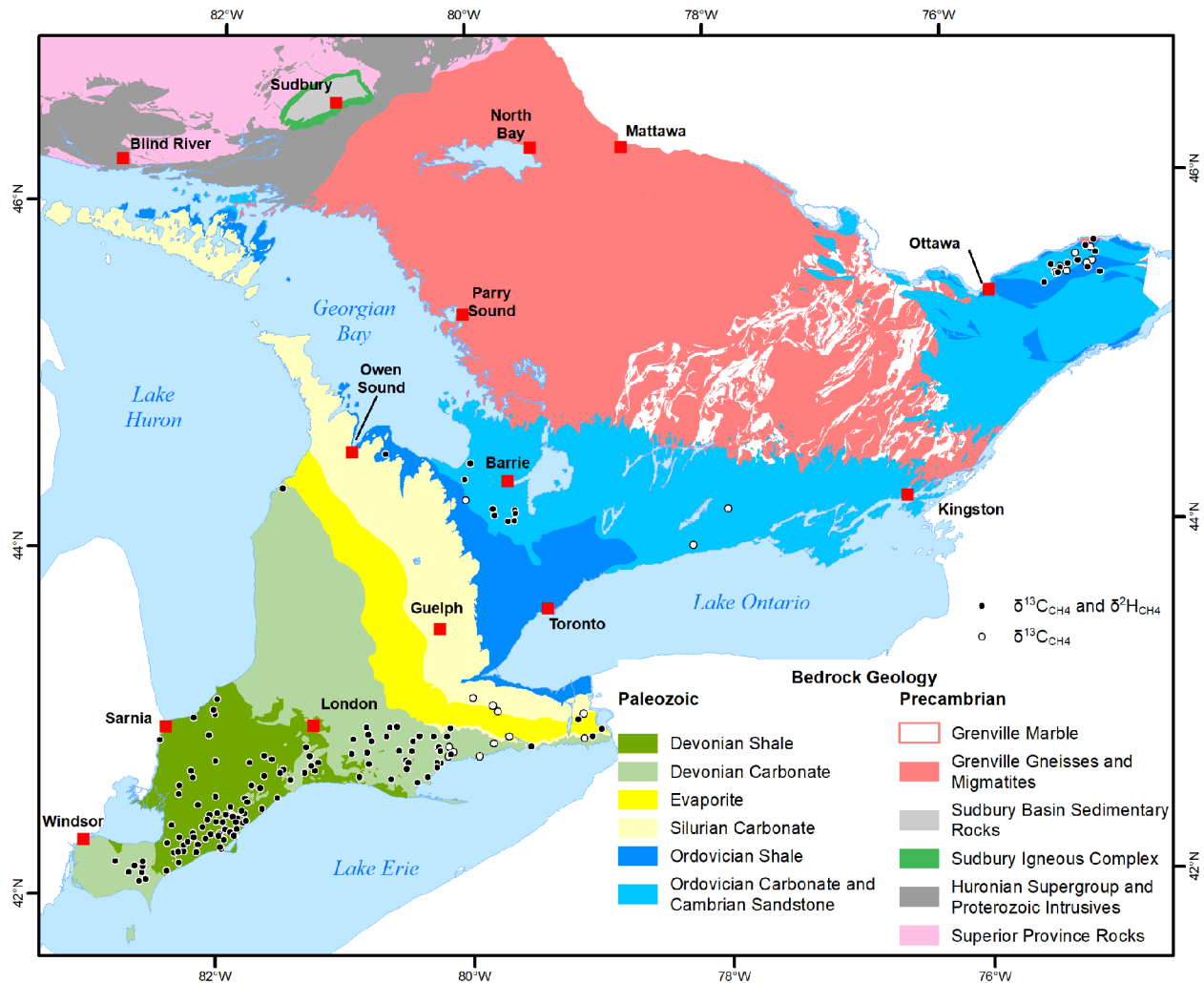


Figure 14.4. Station locations for isotopic analysis of dissolved or vapour-phase methane in groundwater and related parameters analyzed as part of various add-on projects.

The routine analytical determinations of the Ambient Groundwater Geochemistry Project have been described elsewhere (Hamilton, Brauner and Mellor 2007; Hamilton and Brauner 2008; Hamilton 2015). They include comprehensive inorganic analysis of major ions, trace elements, dissolved gases (oxygen, hydrogen sulphide, methane and carbon dioxide), field parameters (pH, temperature, redox, etc.), nitrogen parameters, various aggregate parameters, including dissolved organic and inorganic carbon and the isotopes of water ($\delta^{18}\text{O}$, deuterium and tritium). The new analyses, shortly to be published in Hamilton (in press) and Dell (in preparation), comprise specialty isotopes of dissolved constituents of groundwater, usually for detailed study of their provenience. The new parameters include the isotopes of sulphate and sulphide – $\delta^{34}\text{S}_{(\text{SO}_4)}$, $\delta^{18}\text{O}_{(\text{SO}_4)}$, $\delta^{34}\text{S}_{(\text{S}_2)}$ (Figure 14.2); bulk radionuclides – gross alpha decay, gross beta decay and dissolved radon (Figure 14.3); the isotopes of methane – $\delta^{13}\text{C}_{(\text{CH}_4)}$, $\delta^2\text{H}_{(\text{CH}_4)}$ (Figure 14.4); and related carbon species $\delta^{13}\text{C}_{(\text{DIC})}$ and $\delta^{13}\text{C}_{(\text{DOC})}$ (Figure 14.5), and $\delta^{13}\text{C}_{(\text{CO}_2)}$. In addition to new analyses, the impending data releases will include modelled parameters, such as saturation indices for common minerals and E_H values determined using the most reactive redox couple.

