Recommendations for Exploration 2023–2024

Ministry of Mines

Ontario Geological Survey
Resident Geologist Program

Ontario

ONTARIO CANADA

Recommendations for Exploration 2023–2024

Bedrock geology from

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

Front cover photos, from top to bottom:

Liane Boyer (President and Chief Geoscientist, Broken Rock Resources Ltd.), Paul Winiecki (Pilot, Ministry of Natural Resources and Forestry) and Dorothy Campbell (Regional Resident Geologist, Resident Geologist Program, Thunder Bay South District) scout out OGS lake sediment rare element anomalies in the Obonga Lake area, north of Thunder Bay (photo *courtesy of* Liane Boyer).

Justin Jonsson (District Geologist, Resident Geologist Program, Thunder Bay South District) examines the Crystal Lake Gabbro in Pardee Township, southwest of Thunder Bay. Credit: Colleen Kurcinka, Resident Geologist Program.

Ontario Geological Survey
Resident Geologist Program
Recommendations for Exploration 2023–2024

The Ontario Geological Survey (OGS) is pleased to issue its 2023–2024 Recommendations for Exploration. These recommendations have been prepared by the dedicated and knowledgeable staff located in the 8 Resident Geologist Program (RGP) offices across Ontario. They have been developed using existing OGS geological and mineral exploration data, along with new information derived from the current year's activities.

Ontario's diverse geology provides excellent opportunities for mineral exploration and development. This year's recommendations span the entire province and are focussed on a wide variety of deposit types, commodities, and exploration methods. Once again, many of these recommendations target commodities that are included on Ontario's Critical Minerals List, including lithium, tantalum, cesium, nickel, copper, zinc, platinum group elements, magnesium, molybdenum, and rare earth elements, while others target industrial minerals, gold and silver. We have also included recommendations that highlight how airborne drone magnetic surveys and OGS products (OGS Focus and our new GeologyOntario Site Visits layer) can be used for exploration targeting.

Please review our current Recommendations for Exploration and feel free to discuss these in detail with any of our Resident Geologist Program geoscientists.

Visit GeologyOntario (https://www.hub.geologyontario.mines.gov.on.ca/) and OGSEarth (https://www.geologyontario.mndm.gov.on.ca/ogsearth.html) on the Ministry of Mines Web site to explore the wealth of geoscience and mineral exploration information the Ontario Geological Survey has to offer.

About the Resident Geologist Program

Resident Geologists are the stewards of public geological and mineral exploration information for their districts. They provide a broad range of advisory services on geological topics of interest to the public, to municipal governments and to the mineral industry.

They are the local experts on why geoscience information is important, what information is available and what is happening in exploration.

The program provides primary client services through a network of 8 field offices strategically located across the province.

Our services include

- collecting and maintaining geological data
- monitoring exploration activity
- conducting property examinations
- providing geological and exploration advice

We provide geoscience information to support

- public safety
- environmental planning
- land use planning
- mineral sector investment and economic development

We provide information and training to First Nation Communities regarding prospecting, mineral exploration and mining.

For more information about the Resident Geologist Program please visit the Mines and Minerals Division Web site at https://www.ontario.ca/page/geology-and-geoscience.

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

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Recommendations for Exploration articles in this volume may also appear in the Resident Geologist Program's *Reports of Activities* for the same year. Readers are advised to consult the associated District *Report of Activities* for any updates and revisions to these recommendations.

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

Dorland, G. and Dorado-Troughton, M. 2024. Resident Geologist Program Site Visits in GeologyOntario Spatial Search; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.1-3.

HIGHLIGHTS

- **New compilation highlights recent and historical geological site visits completed by the Resident Geologist Program and pan-provincial property examination articles from past annual Resident Geologist Reports of Activities dating back to 1967**
- **Property examinations contain valuable geological interpretations and data from field work completed by government geoscientists that can be used to inform decision-making for investments in new and existing mineral exploration projects**
- **These articles are now easier to find than ever with GeologyOntario's Spatial Search tool**

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Resident Geologist Program Site Visits in GeologyOntario Spatial Search

Dating back to the 1960s, the Ontario Geological Survey's (OGS) Resident Geologist Program (RGP) has included property examination articles in its annual *Reports of Activities*. These articles serve as valuable point-source summaries for mineral exploration and development properties in Ontario. Although the format and level of detail provided in property examination articles have varied over the years, they are all based on field visits by RGP geologists. Almost all these articles capture exploration history, significant assay results and geological summaries for specific properties and/or mineral occurrences. Most notably, these articles provide third-party geological interpretations and assay results from the field visit, thus giving the mineral rights holder and potential investors an objective evaluation of the geology and mineral potential of the property. Additionally, property examination articles often provide recommendations to guide further exploration work.

GeologyOntario, the Ministry of Mines' Web site for discovering Ontario's geoscience data, has recently been upgraded to include a new Spatial Search tool. The RGP Site Visits layer in Spatial Search has been developed to serve as a tool that will allow users to easily discover RGP property examination articles. These articles are currently easy to overlook, as they are included as relatively brief articles embedded within the annual *Report of Activities* reports that have been published in various formats over the years. From 1967 to 1996, the respective Resident Geologists' reports were compiled within single volumes covering the entire province (as Miscellaneous Papers until 1992 and Open File Reports from 1993 to 1996), while individual Open File Reports have been published for each district since 1997. Resident Geologist District boundaries have also changed numerous times over the years, adding to the challenge of locating articles for specific areas of interest.

The RGP Site Visits layer simplifies the process of locating property examinations by providing a spatially referenced point for each article, presented as a layer in GeologyOntario Spatial Search (Figure 1). A pop-up for each point displays metadata that includes a link to the article, location information, report references, availability of assay data and information on associated Ontario Mineral Inventory occurrences and Assessment Files (Figure 2).

A similar product, known as "Property Examination Articles", was previously available through the OGSEarth Web page, but only covered northwestern Ontario. The new GeologyOntario Site Visits layer now provides province-wide coverage, highlighting potentially overlooked sources of geological interpretations and data that are available in

Dorland, G. and Dorado-Troughton, M. 2024. Resident Geologist Program Site Visits in GeologyOntario Spatial Search; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.1-3.

historical government reports. The product also highlights the value of the expert geological evaluation services, and the research-quality laboratory services that are provided by the OGS. The layer can be useful for immediate and adjacent property holders who may not be aware of the availability of applicable property examination articles. The layer can also be useful for targeting purposes, as several site-visit points relate to properties or portions of properties that are currently open for acquisition.

The layer will be updated regularly going forward with the RGP's annual property examinations, as well as with additional site visit articles that will be collected from other historical OGS reports. Many OGS reports (like the annual *Summary of Field Work and Other Activities* and certain Open File Reports) have sections with detailed site-focused write-ups that are an excellent fit for this layer. The layer also includes recent site visits carried out by RGP staff that may not have a related article in an OGS publication.

The RGP Site Visits layer is now available online through GeologyOntario Spatial Search, under the Layers section, at (https://www.hub.geologyontario.mines.gov.on.ca/).

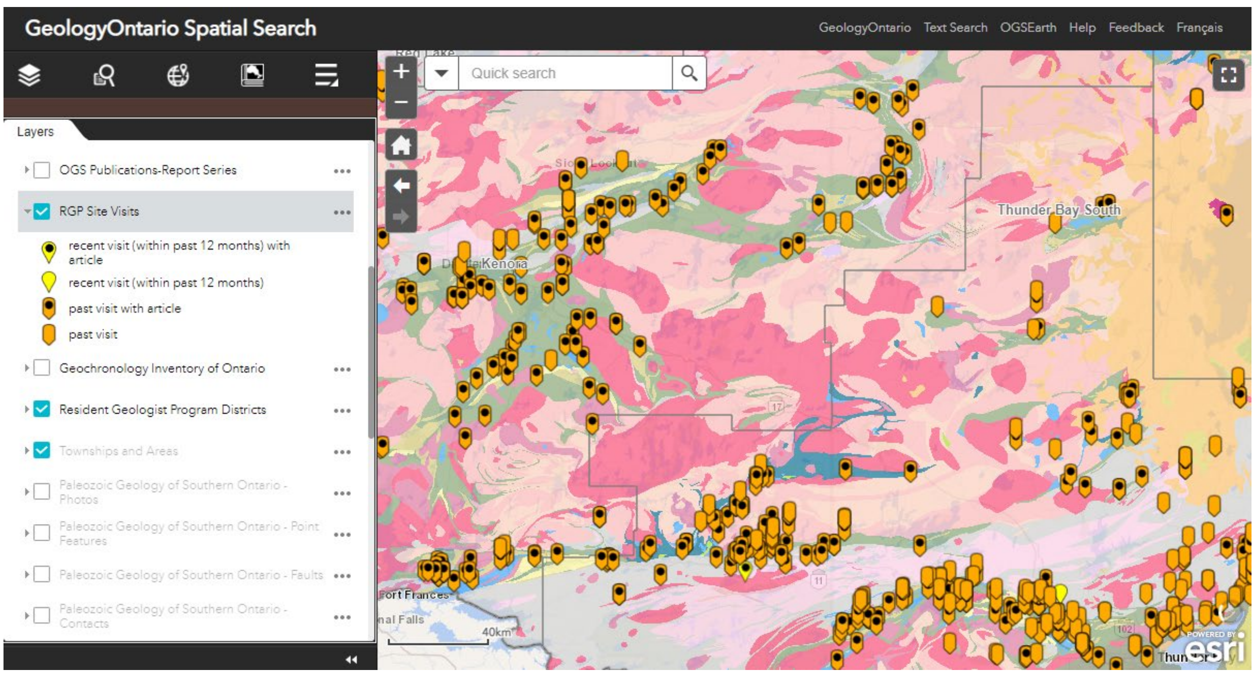

Figure 1. Map showing the RGP Site Visits spatial layer and a selection of site visits within the GeologyOntario Spatial Search platform.

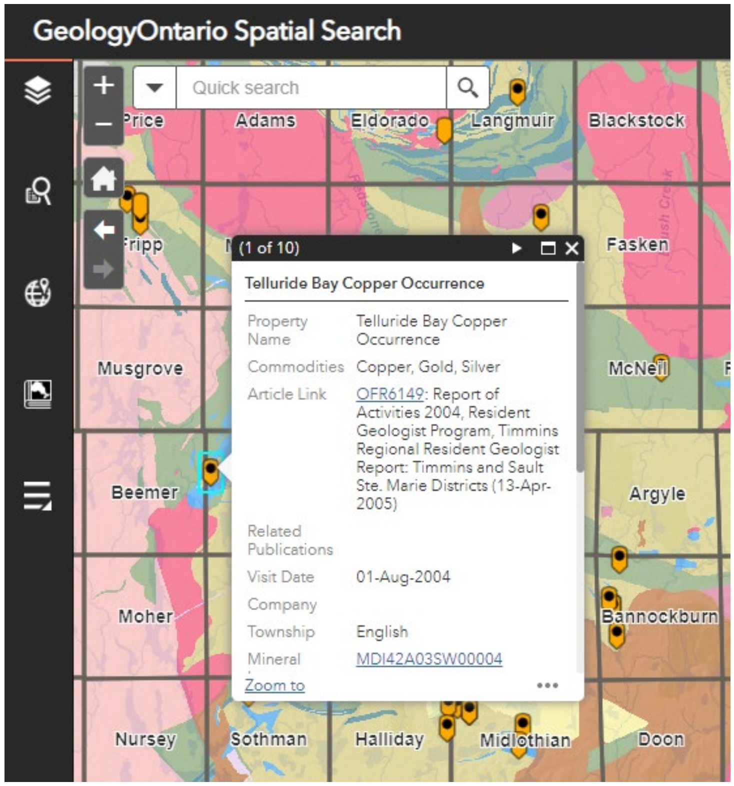

Figure 2. Map with a pop-up showing the metadata displayed for a point in the RGP Site Visits spatial layer.