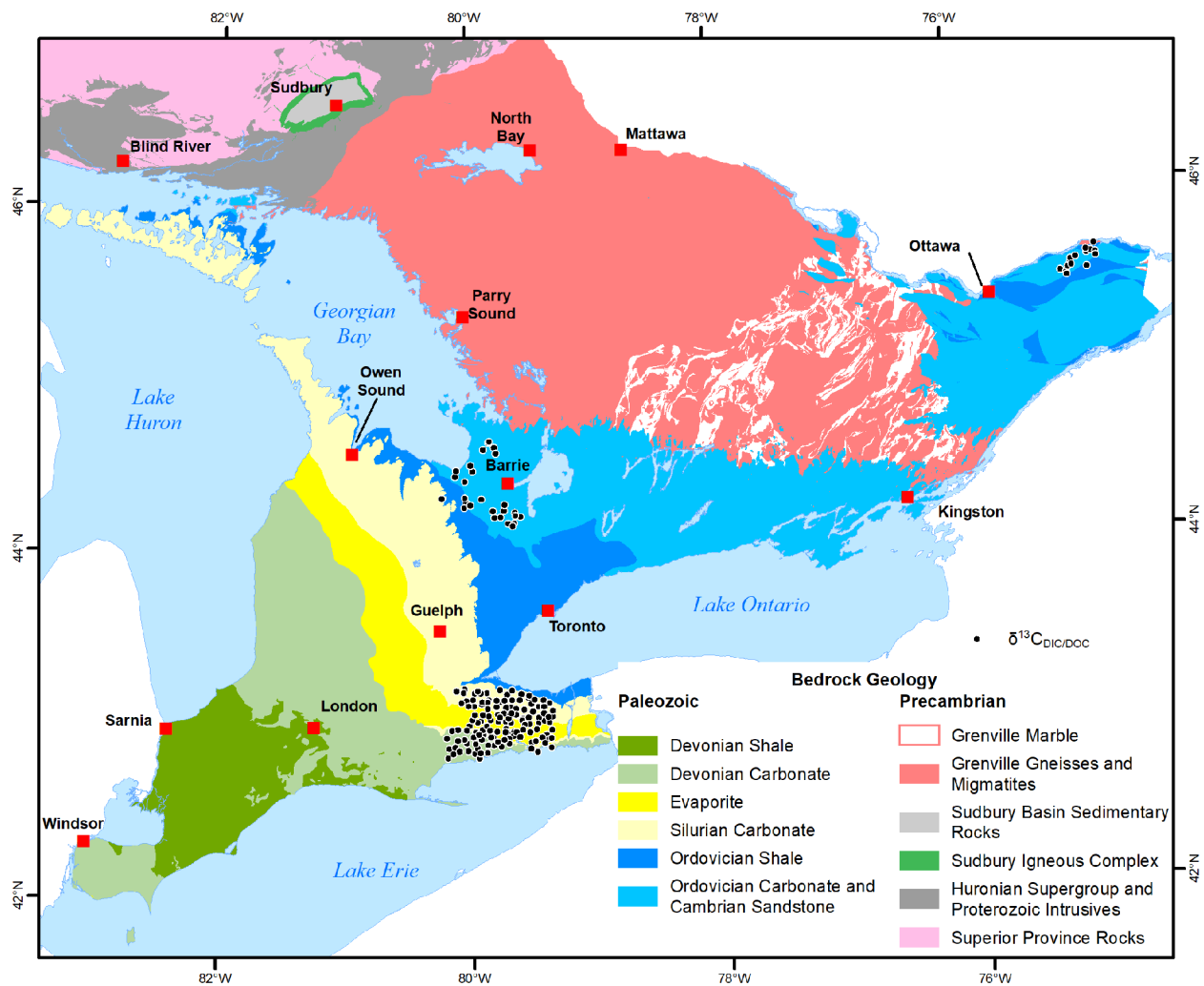


Figure 14.5. Station locations for isotopic analysis of inorganic and dissolved organic carbon dissolved in groundwater and related parameters analyzed as part of various add-on projects.

The results for these related analyses will be presented alongside the routine Ambient Groundwater Geochemistry Project analytical determinations, which will provide informed users with the information needed to assess the origin, timing and other important factors related to dissolved constituents and the water itself. It is our hope that these public-facing data will be used by consultants, academia and the public for years to come.

ACKNOWLEDGMENTS

The field work and data processing on this project involved hard work by many students over the years: Kerstin Brauner, Kathryn Mellor, Alice LeMaux, Candace Freckelton, Ryan Mariotti, Kevin Little, Alyne Lalonde, April Bertrand, Hanna Burke, Joinal Abedin, Edward Matheson, Victoria Lee, Kaya Zoratto, Ashley Landriault, Marc Patenaude, Calla Carbone, Rachel Chouinard, Laura Colgrove, Cedric Mayer, Meagan Francis, Harrison Cortis, Jeremy Dalton, Caitlin Smal, Luke Steer, Stephanie Fudge, Neal McClenaghan, Alex Abbey, Jason Dyer, Shayna Dzilums, Alex Lemieux, Sophie Michel, David O'Reilly, Emily Leblanc, Nitasha Dhillon, Shane Foubister, Andrew Hicks, Arielle Dufresne, Kevin Ho, Amy Cartier and Danielle Brown.

As discussed above, the entirety of the new data in the second revision of MRD 283 (Hamilton, in press) came from add-on projects, and these all involved collaboration with other agencies and groups. Funding from these groups variously supported field work or laboratory analysis or both. Collaborating agencies included the City of Ottawa, South Nation Conservation Authority, Niagara Peninsula Conservation Authority, University of Ottawa, McMaster University, the University of Western Ontario, Queen's University, Guelph University, the University of Waterloo and the Ministry of Natural Resources and Forestry (in its previous capacity). The theses that reported data included in the forthcoming publication (Hamilton, in press) include those by Candace Freckelton, Edward Matheson, Sam Morton, Caitlin Smal, Alex Lemieux, Courtney Rogerson and Elizabeth Priebe.

REFERENCES

- 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 Program: 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 Program: Sudbury area; *in* Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p.32-1 to 32-11.
- Di Iorio, T., Harrison, R.A., Al, T., Majury, A. and Hamilton, S.M. 2019. West Ottawa groundwater study; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.23-1 to 23-9.
- Di Iorio, T., Lemieux, A.J. and Hamilton, S.M. 2015. Township of Alfred and Plantagenet groundwater study; *in* Summary of Field Work and Other Activities 2015, Ontario Geological Survey, Open File Report 6313, p.38-1 to 38-6.
- Di Iorio, T., Melaney, M., Foubister, S. and Hamilton, S.M. 2017. East Ottawa–Champlain Township groundwater study; *in* Summary of Field Work and Other Activities, 2017, Ontario Geological Survey, Open File Report 6333, p.27-1 to 27-8.

- 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, 258p., also available Electronic Thesis and Dissertation Repository, Paper 1105.
- Freckelton, C.N. and Hamilton, S.M. 2012. Ambient Groundwater Geochemistry Project of the Ottawa–St. Lawrence River area; *in* Summary of Field Work and Other Activities, 2012, Ontario Geological Survey, Open File Report 6280, p.37-1 to 37-7.
- 2013. Ambient Groundwater and Geochemistry Project of the Kingston–Peterborough area; *in* Summary of Field Work and Other Activities, 2013, Ontario Geological Survey, Open File Report 6290, p.39-1 to 39-5.
- Freckelton, C.N., Hamilton, S.M. and Longstaffe, F.J. 2010. A 1000 km² region of breathing wells, north of London, Ontario; *in* Summary of Field Work and Other Activities, 2010, Ontario Geological Survey, Open File Report 6260, p.35.1-35.11.
- Hamilton, S.M. 2011. Ambient groundwater geochemistry data for southwestern Ontario, 2007–2010; Ontario Geological Survey, Miscellaneous Release—Data 283.
- 2015. Ambient groundwater geochemistry data for southern Ontario, 2007–2014; Ontario Geological Survey, Miscellaneous Release—Data 283 – Revised.
- *in press*. 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.20-1 to 20-9.
- Hamilton, S.M. and Freckelton, C.N. 2009. Ambient Groundwater Project: Grey–Bruce counties and area, 2009; *in* Summary of Field Work and Other Activities 2009, Ontario Geological Survey, Open File Report 6226, p.27-1 to 27-9.
- Hamilton, S.M., Freckelton, C.N. and Mariotti, R. 2010. The Ambient Groundwater Geochemistry Program: Completion of sampling of southwestern Ontario; *in* Summary of Field Work and Other Activities, 2010, Ontario Geological Survey, Open File Report 6260, p.34-1 to 34-4.
- Hamilton, S.M., Grasby, S.E., McIntosh, J.C. and Osborn, S.G. 2015. The effect of long-term regional pumping on hydrochemistry and dissolved gas content in an undeveloped shale-gas-bearing aquifer in southwestern Ontario, Canada; *Hydrogeology Journal*, v.23, p.719-739.
- Hamilton, S.M., Matheson, E.J., Freckelton, C.N. and Burke, H.E. 2011. Ambient Groundwater Geochemistry Program: The 2011 Aurora–Orillia study area and selected results for the Bruce and Niagara peninsulas; *in* Summary of Field Work and Other Activities, 2011, Ontario Geological Survey, Open File Report 6270, p.32-1 to 32-11.
- Lemieux, A.[J.] 2018. The provenance of, and relationship between, methane and iodine in groundwater in eastern Ontario; unpublished MSc thesis, University of Ottawa, Ottawa, Ontario, 102p.
- Lemieux, A.J., Clark, I.D., and Hamilton, S.M. 2017. Provenance of methane and iodine in an eastern Ontario aquifer; *in* GeoOttawa 2017, 70th Canadian Geotechnical Conference and the 12th Joint Canadian Geotechnical Society – International Association of Hydrogeologists–Canadian National Chapter Groundwater Conference, Ottawa, October 1–4, Conference Proceedings, Paper No.355, 8p.
- 2019. The origin of methane in an eastern Ontario aquifer; *Nuclear Instruments and Methods in Physics Research Section B: Beam Interactions with Materials and Atoms*, v.455, p.213-223.
doi.org/10.1016/j.nimb.2019.01.012

- Lemieux, A.J., Clark, I.D., Hamilton, S.M., Rogerson, C.M. and Kelton, D.F. 2016. The provenance of, and possible relationship between, methane and halogens in groundwater in southeastern Ontario; *in* Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p.33-1 to 33-7.
- Lemieux, A.J., Hamilton, S.M. and Clark, I.D. 2019. Allochthonous sources of iodine and organic carbon in an eastern Ontario aquifer; *Canadian Journal of Earth Sciences*, v.56, p.209-222. doi.org/10.1139/cjes-2018-0082
- Matheson, E. 2011. Analysis of the anomalous groundwater geochemistry of the Niagara Peninsula, Ontario, Canada; unpublished BSc thesis, Queen's University, Kingston, Ontario, Canada, 171p.
- Matheson, E.J., Hamilton, S.M. and Kyser, K. 2018. Shallow groundwater salinization of the Niagara Peninsula, Ontario, Canada; *Geochemistry: Exploration, Environment, Analysis*, v.18, no.2, p.155-174. doi.org/10.1144/geochem2017-072
- McEwan, C.A., Hamilton, S.M., Slater, G.F. and Campbell, J.D. 2015. Geochemical and isotopic sampling to delineate sources of highly mineralized groundwater on the Niagara Peninsula; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.37-1 to 37-8.
- 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.
- Mellor, K.J. 2008. Bedrock lithologies effect on bulk groundwater chemistry in southwestern Ontario; unpublished BSc thesis, University of Birmingham, Birmingham, United Kingdom, 122p.
- Morton, S.R. 2015. Development and evaluation of an aquifer capability screening tool pilot study: Clarence–Rockland, Ontario; unpublished MSc thesis, University of Ottawa and Ottawa–Carleton Geoscience Centre, 176p.
- Morton, S.R., Di Iorio, T., Hamilton, S.M. and Robin, M.J.L. 2013. Development of an Aquifer Mapping Tool, City of Clarence–Rockland; *in* Summary of Field Work and Other Activities, 2013, Ontario Geological Survey, Open File Report 6290, p.40-1 to 40-6.
- Priebe, E.H. 2019. Investigating new approaches for mapping groundwater systems in karstic carbonate bedrock: A case study in the Early Silurian formations of the Niagara Escarpment cuesta, southern Ontario, Canada; unpublished PhD thesis, University of Waterloo, Waterloo, Ontario, 153p.
- Priebe, E.H., Bajc, A.F., Burt, A.K. and Mulligan, R.P.M. 2018. First phase of regional groundwater systems mapping in the County of Simcoe, southern Ontario; *in* Summary of Field Work and Other Activities, 2018, Ontario Geological Survey, Open File Report 6350, p.26-1 to 26-8.
- Priebe, E.H., Mulligan, R.P.M., Bajc, A.F., Cartier, A.M. and Burt, A.K. 2019. Regional groundwater systems mapping in the County of Simcoe, southern Ontario: Second phase of field work; *in* Summary of Field Work and Other Activities, 2019, Ontario Geological Survey, Open File Report 6360, p.22-1 to 22-10.
- Rogerson, C.M. 2018. Groundwater as a source of high iodine levels in milk in eastern and southwestern Ontario dairy herds; unpublished MSc thesis, University of Guelph, Guelph, Ontario, 128p.
- Rogerson, C.M., Kelton, D.F., Hamilton, S.M., Lemieux, A.J. and Clark, I.D. 2016. The investigation of groundwater as a source of high iodine levels in milk from dairy herds in eastern Ontario; *in* Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p.34-1 to 34-5.
- Smal, C.A. 2017. Regional groundwater geochemistry on the Niagara Peninsula; unpublished MSc thesis, McMaster University, Hamilton, Ontario, 288p.

20. Project ON-21-005. Improving Geological Nomenclature in Ontario Well Records



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INTRODUCTION

Geological surveys have a long history of producing two-dimensional maps that depict areas of common sediment textures and depositional environments, rock types and faults. But more than this, they represent the map-makers' interpretation of the geologic history and stratigraphy of the map area within a broader regional context. These maps can be underpinned by new geological and remotely sensed data, which can be expensive and time consuming to acquire, as well as legacy data sets that commonly suffer from inaccuracies or inconsistencies related to location, elevation and observations. With the rise of three-dimensional (3-D) mapping, the availability of reliable subsurface data has become increasingly important. Geologists, hydrogeologists and geotechnical engineers working outside of geological surveys also require accurate surficial and subsurface data for both site-specific and regional-scale projects.