HIGHLIGHTS

- **Magnesium metal is an essential component in automobile castings, aluminum alloys and in iron manufacturing**
- **High-purity dolomite can be used to produce magnesium metal**
- **The high-purity dolomitic marble unit that hosted the past-producing Timminco Metals quarry shows potential along strike for at least 3 km**

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Proven High-Purity Dolomitic Marble (Magnesium) in Southeastern Ontario

Lightweight and Critical

Magnesium metal is an essential component in aluminum alloys, iron manufacturing and lightweight consumer goods, but the leading use for magnesium metal is for lightweight castings used in the automotive industry (United States Geological Survey 2023). The use of lightweight castings is increasing as automobile manufactures seek to decrease vehicle weight for increased fuel efficiency and longer battery life. Modern magnesium casting processes have also diversified, causing an expansion of casting applications in the aerospace and electronics industries (Luo 2013).

In 2022, approximately 90% of the world's production of magnesium came from China; however, this excludes the United States' sole producer that recovers magnesium from brine in Great Salt Lake, Utah – their exact statistics are not publicly available (United States Geological Survey 2023). The fragility of the magnesium supply chain was showcased when, in September 2021, a government shutdown of aluminum production in the Shaanxi province, China, resulted in an international supply crisis and the near depletion of magnesium stocks in Europe (Australian Strategic Policy Institute, *The Strategist*, www.aspistrategist.org.au/magnesium-market-highlights-continuing-fragility-of-global-supply-chains [accessed October 10, 2023]). The increased usage of magnesium metal in the automotive industry and the instability of its supply chain has led to magnesium being classified as a "Critical Mineral" by both Ontario and Canada.

Past-Producing High-Purity Dolomite Deposit in Southern Ontario

Magnesium metal can be produced from dolomite, a calcium-magnesium carbonate mineral, through a thermal reduction process known as the Pidgeon process (Pidgeon 1944). During the process, calcined dolomite is combined with ferrosilicon and fluorspar flux in small-diameter vacuum furnaces, forming magnesium vapour and a residue of calcium silicate and iron oxide. The vapour is condensed externally, producing magnesium metal, which is 99.98% pure (Trusler 1977; Simandl et al. 2007).

Magnesium metal was produced from high-purity dolomitic marble, quarried near Haley Station in Ross Township, at the Timminco Metals deposit (Ontario Mineral Inventory (OMI) number MDI31F10SE00002; Ontario Geological Survey 2023) from 1942 to 2008. Beginning in 1907, the property operated as a building stone and aggregate quarry. The operation was converted to magnesium production in 1942 by Dominion

Dorado-Troughton, M. 2024. Proven high-purity dolomitic marble (magnesium) in southeastern Ontario; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.4-7.

Magnesium Limited using the newly developed Pigeon process with funding from the Government of Canada (Pidgeon 1944). By the end of 1980, production totalled 475 056 312 pounds of magnesium metal with a peak production capacity of approximately 12 000 tons per year (Carter 1984). Before ceasing production, for economic reasons, the operation reportedly had reserves for 50 years at a rate of production of 6000 tons of magnesium metal per year (Sangster et al. 2008). Production of magnesium and aluminum castings by Magellan Aerospace Corp. continues to this day in Haley Station, directly adjacent to the Timminco Metals property, using magnesium sourced from abroad.

The deposit is hosted within Grenville Supergroup carbonate metasedimentary rocks that have been metamorphosed to lower amphibolite facies (Azar 2015), in the Bancroft Terrane of the Central Metasedimentary Belt in the Grenville Province. The dolomite deposit consists of a 75 m wide unit of very pure, white, coarsely crystalline dolomitic marble, striking north and dipping 50°E. The unit contains less than 1% impurities (i.e., SiO_2+Al_2O_3+Fe_2O_3+ "acid insolubles"; Table 1) and is flanked on either side by distinctive units. LeBaron and MacKinnon (1990) provide a detailed report on the high-purity zone, the past-producing mine and its geology. The high-purity dolomite ore zone was quarried in 2 quarries over a strike length of 700 m and appears to be continuous in both directions.

High-purity dolomitic marble is still quarried 3 km to the south of the Timminco Metals deposit in the northeastern corner of the H&H Construction Inc. aggregate quarry (OMI Number MDI31F10SE00009; Ontario Geological Survey 2023) and is visible in the adjacent past-producing Smith Quarry. The high-purity unit in these quarries is very similar to the Timminco dolomite ore to the north, consisting of greater than 99% coarse, white, crystalline dolomite with less than 1% combined tremolite, pale green mica, and traces of graphite (LeBaron and MacKinnon 1990; Table 1). A detailed description of these quarries is also available from LeBaron and MacKinnon (1990).

Recommendations for Exploration

It is recommended that explorers and developers revisit this high-purity dolomite marble near Haley Station, examine the unit along strike to determine its consistency and thickness, and to determine its potential for development. A wealth of historical information on the past-producing Timminco Metals deposit is also available at the Southern Ontario Resident Geologist Office to aid in exploration. It should be noted that the area around Haley Station is private land and not currently open for claim registration. However, landholders may be amenable to agreements and the possibility for exploration should not be discounted.

In addition to the ideal geology, the community of Haley Station has proven transportation infrastructure, active quarries that contain high-purity dolomitic marble and an existing manufacturer that requires a supply of raw magnesium metal. As the instability of the magnesium metal market coincides with an increased demand for magnesium castings in the automobile and aerospace industries, Ontario is well positioned to become a producer of magnesium metal again.

Table 1. Analytical results from 2 high-purity dolomite marble samples. Sample T-2 is from Timminco Metals' No. 2 quarry and sample 89ROSS-02 is from the inactive Smith quarry (data are *from* LeBaron and MacKinnon 1990).

Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	LOI (%)	Total (%)	CaO:MgO	Acid Insolubles (%)	Brightness (%)
T-2	0.31	<0.01	0.05	21.2	30.8	47.1	99.5	1.45	0.4	91.5
89ROSS-02	0.39	<0.01	0.08	21.4	30.8	46.9	99.6	1.44	0.2	90.7

Abbreviation: LOI: loss on ignition

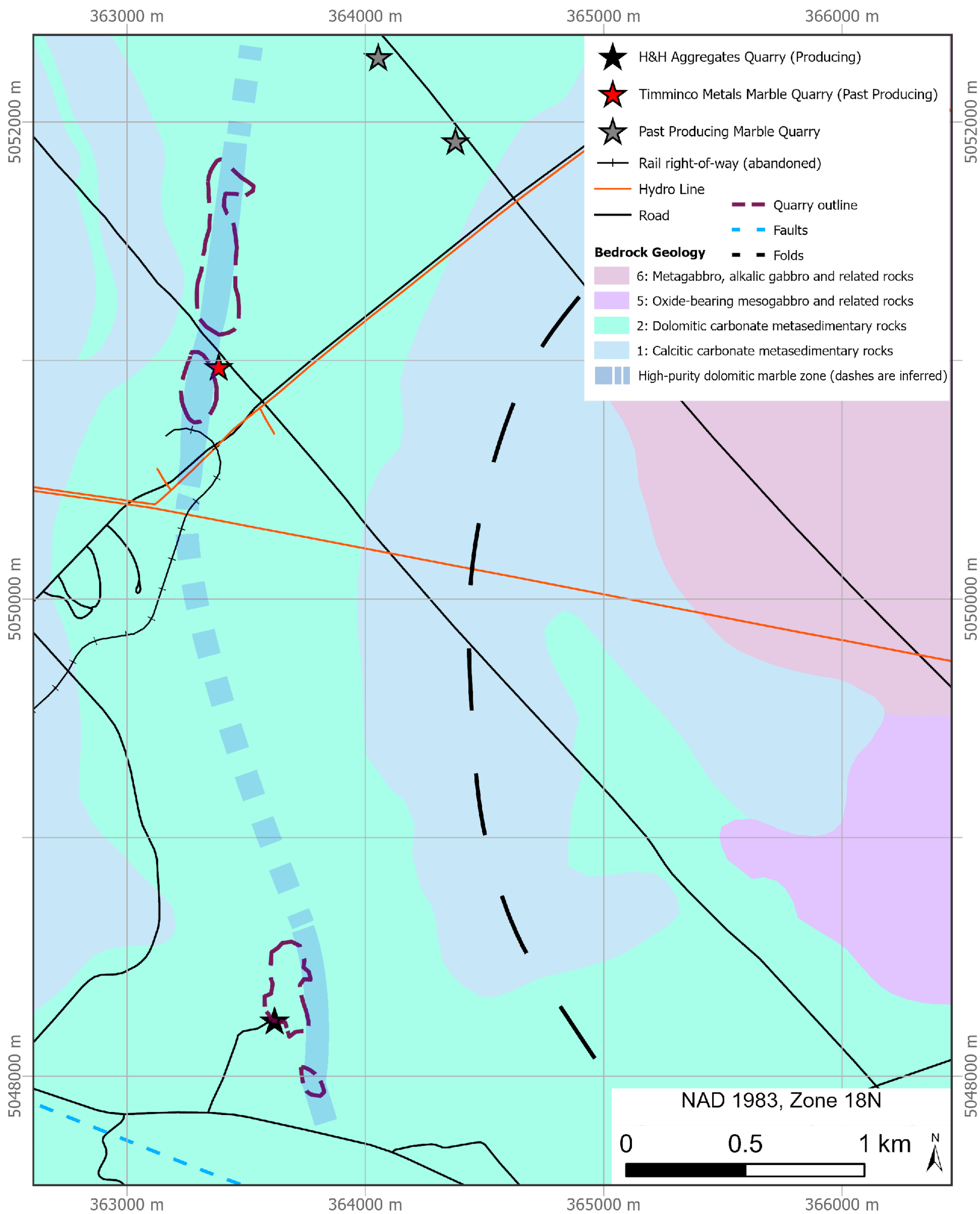

Figure 1. Geological map of the area surrounding the past-producing Timminco Metals marble quarry and the H&H Construction Inc. aggregates quarry. Note the potential for high-purity dolomitic marble along strike between the two sites (data *from* Ontario Geological Survey 2023; high-purity zone *from* LeBaron and MacKinnon 1990; geology *from* Azar 2015).

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Trusler, J.R. 1977. An engineering progress report on the Chromasco Corporation Limited magnesium production facilities, Haley Station, Renfrew County, Ontario; unpublished report for Ontario Ministry of Natural Resources, 80p.