Publicly accessible sources of legacy subsurface data vary in availability, precision and accuracy. This is clearly demonstrated by the more than 46 000 records used for the Ontario Geological Survey's (OGS) ongoing 5000 km² Niagara Peninsula 3-D sediment mapping project (Figure 20.1). Cored boreholes, measured sections and hand-augered holes obtained specifically for the project are the most accurate and detailed data source (e.g., Burt 2017, 2020). These data are critical for understanding the geologic history of the area and interpreting legacy data sets in the region that contain less reliable geological descriptions. Far more plentiful are records hosted in:

1. the Urban Geology Automated Information System (UGAIS) clustered around cities and roads,
2. borehole records from petroleum industry exploration maintained by the Oil, Gas and Salt Resources Library, and
3. well records of the Ministry of Environment, Conservation and Parks' (MECP) containing information about wells constructed or abandoned, which is collected under the Wells Regulation (R.R.O. 1990, Regulation 903).

Well records include information on geological materials, well construction methods and materials, as well as water level, quality and quantity for 887 025 wells drilled across the province (<https://data.ontario.ca/dataset/well-records> [accessed September 16, 2021]). As may be expected, there are challenges in maintaining the consistency of a data set assembled over a 120-year period. In recent years, MECP has worked to improve the location data associated with individual well records through ongoing location verification and assignment of reliability codes to reflect an estimated margin of error. Resolving inaccuracies in overburden and/or bedrock material descriptions will address another major challenge identified by respondents to the Well Record Data Enhancement Study's stakeholder survey administered by WSP Inc. on behalf of the MECP in 2017.

*Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.20-1 to 20-5.*

GEOLOGICAL DATA IN ONTARIO WELL RECORDS

Because of the nature of water well construction methods (e.g., drilling, augering, digging, boring, etc.), geological materials are most commonly identified using cuttings brought to surface during the construction process, which can lead to mis-identification of geological materials and the development of regional biases. Some well records provide descriptions for each geological unit encountered, whereas others summarize the materials simply as overburden or rock. At the time of writing, there were 2 832 509 geological units, with an average of 3.2 units for each well (<https://data.ontario.ca/dataset/well-records> [accessed September 16, 2021]).

Traditionally, paper well records are submitted to MECP by well technicians. These forms are often completed by the well contractor's office staff based on well technicians' notes and signed off by the well technician. Although geological descriptors are suggested on the forms, many of the suggested terms are redundant or have no geological or hydrogeological meaning. Furthermore, the paper format means that local vernacular, such as “*gumbo*”¹, may appear on the well records. After well record submission, MECP staff enter the descriptions into the well record database. Up to 3 material fields are populated using 1 of 82 possible terms and 1 field is populated by colour descriptors. This step can require MECP staff to interpret the descriptions. Each step of the process has the potential to decrease the accuracy of the data.

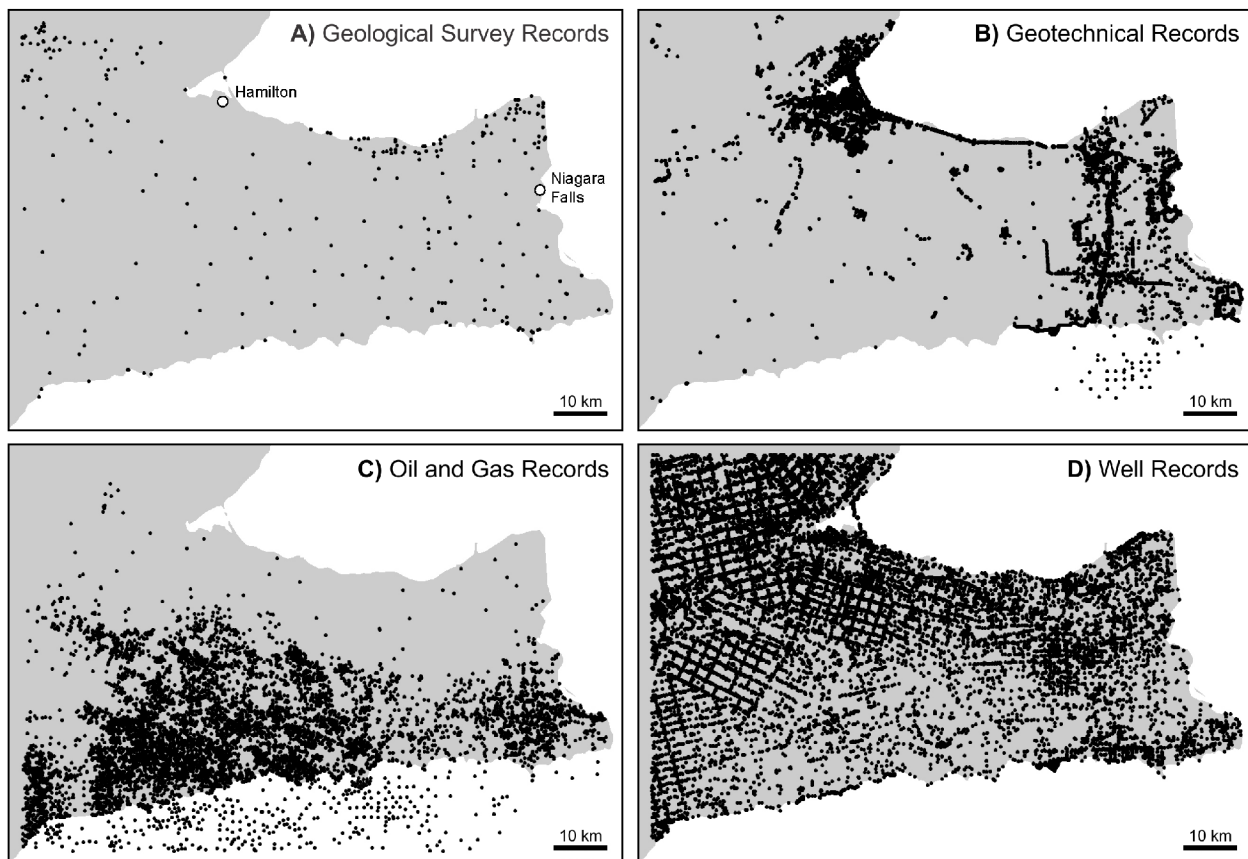


Figure 20.1. Distribution of subsurface data used for the Niagara Peninsula 3-D sediment mapping project. Sources: A) Geological survey records (Burt 2017, 2020); B) geotechnical records (Ministry of Transportation Geocres Database; Urban Geology Automated Information System); C) oil and gas records (Oil, Gas and Salt Resources Library); and D) well record data (Ministry of Environment, Conservation and Parks, well record database; contains information licenced under the Open Government Licence – Ontario (<https://data.ontario.ca/dataset/well-records> [accessed September 16, 2021])).

¹ An informal term for clay that is very sticky when wet.

COLLABORATIVE PROJECT

The OGS and MECP have initiated a two-phase project designed to improve the quality of geological data in well records. Phase 1 will address the approximately 23 000 well records added to the database each year; phase 2 will address the historical records (Figure 20.2).