United States Geological Survey 2023. Mineral commodity summaries 2023; United States Geological Survey, 210p. doi.org/10.3133/mcs2023

HIGHLIGHTS

- **Increasing global demand for high-purity calcite is driven by paper, paint and plastics industries, and the development of a new biopolymer industry**
- **Global demand for high-purity dolomite due to increasing use in agriculture and wastewater treatment**
- **The extensive Grenville marble belts in southeastern Ontario have the potential to host significant economically valuable high-purity marbles**

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Magnificent Marbles of Southeastern Ontario – High-Purity Carbonates

High-purity calcitic and dolomitic marbles are used as sources of industrial minerals. High-purity calcite is used in the manufacturing of paper, paint, plastics, ceramics, adhesives, packaging, pharmaceuticals, as a whitener, and in agriculture. High-purity dolomite is used in the manufacturing of paint, paper, plastics, rubber, ceramics, glass, soaps and detergents, fertilizers, asphalt, concrete, as a flux and refractory material, and as a source of magnesium (Dorado-Troughton, this volume). As technology advances, so too does the use and need for high-purity calcitic and dolomitic marbles.

In September 2023, Global Industry Analysis Inc. released a report stating that the global calcium carbonate market, estimated to be worth US$23.2 billion in 2022, is projected to increase to US$36.2 billion by 2030, with an anticipated compound annual growth rate (CAGR) of 5.7% from 2022 to 2030. Canada's calcium carbonate market is projected to grow at a CAGR of 5% from 2022 to 2030. The major drivers of increased demand for calcium carbonate include the paper industry, use as a filler in paints and coatings, a global increase in agriculture, and the development of a new industry for biopolymers (Calcium Carbonate – Global Strategic Business Report www.researchandmarkets.com/reports/354874/calcium_carbonate_global_strategic_business#tag-pos-4 [accessed September 5, 2023]).

A report released in July 2023, by Grand View Research, predicts the dolomite market will reach around US$3 billion by 2030, with a CAGR of 6.8% from 2023 to 2030. Drivers for the dolomite market are increased steel production, growing demand for dolomite in agriculture, glass and ceramic manufacturing, and use in wastewater treatment (Dolomite Market Size, Share and Trends Analysis Report by Product (Calcined, Sintered), by End-Use (Iron and Steel, Construction, Glass and Ceramics), by Region, and Segment Forecast, 2023 – 2030 www.researchandmarkets.com/reports/5165364/dolomite-market-size-share-and-trends-analysis#src-pos-16 [accessed September 11, 2023]).

High-Purity Marbles in Southeastern Ontario

The Central Metasedimentary Belt within the Grenville Province of southeastern Ontario hosts extensive marble belts (Figure 1), many of which are known to contain high-purity calcitic and dolomitic marbles. Omya is a current producer of high-purity calcite from their Tatlock quarry in Darling Township. The quarry is about 1 km long by 400 m wide (www.lanarkhighlands.ca/lh-discover/visiting/omya-s-tatlock-quarry) and extracts up to 650 000 t yearly depending on demand from the paint, paper and plastic industries (LeBaron and Smith 2018).

Mancini, L.M. 2024. Magnificent marbles of southeastern Ontario – High-purity carbonates; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.8-12.

Other locations where deposits of high-purity marbles have been documented are listed below:

- In 1974, Omya completed a diamond-drilling program on the Lockwood property in Elzevir Township. From the results, Omya estimated the deposit contained 3 million tonnes of white, high-purity calcitic marble (LeBaron and MacKinnon 1990).
- Coloured Aggregates produces terrazzo from white dolomitic marble in Ashby Township (LeBaron and Smith 2018).
- There are several past producers of high-purity calcite and dolomite, including Jamieson Lime Company in Horton Township. The Jamieson quarry produced a high-calcite lime in 2 kilns with a combined 23 t per day capacity (Gouge 1938).
- A second quarry owned by Jamieson, the Payne quarry in Horton Township, shipped around 136 t per week of dolomite to paper mills during summer months (Satterly 1944). Results from sample PM54, collected from the Payne quarry by the Ontario Geological Survey in 1977, showed a high-purity, high-brightness calcite-dolomite marble (Table 1).

Figure 1 shows the locations of the properties mentioned above.

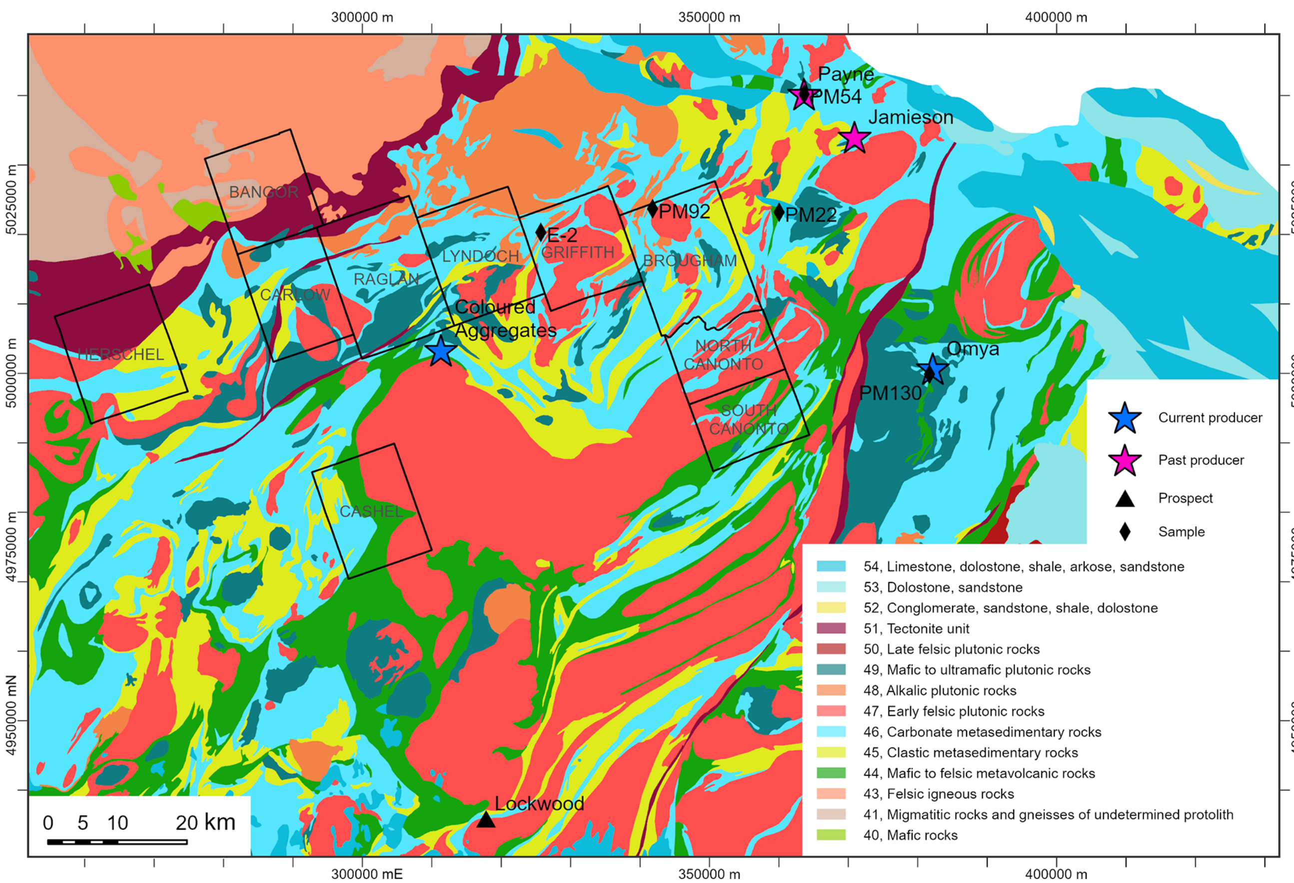

Figure 1. Simplified geological map of the Central Metasedimentary Belt in southeastern Ontario showing the locations of the high-purity carbonate properties mentioned in the article (Lockwood property, and the Jamieson, Payne and Tatlock quarries) and the samples from Table 1. The townships with available claim cells are outlined in black. Data *from* Vos and Storey (1979), Storey and Vos (1981) and LeBaron and MacKinnon (1990). Geology *from* Ontario Geological Survey (2011). Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 18N.

Results from several geochemical studies conducted by the Ontario Geological Survey show that many of the Grenville marbles contain high-purity, high-whiteness and brightness calcite and dolomite deposits. Table 1 lists 5 results from the approximately 2000 samples collected and analyzed by the Ontario Geological Survey from the early 1900s to 2018. The 5 samples demonstrate the high-purity potential of marbles in the Bancroft, Elzevir and Sharbot Lake terranes (*see* Figure 1). For more information on the geochemical studies of the Grenville marbles, please refer to the following studies:

- Marbles of the Pembroke–Renfrew Area (Vos and Storey 1979),
- Industrial Minerals of the Pembroke–Renfrew Area, Part 1: Marble (Storey and Vos 1981),
- Geochemistry of Grenville Marble in Southeastern Ontario (Grant, Papertzian and Kingston 1989),
- Precambrian Dolomite Resources in Southeastern Ontario (LeBaron and MacKinnon 1990),
- Precambrian and Paleozoic Geology of the Perth Area, Grenville Province (Easton 2015),
- Geology and Mineral Potential of the Carleton Place Area, Grenville Province (Easton 2018).

Table 1. Selection of samples from geochemical studies conducted by the Ontario Geological Survey in southeastern Ontario. Sample locations within the Grenville marbles are shown in Figure 1.

Sample	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	MgO (%)	CaO (%)	LOI (%)	Total (%)	CaO:MgO	Acid Insolubles (%)	Brightness (%)
[1]PM22	0.83	0.2	0.4	21.1	30	47.7	100.2	1.42	0.2	91.3
[1]PM54	1	0.1	0.3	21.5	30.4	47.2	100.5	1.41	0.32	91
[1]PM92	1.09	<0.1	0.3	21.5	30.2	47.3	100.4	1.4	0.72	90.1
[1]PM130	0.73	<0.1	0.2	1.1	53.3	44.6	99.9	48.45	0.52	93.6
[2]E-2	1.56	0.03	0.14	21.2	30.9	45.6	99.4	1.46	1.4	90.3

Abbreviation: LOI: Loss on Ignition. [1]Vos and Storey (1979); [2]LeBaron and MacKinnon (1990).

Recommendations for Exploration

With the predicted increase in demand for high-purity calcite and dolomite, it is recommended to continue exploration of the marble belts in southeastern Ontario. The online Ontario Mineral Inventory database (Ontario Geological Survey 2023) lists 40 locations for high-purity marbles that include past producers, prospects, occurrences and discretionary occurrences (Table 2). These locations are in townships with marble belts that were sampled for the Ontario Geological Survey's geochemical studies. Townships with available claim cells in these marble belts include Brougham, Cashel, Griffith, Herschel, Lyndoch, South Canonto and Raglan. Townships with available claim cells in marble belts that had minor amounts of exploration include Bangor, Carlow, Glamorgan and North Canonto.

Although there has been significant exploration and production in Grenville marbles, only portions of the marble belts have been examined. Much more exploration is required to fully establish the Central Metasedimentary Belt's potential to host significant, economically valuable high-purity calcite and dolomite deposits.

Table 2. High-purity marble occurrences in the Central Metasedimentary Belt in southeastern Ontario. Data *from* OMI (Ontario Mineral Inventory), Ontario Geological Survey (2023).

OMI Number	Township	Location Name	Deposit Status
MDI31F07NW00008	Admaston	Colton Lake	Occurrence
MDI31F07SE00035	Bagot	Goudge Sample 138	Discretionary Occurrence
MDI31F07SW00029	Bagot	Bagot Lot 29 Con 8 Area A	Occurrence
MDI31F07SW00031	Bagot	MA6 Calabogie west, north part	Discretionary Occurrence
MDI31F07SE00018	Bagot	Sample PM17	Discretionary Occurrence
MDI31F07SE00036	Bagot	Goudge Sample 137	Discretionary Occurrence
MDI31C12SW00011	Belmont	Belmont Calcite	Developed Prospect With Reported Reserves or Resources
MDI31F07SW00032	Blithfield	MA6 Calabogie West - South Part	Discretionary Occurrence
MDI31E01SE00005	Blithfield	Calabogie Lake	Discretionary Occurrence
MDI000000003127	Brougham	K9 Graphite	Occurrence
MDI000000001256	Brougham, Grattan	Highway 41 Area	Occurrence
MDI31F06NW00008	Brudenell	OGS Sample PM-39	Occurrence
MDI31F04NE00020	Carlow	Miller Sample 1903-1	Discretionary Occurrence
MDI31F06NE00021	Grattan	Newfoundout Area	Discretionary Occurrence
MDI31F06SE00026	Griffith	Two Island Quarry	Prospect
MDI31F06SE00016	Griffith	Sample PM87	Discretionary Occurrence
MDI31F07NE00028	Horton	Jamieson Quarry #4	Past Producing Mine Without Reserves or Resources
MDI31F10SE00005	Horton	Payne Quarry	Past Producing Mine Without Reserves or Resources
MDI31F07NE00015	Horton	Renfrew East Quarry	Past Producing Mine Without Reserves or Resources
MDI31F07NE00018	Horton	Jamieson Lime Quarry	Past Producing Mine Without Reserves or Resources
MDI31F07NE00017	Horton	Renfrew Town Quarry	Prospect
MDI31F06SW00033	Lyndoch	OGS Sample PM41	Discretionary Occurrence
MDI31E01SE00002	Lyndoch	OGS Sample 1953-2	Occurrence
MDI31F06SW00022	Lyndoch	OGS Sample PM 42	Discretionary Occurrence
MDI31F06SW00021	Lyndoch	OGS Sample PM 40	Discretionary Occurrence
MDI31F03NE00006	Matawatchan	Roquette Lake	Discretionary Occurrence
MDI000000001252	Matawatchan	Leclaire Lake	Discretionary Occurrence
MDI31F03NE00013	Matawatchan	Anna Lake Area	Discretionary Occurrence
MDI31F03NE00007	Matawatchan	Camel Chute	Discretionary Occurrence
MDI31F03NE00004	Matawatchan	Centennial Lake Area	Discretionary Occurrence
MDI31F03NE00008	Matawatchan	Wolfe Rapids	Discretionary Occurrence
MDI31F04SW00121	Mayo	Wanamaker Lake Area	Discretionary Occurrence
MDI31F07NE00053	McNab	Goudge Sample 142	Discretionary Occurrence
MDI31F07NE00038	McNab	East of Goshen Station	Discretionary Occurrence
MDI31F06SW00106	Raglan	Schutt Area	Discretionary Occurrence
MDI31F10NW00021	Ross	Forresters Marble	Discretionary Occurrence
MDI31F10NE00002	Ross	Sample 89 ROSS-04	Occurrence
MDI31F10SE00006	Ross	Dominion Magnesium Ltd.	Past Producing Mine Without Reserves or Resources
MDI31F06NE00020	Sebastopol	Clontarf Marble Area	Occurrence
MDI31F11NE00004	Wilberforce	Albert Biederman Quarry	Past Producing Mine Without Reserves or Resources

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Magmatic Sulphide Mineralization (Nickel-Copper-Cobalt-Platinum Group Elements) Associated with Mafic Intrusive Rocks in the Southern Province, Sudbury RGP District

HIGHLIGHTS

- **Magmatic sulphide mineralization (Ni-Cu-Co-PGE) is associated with the East Bull Lake and Nipissing intrusive suites in the Sudbury RGP District**
- **The intrusions hosting the mineralization are layered (differentiated), with the stratiform mineralization generally occurring at, or within 100 m of, the basal contact**

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Sudbury is famous for the nickel-copper-cobalt-platinum group elements (Ni-Cu-Co-PGE) mineralization associated with the Sudbury Igneous Complex (SIC; impact melt sheet). However, magmatic sulphide mineralization, which includes all, or any of, Ni-Cu-Co-PGE, also occurs in mafic intrusive rocks not associated with the Sudbury Igneous Complex in the Southern Province within the Sudbury Resident Geologist Program (RGP) District (Figure 1). The 2 main intrusive suites hosting the mineralization are the East Bull Lake intrusive suite (EBLIS) and the Nipissing intrusive suite (Nipissing). Based on the Ontario Mineral Inventory (OMI; Ontario Geological Survey 2023), there are 55 records (excluding the "Discretionary Occurrence" category) of mafic intrusion-hosted magmatic sulphide mineralization in either EBLIS or Nipissing intrusions. Of these 55 OMI records, 49 are categorized as "Occurrences" and 3 as "Prospects". Importantly, of the remaining 3 records, 1 is categorized as a "Past-Producing Mine" with reserves and resources, and 2 are categorized as "Developed Prospects" with resources, all of which are National Instrument 43-101 (NI 43-101) compliant estimates. The "Past-Producing Mine", "Developed Prospects" and "Prospects" are listed in Table 1 and labeled on Figure 1. The exploration projects with associated NI 43-101–compliant reserve or resource estimates are the East Bull Palladium Project (Canadian Palladium Resources Inc.; Stone et al. 2022), the River Valley Palladium Project (New Age Metals Inc.; Bradfield et al. 2023), and the Shakespeare [*nickel*] project (Magna Mining Inc.; Armitage et al. 2022). Of the 52 OMI records categorized as "Occurrences" or "Prospects", 5 of the occurrences are located on unclaimed land (Table 2, *see* Figure 1).

The EBLIS and Nipissing intrusions hosting the magmatic sulphide mineralization are layered mafic intrusions (Easton, James and Jobin-Bevans 2010; Jobin-Bevins 2004, and references therein; Figure 2). The mineralization generally occurs as disseminated and blebby sulphides in the lower sections of the stratigraphy at, or within 100 m of, the basal contact (Easton, James and Jobin-Bevans 2010; Jobin-Bevins 2004; *see* Figure 2). Many of the occurrences hosted in Nipissing intrusions have mineralization restricted to their lower 100 m (as described in their OMI records). However, at the Shakespeare deposit the mineralization occurs near the centre of the intrusion at the base of the upper magmatic package (Sproule et al. 2007; *see also* Figure 2). In the EBLIS, the units hosting the mineralization are described as chaotic, inclusion bearing,

Péloquin, A.S. 2024. Magmatic sulphide mineralization (nickel-copper-cobalt-platinum group elements) associated with mafic intrusive rocks in the Southern Province, Sudbury RGP District; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.13-17.

brecciated and/or varitextured (Hrominchuk 2000; Peck et al. 1995; Bradfield et al. 2023; Stone et al. 2022). The texture or morphology of the units hosting the mineralization in the Nipissing intrusive suite is less well documented. The addition of sulphur through crustal contamination is considered necessary to produce magmatic nickel deposits (Keays and Lightfoot 2009). Assimilation of sulphur due to crustal contamination induces sulphur saturation, which triggers the precipitation of sulphides. This process is interpreted to be one of the controls for the magmatic sulphide mineralization in the Nipissing and EBLIS intrusions (e.g., the River Valley intrusion; Jobin-Bevans 2004).

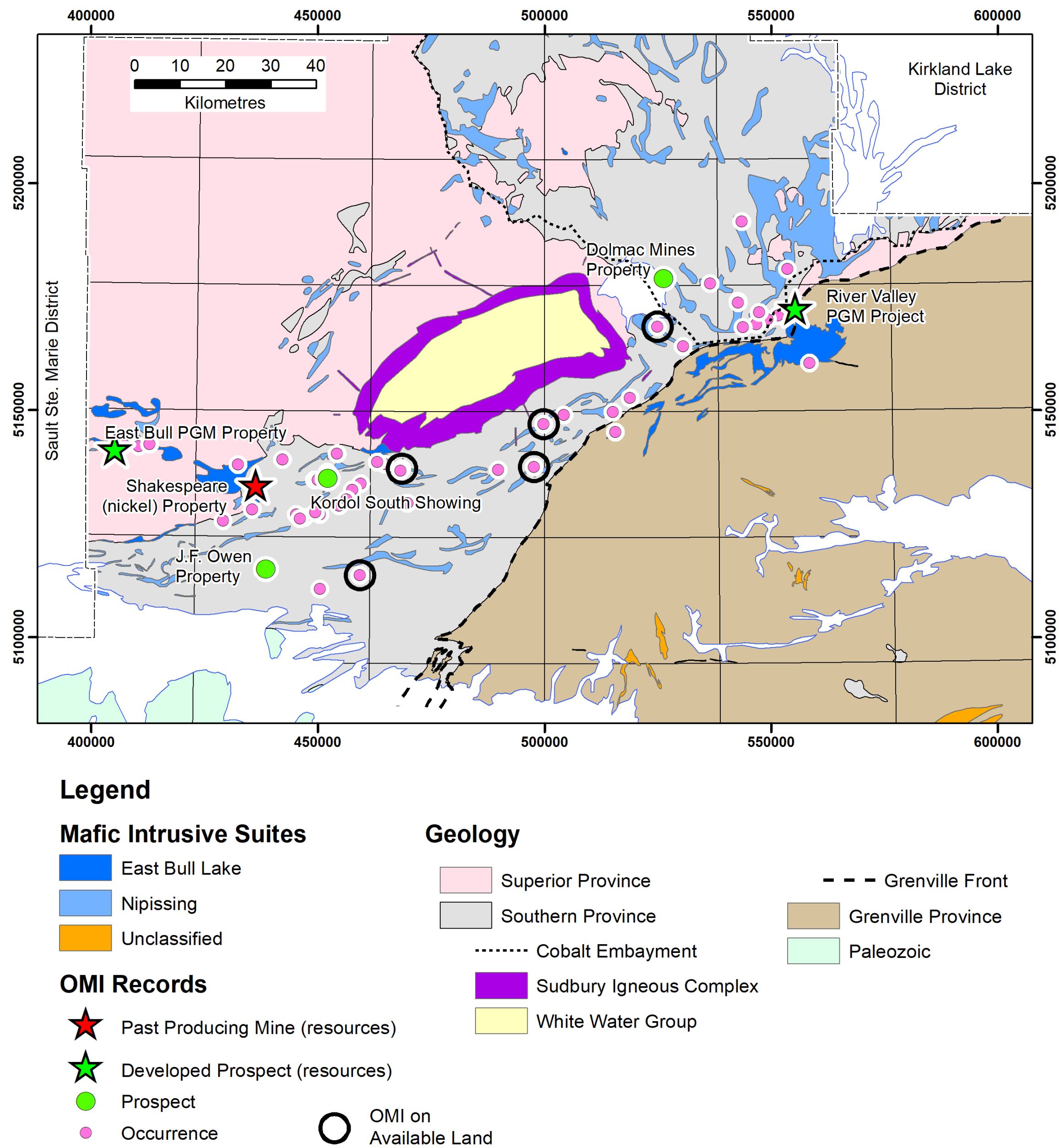

Figure 1. Simplified geological map (*after* Ontario Geological Survey 2011) showing mafic intrusive suites and associated Ni-Cu-Co-PGE mineralization (Ontario Geological Survey 2023) in the Southern Province, Sudbury District. Location information provided as Universal Transverse Mercator (UTM) co-ordinates using North American Datum 1983 (NAD83) in Zone 17.