Phase 1

In phase 1, a simplified, standardized, and meaningful nomenclature for geological materials will be developed. As noted, there are currently 82 descriptors available for selection and, at the time of writing, these terms have been used 4 454 407 times in the well records. Counting the number of times each term is used reveals that the top 20 terms are used 90% of the time and the bottom 38 terms are used 1% of the time (Figure 20.3A). Exploring the data set in greater detail reveals that sediment terms, such as clay, sand and gravel (Table 20.1), dominate the data set at 68%, whereas rock terms, such as limestone and granite, form 17.5% of the data set. Terms for unknowns or terms applied to both sediments and rocks account for the remaining 14.5%. Combining colour and material descriptors results in 36 495 unique combinations of terms. The 100 most commonly used combinations account for 60% of the records, whereas the remaining 36 395 account for 40% (Figure 20.3B). More than 20 000 combinations are used only once or twice. These trends suggest that simplifying the terminology will indeed reduce the complexity and increase the useability of the data set.

This process will be informed by the approaches taken by other jurisdictions. For example, some jurisdictions have adopted pick-lists for material descriptions, whereas others kept free-form entry. Some jurisdictions have separate fields for sediments, bedrock, moisture and hardness. Regardless of the final

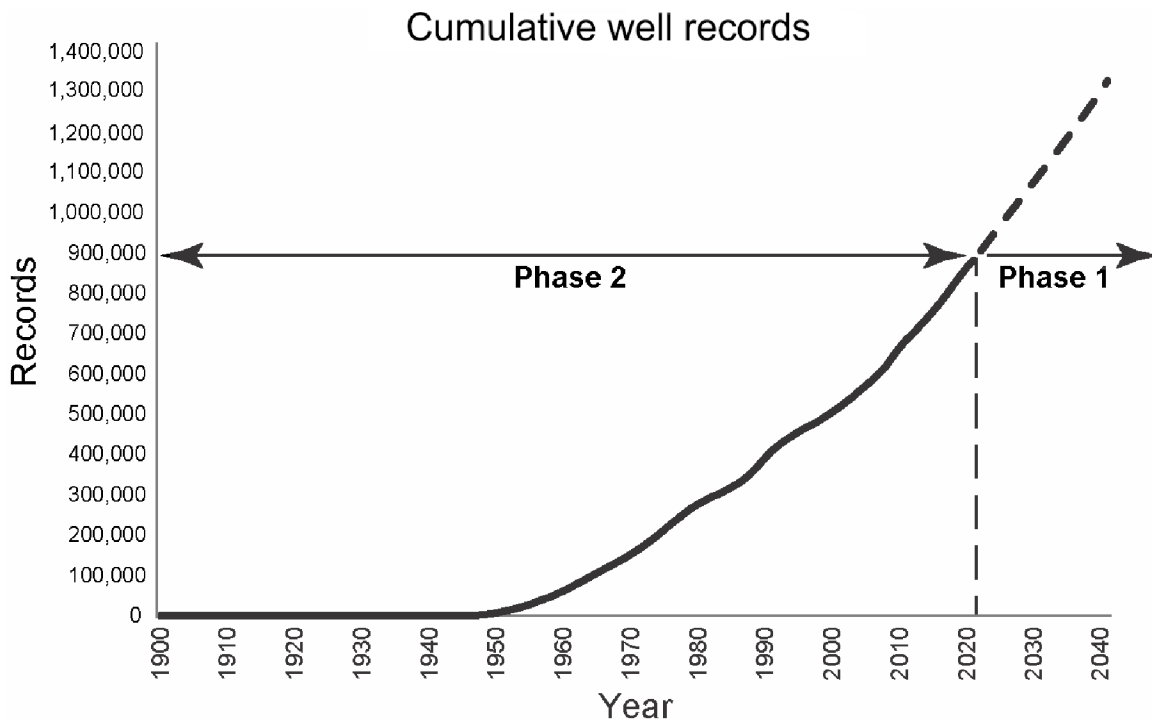


Figure 20.2. Graph showing the cumulative number of well records currently held by MECP (solid line) and projected number of records (dashed line). Phase 1 of the project will address new well records; phase 2 will focus on integrating the data sets. Source: <https://data.ontario.ca/dataset/well-records> [accessed September 16, 2021].

approach taken, establishing nomenclature that is convenient for well technicians to use and that retains sufficient detail to satisfy the requirements of geological and hydrogeological projects may be problematic. A stakeholder team of well technicians, college instructors and practitioners will be consulted on how current terms are used and on the development of a list of revised new terms.

Training drillers and technicians on the new terminology will be required. A guidance document providing simple (plain language) descriptions and tips for identifying and describing geological materials, accompanied by representative photographs (outcrops, cores and cuttings), is envisioned, along with short hard-copy field reference sheets and content for a mobile device-friendly guide.