Table 1. Mafic intrusion-related Ni-Cu-Co-PGE in the Sudbury RGP District, more significant than “Occurrence” in Ontario Mineral Inventory (Ontario Geological Survey 2023).[1] (Labeled on Figure 1.)

OMI ID	OMI Status	Name	Intrusive Suite	Township	Easting (NAD83)	Northing (NAD83)
MDI41I05SW00076	Past Producing Mine (resources * reserves)	Shakespeare	Nipissing	Shakespeare	436297	5133525
MDI000000001421	Developed Prospect (resources)	River Valley PGM Project	EBLIS	Dana	555371	5172514
MDI000000002507	Developed Prospect (resources)	East Bull PGM Property	EBLIS	Gerow	405231	5141483
MDI41I05SE00069	Prospect	Kordol South Showing	Nipissing	Hyman	452170	5134999
MDI41I04NW00031	Prospect	J.F.Owen Property	Nipissing	Mongowin	438502	5115025
MDI41I15SE00022	Prospect	Dolmac Mines Property	Nipissing	Rathbun	526276	5179010

[1] A full list of the OMI records on Figure 1 is available from the author.
Abbreviations: ID, identification; NAD83, North American Datum 1983; OMI, Ontario Mineral Inventory.

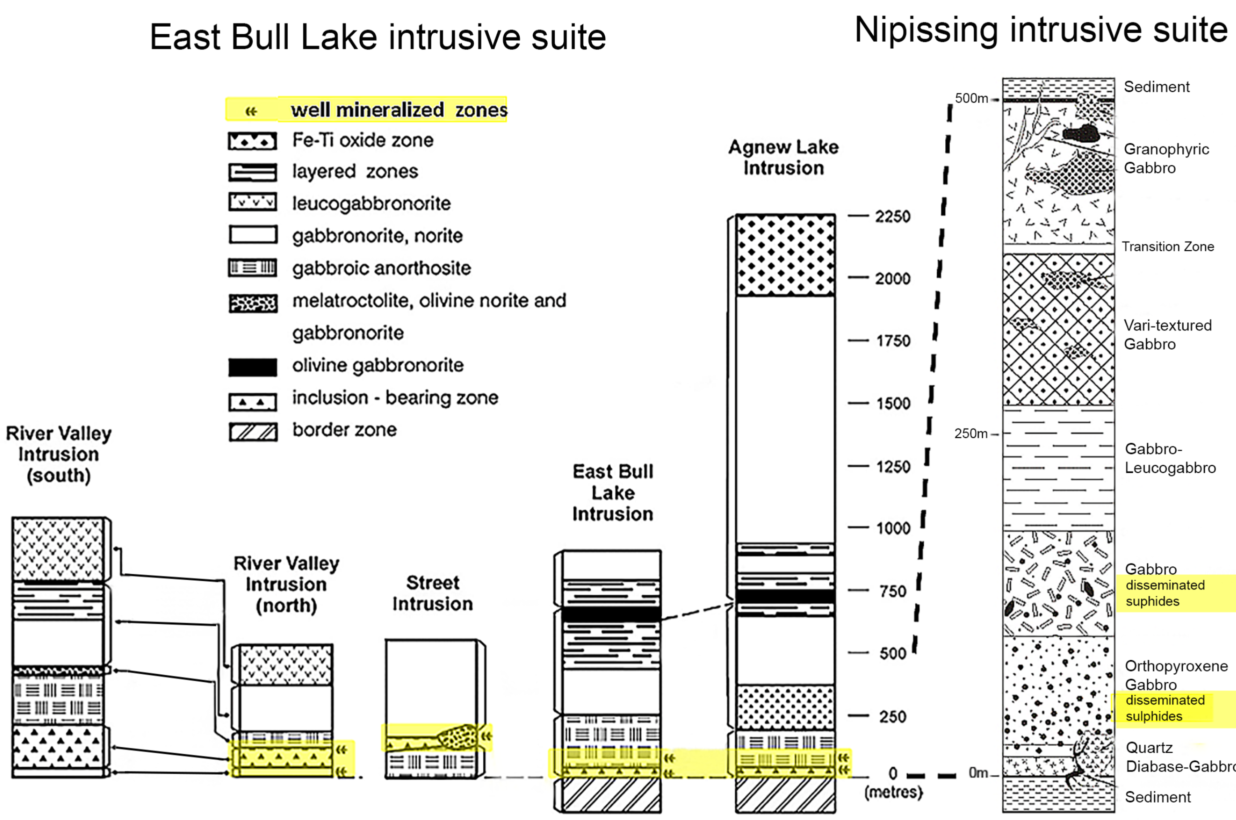

Figure 2. Generalized stratigraphic columns for the several East Bull Lake intrusions and a composite of the Nipissing intrusive suite, showing the layering of the intrusions and the position of the mineralization within the sections (EBLIS *modified from* Easton et al. 2010, which includes data *from* Easton 2003 (River Valley section) and modified figures *from* Peck et al. 1995 (East Bull Lake section), Vogel 1996 (Agnew Lake Intrusion section); Nipissing intrusive suite section *modified from* Jobin-Bevans 2004, which is itself *modified after* Lightfoot and Naldrett 1996).

Table 2. Mafic intrusion-related Ni-Cu-Co-PGE occurrences in the Sudbury RGP District, from the Ontario Mineral Inventory (Ontario Geological Survey 2023) that are located on unclaimed land. (Circled on Figure 1.)

OMI ID	OMI Status	Name	Intrusive Suite	Township	Easting (NAD83)	Northing (NAD83)
MDI000000001930	Occurrence	Consolidated Venturex Holdings Inc.	Nipissing	Denison	468497	5137120
MDI41I06NE00053	Occurrence	Ramsey Lake	Nipissing	McKim	499780	5146941
MDI41I10NE00078	Occurrence	West Side Outlet Bay	Nipissing	Scadding	524886	5168325
MDI41I04NE00039	Occurrence	Little Bear Lake	Nipissing	Roosevelt	459249	5113631
MDI41I06NE00066	Occurrence	Meito-Laasko	Nipissing	Broder	497629	5137494

Abbreviations: ID, identification; NAD83, North American Datum 1983; OMI, Ontario Mineral Inventory.

Recommendations for Exploration

Hrominchuk (2000) provided recommendations for exploring for PGEs in the EBLIS, which can also be applied to the Nipissing, and are listed below (quoted):

- Detailed geological mapping, concentrating on rocks located at or near areas where an igneous contact is known or inferred. [Including noting the presence of sulphide- or sulphur-bearing units that could be assimilated into the magma resulting in sulphur saturation.].
- Focus on rocks that show evidence of contamination (e.g., fragment-bearing, quartz-eye-bearing), and those areas containing rocks with a contaminated geochemical signature.
- Mapping and sampling of heterogeneous gabbronoritic rocks of the Inclusion/Fragment-Bearing Zone. These may occur some hundreds of metres or more from the contact of the intrusion.
- Sampling of, and determination of PGE concentration, in intrusion rocks without visible sulphides or oxides, as many samples that are highly anomalous in PGE are largely devoid of sulphide.
- The use of geophysical surveys to: 1) identify contacts in areas where exposure is poor and to determine intrusion thickness near to the footwall (e.g., magnetic, gravity surveys), and 2) outline mineralization in areas of high mineral potential (e.g., induced-polarization surveys).
- Utilization of surficial sediment techniques (Tardif 2000) in areas of poor exposure or for regional exploration in drift covered areas.

In addition, Miscellaneous Release—Data (MRD) 336 (Jobin-Bevins 2016) provides a detailed geochemical exploration guide for Nipissing gabbros, which may also be useful for non-Nipissing intrusion-related Ni-Cu-Co-PGE exploration. Within the MRD, the reader is referred to the file *MRD336_Nipissing Gabbro Exploration Guidelines.pdf*.

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5

HIGHLIGHTS

- **A quick and easy way to look for quality exploration areas open for registration**
- **OGSFocus available using Google Earth or ArcGIS/ QGIS – take your pick!**
- **Helping novice and experienced prospectors find quality areas to explore**

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Finding High Quality Exploration Areas Open for Registration, in the Kirkland Lake District, Using the OGSFocus Tool

Resident Geologist Program staff are occasionally asked for recommendations for potential prospecting or exploration areas that are open for registration. OGSFocus (Ontario Geological Survey 2023a) is a quick and easy-to-use self-help tool, that can assist both experienced and novice prospectors alike in the daunting task of where to put those precious exploration dollars to work!

OGSFocus is a series of map layers that quantify data from the Ontario Assessment File Database (OAFD), Ontario Drill Hole Database (ODHD) and Ontario Mineral Inventory (OMI) database. A score based on the quantity of available data is assigned to each cell in the Mining Lands Administration System (MLAS) provincial grid along with a relative data rating. The resulting "Data Rating Grid" (DRG) provides a visual representation of the quantity of data available. OGSFocus layers can be used as a targeting tool to draw attention to areas of considerable historical exploration including those available for acquisition, in addition to highlighting those areas open for registration where, for various reasons, relatively little exploration data is publicly available. A more precise overview and technical description of OGSFocus is presented by Cundari (2021).

The OGSFocus tool can be accessed from the OGSEarth portal at www.geologyontario.mndm.gov.on.ca/ogsearth.html#ogsfocus or using the new GeologyOntario portal at www.hub.geologyontario.mines.gov.on.ca, where links can be found to download files in both *.kml* and *.shp* file formats, for direct use with Google Earth or ArcGIS/QGIS, respectively. Files are updated bi-weekly.

This article provides a district-scale presentation to demonstrate the distribution of areas open for registration and the accompanying DRGs, valid as of August 15, 2023. Whilst the DRGs presented here may no longer be valid at the time of publication, the general demonstration of how OGSFocus can be used remains unchanged.

A general map of the Kirkland Lake District showing the DRG (using ArcGIS) is shown in Figure 1. The DRG provides a visual representation of the quantity of exploration data available, where warm colours or high ratings (i.e., orange and red have the highest ratings) indicate greater quantities of available technical data (e.g., assessment filings, drilling information and mineral occurrence information). The author has arbitrarily selected 4 areas of interest, which are representative of the district, and provides some suggestions for potential areas of exploration open for registration, at the time of writing.

Chadwick, P.J. 2024. Finding high quality exploration areas open for registration, in the Kirkland Lake District, using the OGSFocus Tool; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.18-24.

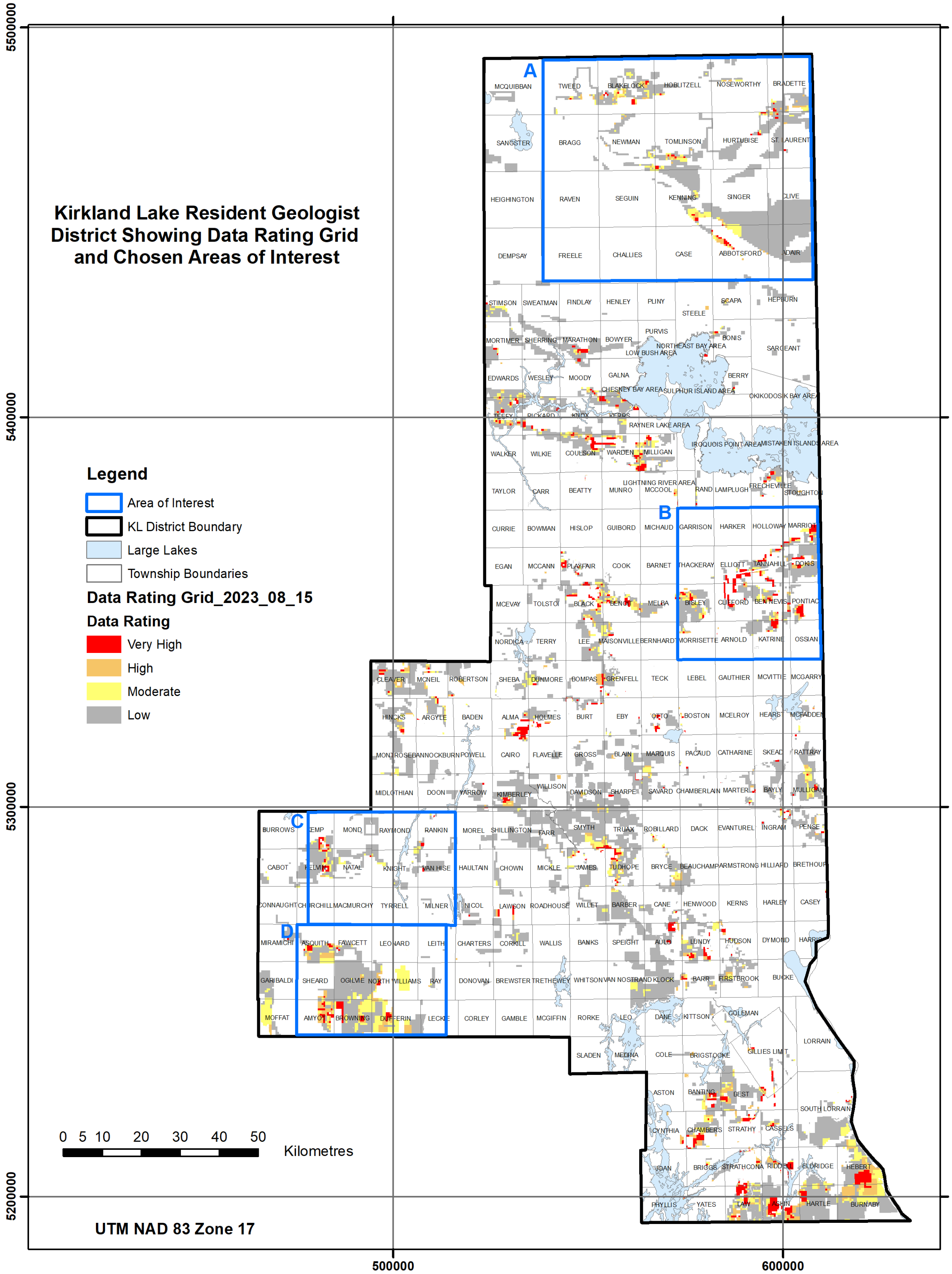

Figure 1. Kirkland Lake Residential Geologist District showing Data Rating Grid (Ontario Geological Survey 2023a) and selected areas of interest, shown as blue boxes and labelled A, B, C and D.

A geological map of Target Block-A showing the DRG, Ontario Mineral Inventory (OMI) locations and major faults is shown in Figure 2 and the same area showing the DRG using Google Earth™ is shown in Figure 3. Cells showing a high data rating that are also open for registration are shown as red squares on Figures 2 and 3. Candidates for exploration may be those also associated with major geological structures, such as the fault in the southern half of Tomlinson Township.

There are many reasons why areas open for registration have high or low data ratings. For example, ground access to the area or an abundance of overburden may affect the likelihood of an area being explored. In any case, an explorer must do their due diligence and assess the area of interest firsthand. It is worth keeping in mind that a lack of available data for an area does not necessarily diminish its potential for a discovery!

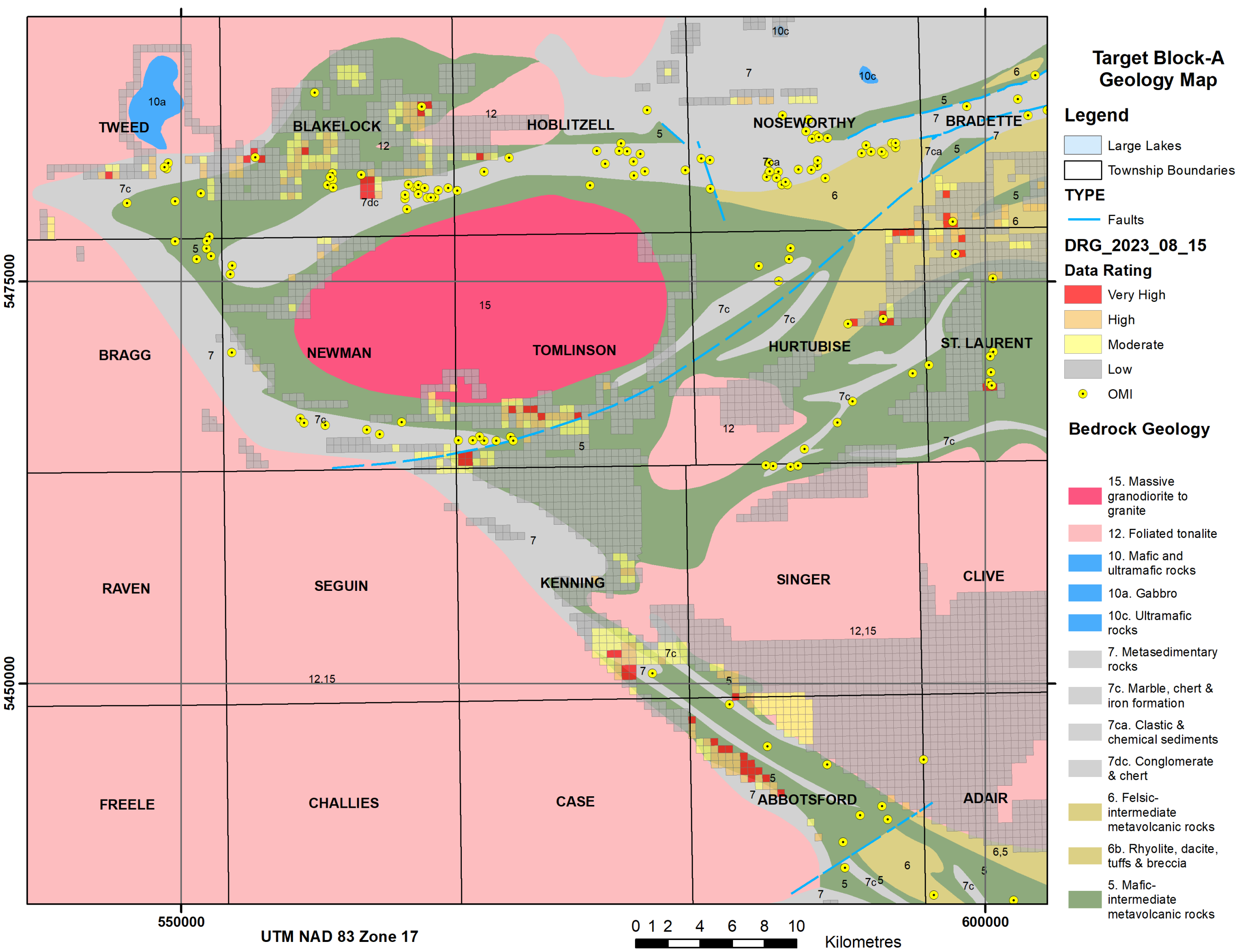

Figure 2. Geological map of Target Block-A (Ontario Geological Survey 2011), showing the Data Rating Grid for areas open for registration (Ontario Geological Survey 2023a) and Ontario Mineral Inventory locations (Ontario Geological Survey 2023b).

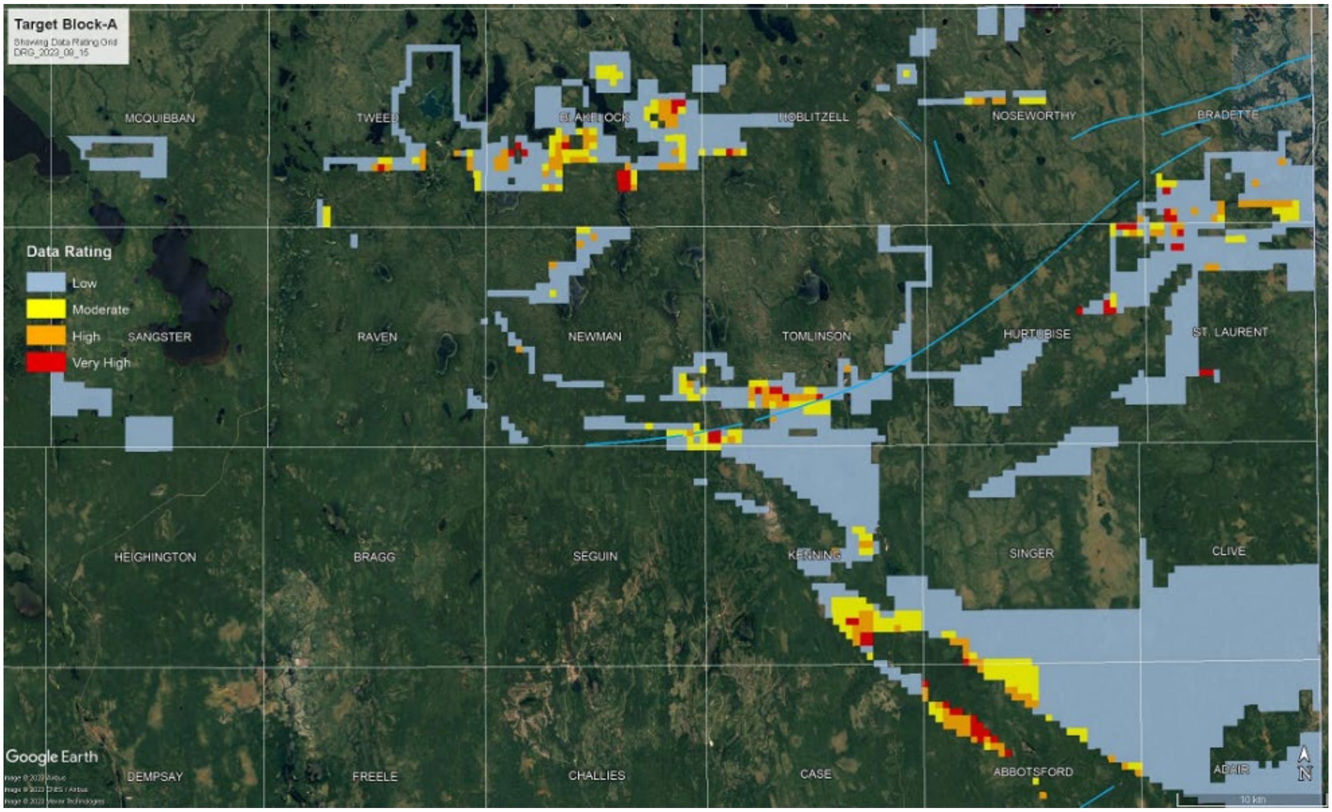

Figure 3. Google Earth™ mapping service image (image ©2022 Maxar Technologies) of Target Block-A, showing OGSFocus layer and major faults (blue lines) *from* Ontario Geological Survey (2011). Available online at https://www.geologyontario.mndm.gov.on.ca/ogsearth.html#ogsfocus. [accessed August 15, 2023]