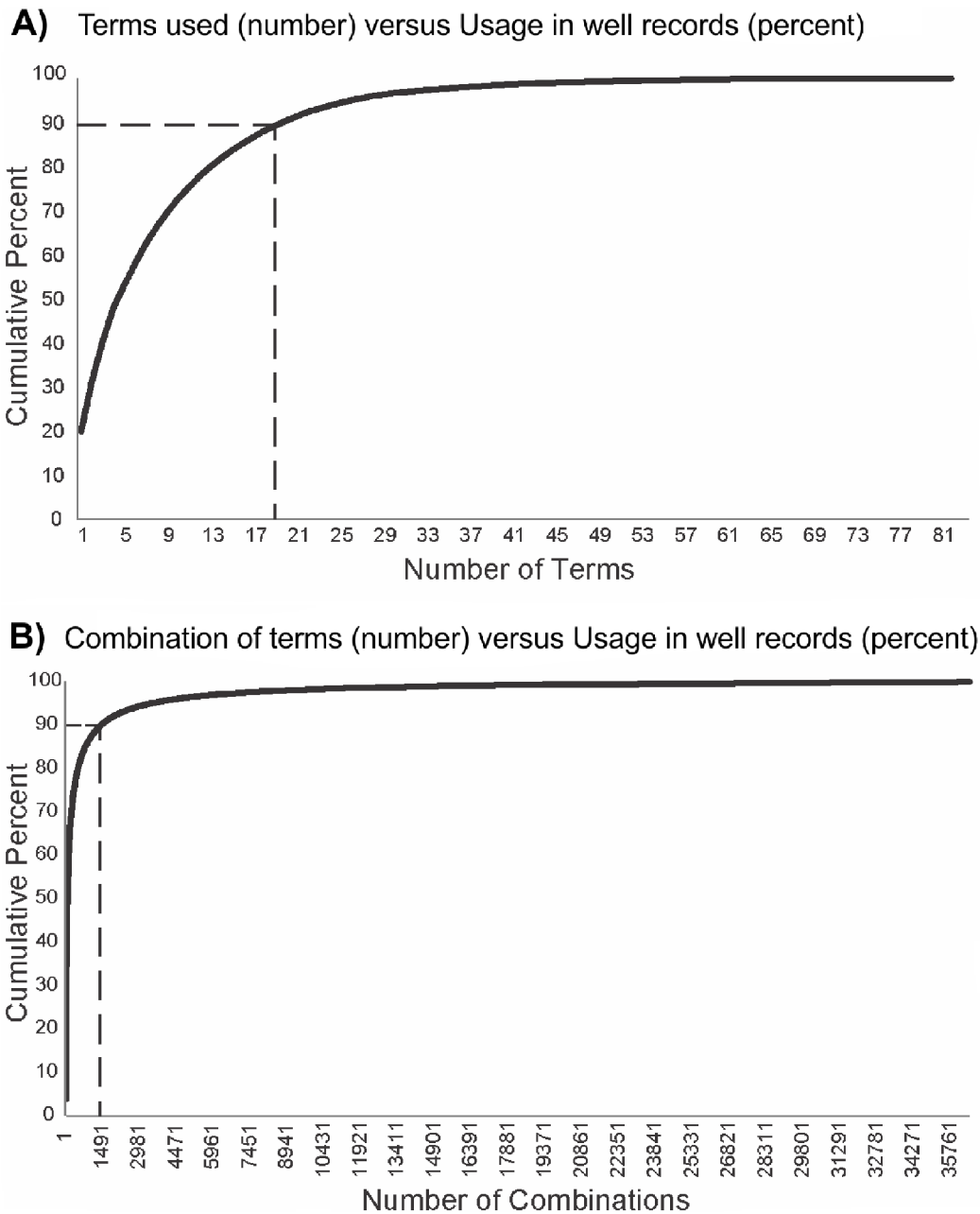


Figure 20.3. A) Cumulative percent curve illustrating that some material terms are used more commonly than others in the well records. B) Cumulative percent curve illustrating that a small number of combinations of terms account for most of the terms used in well records. Source: <https://data.ontario.ca/dataset/well-records> [accessed September 16, 2021].

Table 20.1. Material descriptors currently used in well records classified into rock, sediment and other terms.

Rock	Sediment	Other
Limestone	Topsoil	Unknown
Dolomite	Muck	Fill
Shale	Peat	Previously dug
Sandstone	Clay	Previously drilled
Slate	Silt	Other
Quartzite	Quicksand	Very
Granite	Fine sand	Thick
Greenstone	Medium sand	Thin
Rock	Coarse sand	Weathered
Basalt	Gravel	Water-bearing
Chert	Stones	Dense
Conglomerate	Boulders	Dirty
Feldspar	Hardpan	Dry
Flint	Sand	Dark-coloured
Gneiss	Fine gravel	Light-coloured
Greywacke	Medium gravel	Layered
Gypsum	Coarse gravel	Cemented
Iron Formation	Pea gravel	Clean
Marble	Marl	Fine-grained
Quartz	Till	Medium-grained
Schist	Wood fragments	Coarse-grained
Soapstone	Clayey	Hard
Crystalline	Sticky	Limy
Fractured	Stoney	Loose
Fossiliferous	Gravelly	Packed
Shaly	Silty	Porous
	Sandy	Sharp
	Overburden	Soft

Phase 2

Phase 2 of the project will address historical records, providing clients with a streamlined data set. The original terms used in the historical records will be consolidated and retained in a separate field for reference. Each term will then be converted into the new nomenclature. Note that correcting mis-identified materials, regional nomenclature biases or interpreting materials or stratigraphic units would not be undertaken.

It is anticipated that the simplified nomenclature will increase internal (i.e., OGS, MECP) and external client efficiency and improve the quality and reliability of these data for use in future 3-D subsurface geological, hydrogeological and geotechnical projects that incorporate well record data. As of writing, specific timelines for completion of this project have not been set.

ACKNOWLEDGMENTS

The authors thank Michael Easton (OGS), Cassandra Lofranco (MECP) and Cynthia Carr (MECP) for reviewing this article and Julien Bonin (OGS) for revising our draft figures.

REFERENCES

- Burt, A.K. 2017. Graphic logs with analytical and geochronological data from hand auger, probe and section sites in the Niagara Peninsula; Ontario Geological Survey, Miscellaneous Release—Data 353.
- 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.

Geoscience Laboratories

21. Summary of Quality-Control Data for the Geoscience Laboratories Methods AAF-101, AAF-102, AAF-103, AAF-104, AAF-200, CTK-100, IMP-200 and SGT-R01



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INTRODUCTION

This article summarizes the results of analyses for quality-control samples for the Geoscience Laboratories' methods AAF-101, AAF-102, AAF-103, AAF-104, AAF-200, CTK-100, IMP-200 and SGT-R01. The AAF test codes represent analysis by flame atomic absorption after acid digestion where the AAF-101 provides results for cobalt, copper and nickel (Co, Cu, Ni); AAF-102 for copper, lead and zinc (Cu, Pb, Zn); and AAF-104 for cobalt, copper, nickel, lead and zinc (Co, Cu, Ni, Pb and Zn); AAF-103 for lithium (Li); and AAF-200 analyzes for silver (Ag). The CTK-100 method code provides results for calcite and dolomite determination by Chittick apparatus. The IMP-200 test code is the determination of gold, iridium, palladium, platinum, rhodium and ruthenium (Au, Ir, Pd, Pt, Rh, Ru) by nickel sulphide fire-assay followed by inductively coupled plasma mass spectrometry (ICP-MS). The SGT-R01 test code represents specific gravity determination.

The quality-control data for the AAF-101, AAF-102, AAF-103, AAF-104 and AAF-200 methods are summarized for September 15, 2016, to August 23, 2021, and capture results obtained since a summary was last published (Hargreaves 2016). The quality-control data for the CTK-100 and SGT-R01 are summarized from August 1, 2015, to August 23, 2021, to also capture results obtained since a summary was last published (Hargreaves 2015). The IMP-200 quality-control data are summarized from November 29, 2018, to August 23, 2021, and encapsulate results obtained since the method was transferred to new ICP-MS instrumentation.

ACKNOWLEDGMENTS

The author would like to thank Marcus Burnham, Susan Dagostino, Nathan Guitard, Brent Handford and Troy Richardson, Geoscience Laboratories, for their help in preparing this article.

REFERENCES

Hargreaves, J.C. 2015. Summary of quality-control data for the Geoscience Laboratories methods CTK-100, SGT-R01, IMP-200, XRF-M01, XRF-M02, XRF-T02 and XRF-T03; *in* Summary of Field Work and Other Activities, 2015, Ontario Geological Survey, Open File Report 6313, p.39-1 to 39-11.

——— 2016. Summary of quality-control data for the Geoscience Laboratories methods AAF-101, AAF-102, AAF-200, IAC-100, IAO-100 and IAL-100; *in* Summary of Field Work and Other Activities, 2016, Ontario Geological Survey, Open File Report 6323, p.37-1 to 37-9.

Summary of Field Work and Other Activities, 2021,
Ontario Geological Survey, Open File Report 6380, p.21-1 to 21-5.

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Table 21.1. Summary of results obtained by the AAF-101, AAF-102 and AAF-104 methods for in-house and certified reference materials from September 15, 2016 to August 23, 2021.