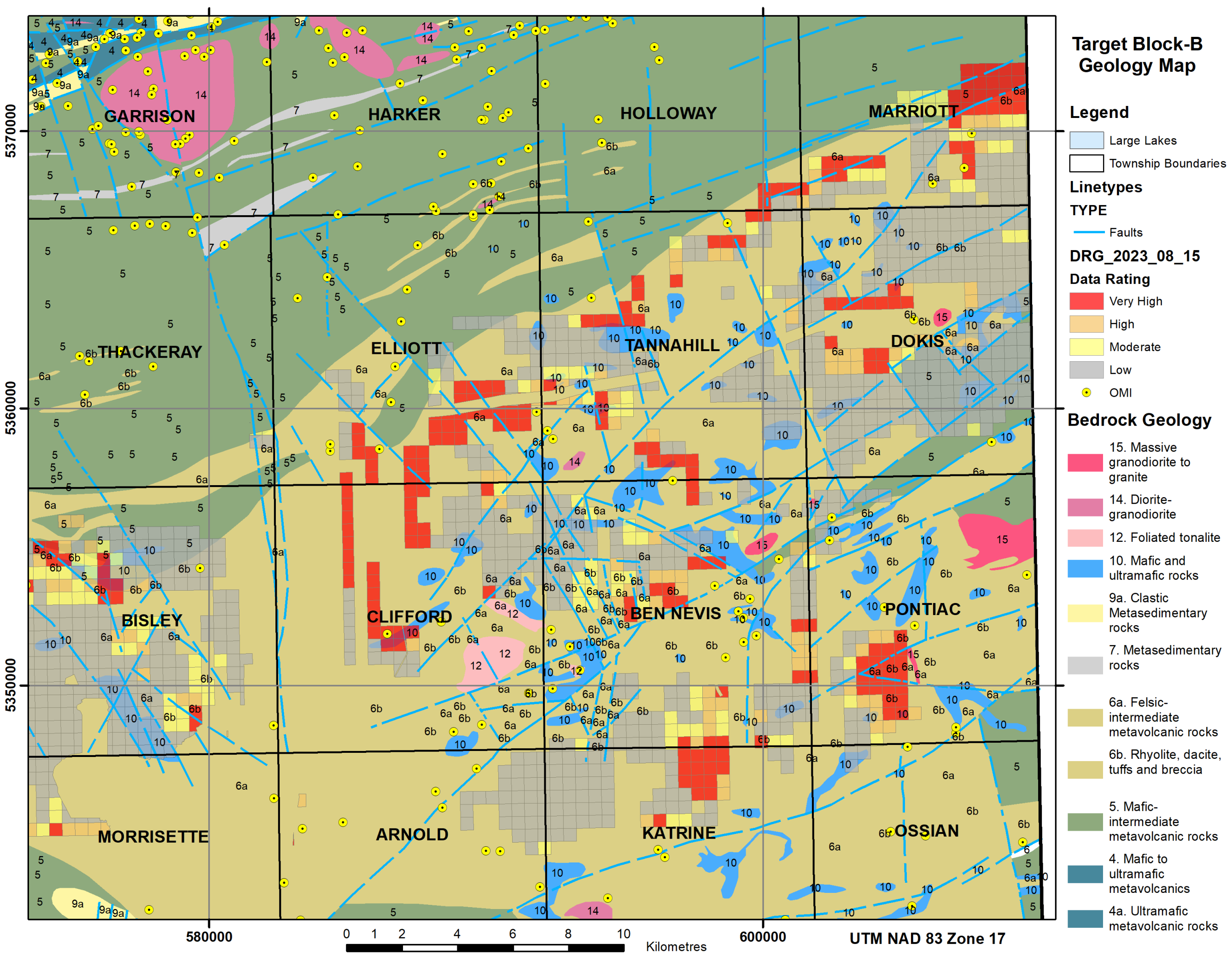

Figure 4. Geological map of Target Block-B (Ontario Geological Survey 2011), showing the Data Rating Grid for areas open for registration (Ontario Geological Survey 2023a) and Ontario Mineral Inventory locations (Ontario Geological Survey 2023b).

An overview of Target Block-B is represented in Figure 4 and shows some notable areas open for registration in Bisley, Ben Nevis and Dokis townships that are proximal to geological structures (faults) and rock types considered favourable to contain both vein-hosted lode-gold and volcanogenic massive sulphide (VMS) mineralization.

Target Block-C, as shown in Figure 5, shows a relative sparsity of cells open for registration; however, there are pockets of cells with high data ratings in areas of favourable rock types and structures as seen in Kemp and Kelvin townships. A group of cells open for registration in the northern and southwestern parts of Rankin Township and extending into the northeast corner of Knight Township, might also be good areas for entry-level prospecting and exploration.

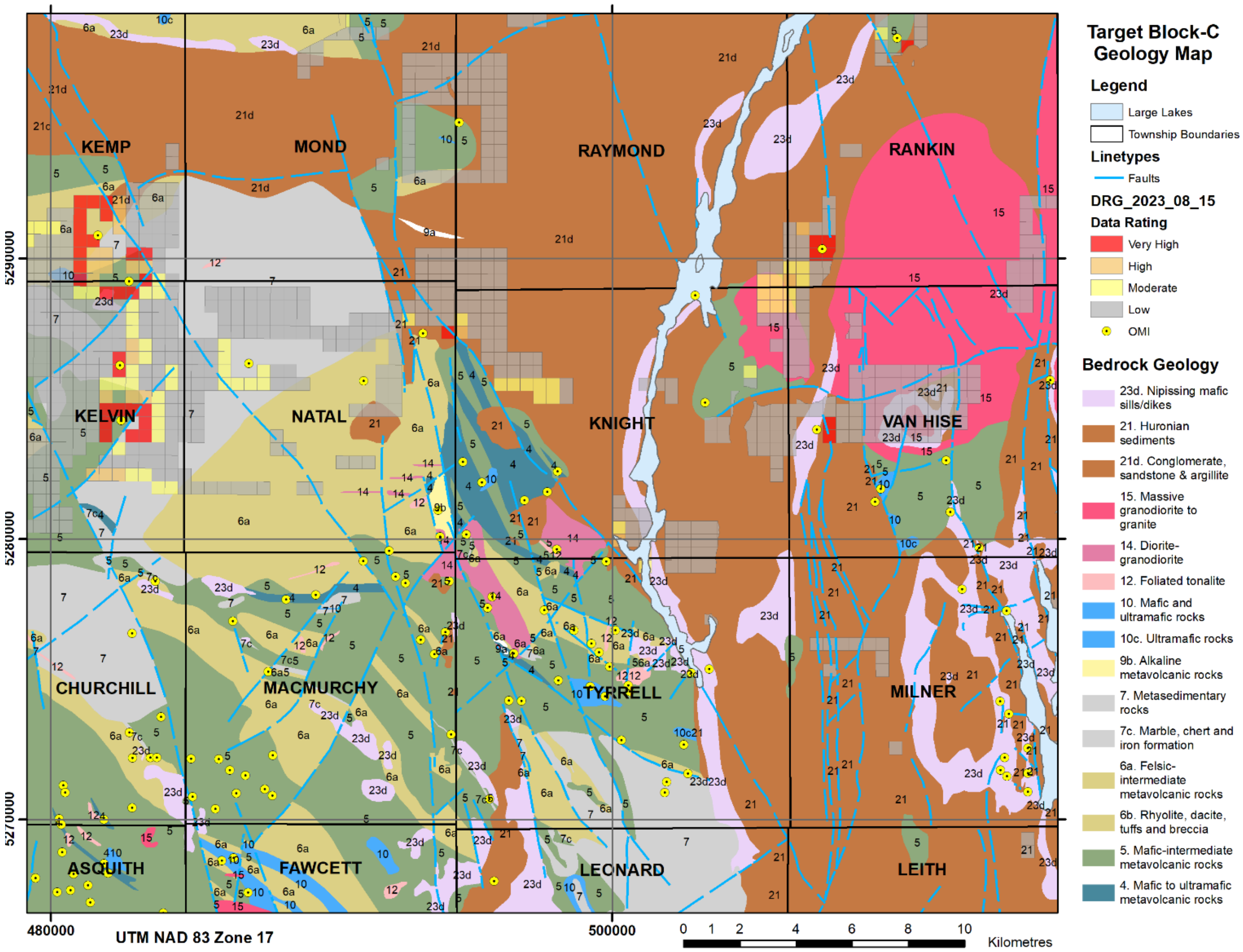

Figure 5. Geological map of Target Block-C (Ontario Geological Survey 2011), showing the Data Rating Grid for areas open for registration (Ontario Geological Survey 2023a) and Ontario Mineral Inventory locations (Ontario Geological Survey 2023b).

A final area of interest, Target Block-D, situated in the southwest corner of the Kirkland Lake District, is shown in Figure 6. The abundance of areas open for registration with high data ratings is evident, and worthy of assessment and evaluation. An example is in Asquith Township, where there are multiple OMI locations within mafic metavolcanic rocks and a mapped north-trending fault, which could be a good gold target. Similarly, the southeastern part of Amyot Township warrants follow-up assessment. Both North Williams and Dufferin townships have abundant cells open for registration, and many with a high data rating – likely because of previous exploration for cobalt and/or silver mineralization associated with Nipissing mafic sills and dikes and Huronian Supergroup sedimentary rocks.

It is important to note that the data ratings presented here are valid as of mid-August 2023, and the availability of cells open for registration and their associated data ratings may change by the time of publication. However, using OGSFocus to find potential areas of exploration open for registration remains worthwhile!