Material	Provider	Description	Co (ppm)	Cu (ppm)	Ni (ppm)
In-house Reference Materials					
LK-NIP-1	In-house	Diabase	51 ± 4 (9)	164 ± 4 (11)	137 ± 6 (9)
MRB-29	In-house	Basalt	47 ± 3 (86)	147 ± 6 (102)	97 ± 11 (83)
Certified Reference Materials					
NIST-8607	NIST	Tungsten Ore	< 8	778 ± 17 (47)	< 16
<i>Certificate</i>			2.7 ± 0.3	790 ± 20	4.1 ± 1.0
RTS-3a	CANMET	Sulphide Ore	141 ± 4 (80)	2,280 ± 54 (96)	53.7 ± 3.0 (78)
<i>Certificate</i>			143 ± 4	2,353 ± 30	61.3 ± 2.5
SU-1a	CANMET	Ni-Cu-Co Ore	354 ± 8 (25)	9,392 ± 180 (26)	11,860 ± 350 (23)
<i>Certificate</i>			410 ± 10	9,670 ± 50	12,330 ± 80
SU-1b	CANMET	Ni-Cu-Co Ore	612 ± 61 (63)	11,440 ± 510 (69)	18,850 ± 1,730 (60)
<i>Certificate</i>			672 ± 13	11,850 ± 140	19,530 ± 170
SY-4	CANMET	Diorite Gneiss	< 8	7.8 ± 0.6 (4)	< 16
<i>Certificate</i>			2.8 ± 0.2	7 ± 1	9 ± 1

Material	Provider	Description	Pb (ppm)	Zn (ppm)
In-house Reference Materials				
LK-NIP-1	In-house	Diabase	< 14	101 ± 6 (11)
MRB-29	In-house	Basalt	< 14	109 ± 6 (86)
Certified Reference Materials				
NIST-8607	NIST	Tungsten Ore	2,730 ± 650 (56)	3,160 ± 950 (48)
<i>Certificate</i>			2,600 ± 100	2,900 ± 100
RTS-3a	CANMET	Sulphide Ore	193 ± 7 (90)	2,949 ± 68 (80)
<i>Certificate</i>			209 ± 7	2,890 ± 50
SU-1a	CANMET	Ni-Cu-Co Ore	45 ± 5 (21)	182 ± 7 (18)
<i>Certificate</i>			100*	N/A
SU-1b	CANMET	Ni-Cu-Co Ore	34 ± 4 (68)	264 ± 17 (58)
<i>Certificate</i>			58 ± 5	235 ± 19
SY-4	CANMET	Diorite Gneiss	< 14	93.4 ± 1.2 (4)
<i>Certificate</i>			10 ± 1	93 ± 2

Notes: Compiled data given as mean ± 1 standard deviation of results (number of measurements).

Certificate value is average ± 95% confidence interval on the population mean.

**Provisional/Information values.*

N/A: data not available.

Abbreviations: NIST = National Institute of Standards & Technology;

CANMET = Canada Centre for Mineral and Energy Technology.

Table 21.2. Summary of results obtained by the AAF-103 methods for in-house and certified reference materials from September 15, 2016 to August 23, 2021.

Material	Provider	Description	Li (ppm)
In-House Reference Materials			
MRB-29	In-house	Basalt	13.94 ± 0.23 (10)
OPEG-1	In-house	Evolved Pegmatite	280.4 ± 2.2 (7)
Certified Reference Materials			
NIST-8607 <i>Certificate</i>	NIST	Tungsten Ore	214 ± 7 (8) 200*
RTS-3a <i>Certificate</i>	CANMET	Sulphide Ore	17.8 ± 1.5 (9) 10*
SU-1a <i>Certificate</i>	CANMET	Ni-Cu-Co Ore	18.3 ± 1.5 (6) N/A
SU-1b <i>Certificate</i>	CANMET	Ni-Cu-Co Ore	12.2 ± 1.6 (7) N/A
SY-4 <i>Certificate</i>	CANMET	Diorite Gneiss	42.1 ± 0.4 (7) 37 ± 2

Notes: Compiled data given as mean ± 1 standard deviation of results (number of measurements).

Certificate value is average ± 95% confidence interval on the population mean.

*Provisional/Information values. N/A: data not available.

Abbreviations: NIST = National Institute of Standards & Technology;

CANMET = Canada Centre for Mineral and Energy Technology.

Table 21.3. Summary of results obtained by the AAF-200 methods for in-house and certified reference materials from September 15, 2016 to August 23, 2021.

Material	Provider	Description	Ag (ppm)
In-House Reference Materials			
MRB-29	In-house	Basalt	3.2 ± 0.4 (133)
Certified Reference Materials			
MP-1a <i>Certificate</i> ‡	CANMET	Zn-Sn-Cu-Pb Ore	64.5 ± 2.1 (53) 69.7 ± 2.2
MP-1b <i>Certificate</i> ‡	CANMET	Zn-Sn-Cu-Pb Ore	47.8 ± 1.4 (17) 47.0 ± 1.8
NIST-2710 <i>Certificate</i> ‡	NIST	Montana Soil	34 ± 5 (46) 35.3 ± 1.5
OREAS 600 <i>Certificate</i> †	OREAS	Ag-Cu-Au Ore	25.1 ± 0.7 (34) 24.3 ± 0.9

Notes: Compiled data given as mean ± 1 standard deviation of results (number of measurements).

‡*Certificate value is average ± 95% confidence interval on the population mean.*

†*Certificate value is the average ± 1 standard deviation of the laboratory means.*

*Provisional/Information values. N/A: data not available.

Abbreviations: CANMET = Canada Centre for Mineral and Energy Technology;

NIST = National Institute of Standards & Technology.

Table 21.4. Summary of results obtained by the CTK-100 method for in-house and certified reference materials from August 1, 2015 to August 23, 2021.

Material	Provider	Description	Calcite (wt %)	Dolomite (wt %)	Total Carbonate (wt %)
In-House Reference Material					
CTK-2	In-house	Calcareous rock	5.3 ± 0.5 (321)	6.7 ± 0.6 (321)	12.0 ± 0.5 (321)
Certified Reference Material					
SO-3	CANMET	Calcareous soil	24.5 ± 1.2 (145)	27.9 ± 2.5 (145)	52.4 ± 2.4 (145)

Notes: Compiled data given as mean ± 1 standard deviation of results (number of measurements).

Table 21.5. Summary of results obtained by the IMP-200 methods for certified reference materials from November 29, 2018 to August 23, 2021.

Material	Provider	Description	Au (ppb)	Ir (ppb)	Pd (ppb)	Pt (ppb)	Rh (ppb)	Ru (ppb)
Certified Reference Materials								
OKUM-1 <i>Certificate</i>	IAG	Ultramafic Komatiite	0.85 ± 0.08 (4) <i>N/A</i>	0.80 ± 0.05 (4) <i>N/A</i>	10.43 ± 0.13 (4) <i>N/A</i>	9.22 ± 0.30 (4) <i>N/A</i>	1.10 ± 0.05 (4) <i>N/A</i>	3.34 ± 0.10 (4) <i>N/A</i>
OREAS 13b <i>Certificate‡</i>	OREAS	PGE-Cu-Ni Ore	193.9 ± 3.1 (12) <i>201 ± 7</i>	18.31 ± 0.19 (12) <i>17.9 ± 1.3</i>	131.3 ± 1.5 (12) <i>134 ± 4</i>	200.8 ± 1.5 (12) <i>204 ± 13</i>	40.7 ± 0.4 (12) <i>43 ± 2</i>	74.8 ± 1.4 (12) <i>78 ± 6</i>
OREAS 14P <i>Certificate†</i>	OREAS	Massive Sulphide	48.6 ± 0.6 (11) <i>51 ± 2</i>	53.7 ± 0.8 (11) <i>N/A</i>	147 ± 4 (11) <i>150 ± 3</i>	100.2 ± 1.6 (11) <i>99 ± 3</i>	60.3 ± 1.8 (11) <i>N/A</i>	123 ± 4 (11) <i>N/A</i>
OREAS 45d <i>Certificate‡</i>	OREAS	Ferruginous Soil	22.0 ± 0.6 (4) <i>23 ± 2</i>	1.47 ± 0.06 (4) <i>N/A</i>	34.68 ± 0.15 (4) <i>35 ± 2</i>	47.2 ± 0.4 (4) <i>48 ± 3</i>	4.17 ± 0.04 (4) <i>N/A</i>	3.50 ± 0.10 (4) <i>N/A</i>
OREAS 45f <i>Certificate‡</i>	OREAS	Lateritic Soil	17.10 ± 0.17 (3) <i>19.3 ± 1.7</i>	1.27 ± 0.12 (3) <i>N/A</i>	56.7 ± 0.6 (3) <i>56.6 ± 4.0</i>	36.8 ± 0.6 (3) <i>38.1 ± 2.5</i>	3.35 ± 0.07 (3) <i>N/A</i>	3.0 ± 0.4 (3) <i>N/A</i>
OREAS 681 <i>Certificate‡</i>	OREAS	PGE Ore	47.0 ± 1.3 (26) <i>47 ± 4.7</i>	12.19 ± 0.22 (26) <i>11 ± 1.3</i>	239.4 ± 2.1 (26) <i>238 ± 14</i>	513 ± 5 (26) <i>496 ± 33</i>	33.77 ± 0.29 (26) <i>32 ± 2.8</i>	66.4 ± 1.1 (26) <i>63 ± 7.6</i>
OREAS 682 <i>Certificate‡</i>	OREAS	PGE Ore	70.2 ± 1.7 (37) <i>72 ± 3.3</i>	21.68 ± 0.30 (37) <i>20 ± 1.0</i>	442 ± 5 (37) <i>440 ± 26</i>	855 ± 11 (37) <i>820 ± 52</i>	62.6 ± 0.8 (37) <i>60 ± 1.9</i>	117.5 ± 1.7 (37) <i>112 ± 10</i>
OREAS 683 <i>Certificate‡</i>	OREAS	PGE Ore	194 ± 4 (32) <i>195 ± 11</i>	50.5 ± 0.7 (32) <i>50 ± 1.6</i>	872 ± 12 (32) <i>858 ± 40</i>	1,782 ± 22 (32) <i>1,723 ± 143</i>	149.3 ± 2.0 (32) <i>146 ± 13</i>	262 ± 4 (32) <i>252 ± 23</i>
OREAS 684 <i>Certificate‡</i>	OREAS	PGE Ore	241.3 ± 1.5 (4) <i>237 ± 13</i>	105.3 ± 0.8 (4) <i>100 ± 6</i>	1,787 ± 58 (4) <i>1,740 ± 48</i>	3,957 ± 106 (4) <i>3,800 ± 189</i>	295.9 ± 3.0 (4) <i>280 ± 13</i>	582 ± 8 (4) <i>550 ± 31</i>
TDB-1 <i>Certificate†</i>	CANMET	Diabase	5.8 ± 0.4 (10) <i>6.3 ± 1</i>	0.067 ± 0.008 (10) <i>0.15*</i>	21.8 ± 0.6 (10) <i>22.4 ± 1.4</i>	4.66 ± 0.26 (10) <i>5.8 ± 1.1</i>	0.445 ± 0.008 (10) <i>0.7*</i>	0.260 ± 0.028 (10) <i>0.3*</i>
UMT-1 <i>Certificate†</i>	CANMET	Ultramafic Ore Tailings	47 ± 9 (15) <i>48 ± 2</i>	9.4 ± 0.4 (15) <i>8.8 ± 0.6</i>	107.4 ± 2.8 (15) <i>106 ± 3</i>	133 ± 11 (15) <i>129 ± 5</i>	9.85 ± 0.29 (15) <i>9.5 ± 1.1</i>	10.02 ± 0.29 (15) <i>10.9 ± 1.5</i>
WGB-1 <i>Certificate†</i>	CANMET	Gabbro	1.9 ± 0.7 (8) <i>2.9 ± 1.1</i>	0.189 ± 0.020 (8) <i>0.33 ± 0.17*</i>	12.0 ± 1.5 (8) <i>13.9 ± 2.1</i>	4.6 ± 0.7 (8) <i>6.1 ± 1.6</i>	0.203 ± 0.021 (8) <i>0.32 ± 0.21*</i>	0.161 ± 0.027 (8) <i>0.3*</i>

Notes: Compiled data given as mean ± 1 standard deviation of results (number of measurements).

‡Certificate value is the average ± 1 standard deviation of the laboratory means.

†Certificate value is the recommended working value ± its 95% confidence interval.

* Provisional values.

N/A: data not available.

Abbreviations: CANMET = Canadian Centre for Mineral and Energy Technology; IAG = International Association of Geoanalysts; OREAS = Ore Research & Exploration.

Table 21.6. Summary of results obtained by the SGT-R01 methods for in-house and certified reference materials from August 1, 2015 to August 23, 2021.

Material	Description	Specific Gravity (g/cm³)
SG-C0	Quartzite	2.6668 ± 0.0017 (467)
SG-C1	Gabbro	2.9547 ± 0.0013 (389)
SG-C2	Rhyolite	2.6629 ± 0.0011 (83)
SG-C3	Granite	2.6275 ± 0.0011 (17)

Note: Compiled data given as mean ± 1 standard deviation of results (number of measurements).

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Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
<i>SI Unit</i>	<i>Multiplied by</i>	<i>Gives</i>	<i>Imperial Unit</i>	<i>Multiplied by</i>	<i>Gives</i>
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

	<i>Multiplied by</i>	
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 978-1-4868-5624-4 (print)

ISSN 1916-6117 (online)
ISBN 978-1-4868-5625-1 (PDF)