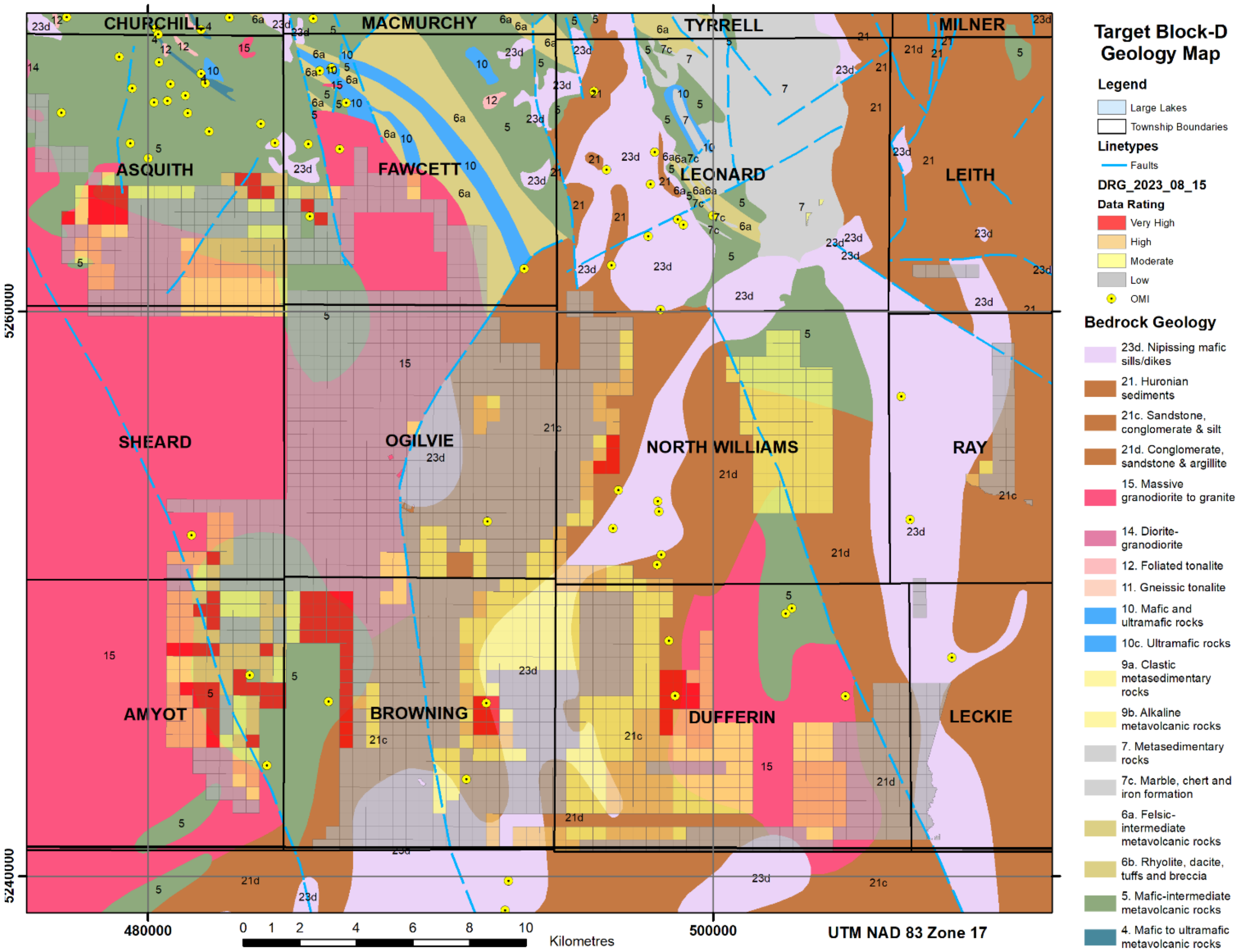

Figure 6. Geological map of the Target Block-D area (Ontario Geological Survey 2011), showing Data Rating Grid for areas open for registration (Ontario Geological Survey 2023a) and Ontario Mineral Inventory locations (Ontario Geological Survey 2023b).

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Nickel-Copper-PGE and Vein Gold Mineralization Proximal to the Round Lake Batholith

HIGHLIGHTS

- **Little information on the critical mineral potential of the near-parallel mafic to ultramafic metavolcanic rocks**
- **Komatiitic rocks proximal to the east margin of the Round Lake batholith could be channelized sheet flows**
- **Initial sampling from field investigation returned 860 ppm Ni, 413.2 ppm Cu and 18.42 weight % Fe**

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The Round Lake batholith is a large multiphase granitoid complex in the southern Abitibi Subprovince. The dominant rock type present within the batholith is a grey, medium-grained, massive, or moderately foliated to locally gneissic, biotite ± hornblende tonalite. At its eastern border, the batholith occupies the core of a regional anticline and is in contact with mafic to intermediate metavolcanic rocks (Figure 1). Foliation and gneissosity of the batholith define a geometry paralleling that defined by the stratigraphy and internal greenstone belt fabrics, indicating that the batholith has been folded along with the greenstone belt (Beakhouse 2011).

The mafic to intermediate metavolcanic rocks proximal to the eastern margin of the Round Lake batholith (EMRLB) contain documented occurrences of "critical" minerals dominated by copper, especially in the northeast and northwest quadrants of Pacaud and Catharine townships, respectively. However, there is little information on the critical mineral potential of the near-parallel mafic to ultramafic metavolcanic rocks (unit 4 on Figure 1) proximal to the EMRLB. The objective of this document is to direct mineral explorers' attention to these parallel mafic to ultramafic metavolcanic rock units, based on the results of field-based geological and geochemical investigations completed during the summer of 2023. Although bedrock was difficult to locate because of poor access and thick glacial overburden, basaltic and komatiitic rocks are exposed in limited roadcuts along Highway 560 in the northeast quadrant of Dack Township. Bedrock outcrops at 3 localities (*see* A, B and C on Figure 1) were investigated during this study and are described below.

Locality A (UTM 580175E 5297647N)

At this locality, a new 40 m long bedrock exposure can be seen where a new culvert was recently installed on the north side of Highway 560 (Photo 1A). The rocks are komatiitic. They are dark green to black in colour, fine- to coarse-grained, very weakly to locally strongly magnetic, and with weak and patchy red hematitic alteration. There are narrow (approximately 3 cm wide), parallel, very fine-grained seams within the rocks, with olivine and pyroxene spinifex texture noted. Sulphide mineralization is uncommon, occurring only up to 2% in places as fine disseminations of pyrite and chalcopyrite (Photo 1B).

Locality B (UTM 581359E 5298059N)

The outcrops at this locality are immediately north of Highway 560 and are similar to those at Locality A. Photo 1C shows knobby (cumulate?)

Suma-Momoh, J. 2024. Nickel-copper-PGE and vein gold mineralization proximal to the Round Lake batholith; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.25-28.

textures at this locality. A fine-grained basaltic outcrop at UTM 581376E and 5298070N is strongly magnetic, with visible black octahedral magnetite crystals. There are only up to about 1% very finely disseminated sulphides in the samples collected.

Locality C (UTM 581485E 5298108N)

A basaltic rock face is seen south of Highway 560 at this locality. Close examination revealed a pyrite-rich (up to 5% locally) mineralized breccia zone within the basaltic rock. A thin (approximately 2.5 cm wide), white crystalline quartz vein intrudes the rock face with an attitude of 112/49S. The quartz vein contains up to approximately 10% pyrite (Photo 1D).

All komatiitic rocks, regardless of assemblage, represent favourable magma sources for nickel-copper-PGE (platinum group element) mineralization (Ayer et al. 2005; Lesher and Keays 2002). The best-known examples, of Archean age, are in the Kambalda region of Western Australia. These deposits are localized in the lower parts of thick dunitic units that are interpreted as lava channels. Komatiite lava flowing turbulently through the channels thermally eroded and melted sulphur-rich floor rocks, leading to the segregation of nickel-copper-PGE-rich

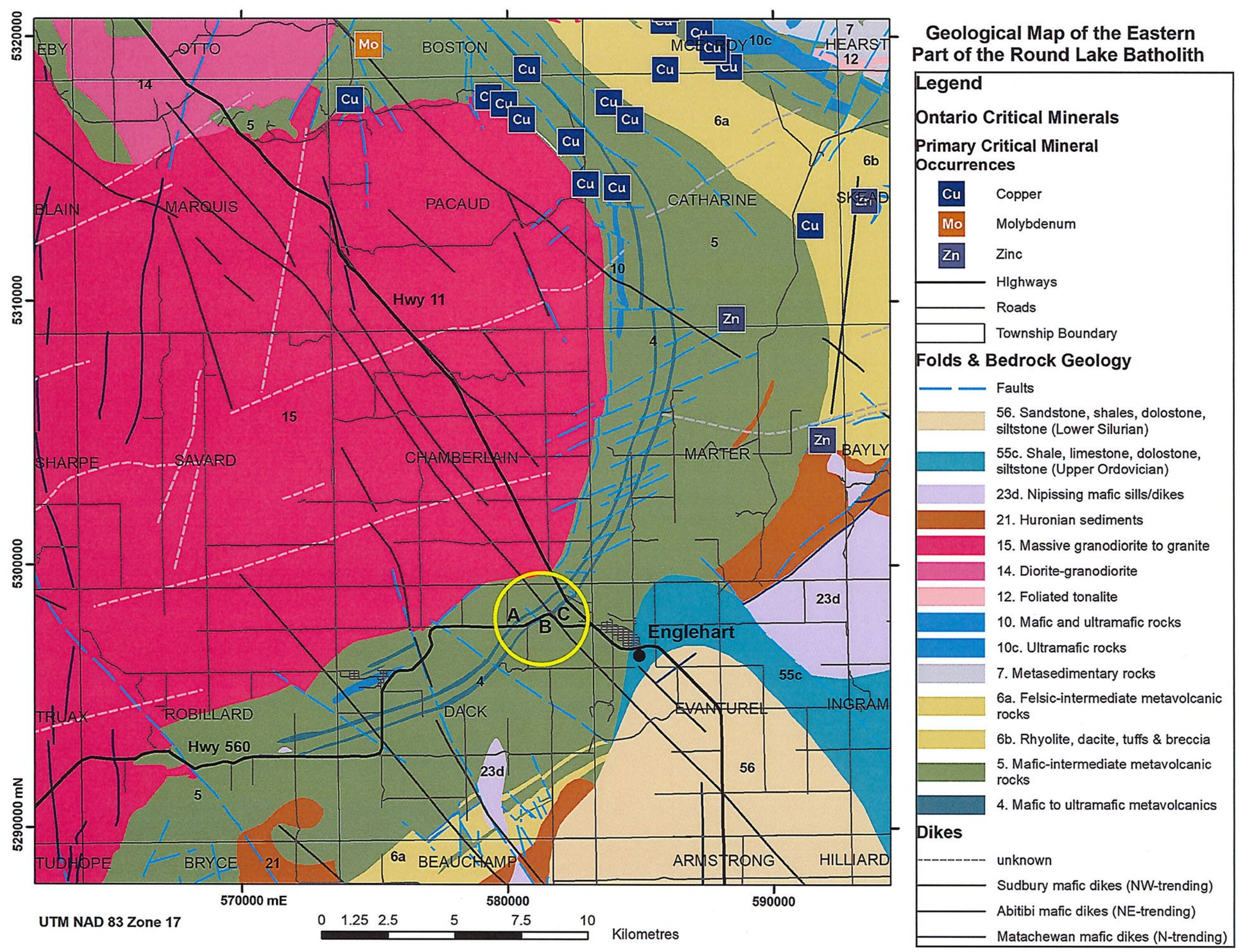

Figure 1. Geological map showing the eastern margin of the Round Lake batholith and associated Ontario Mineral Inventory "critical" mineral occurrences (Cu = copper, Mo = molybdenum, Zn = zinc), *from* Ontario Geological Survey (2023). Geology *from* Ontario Geological Survey (2011). Study area (localities A, B and C) enclosed by yellow circle. Universal Transverse Mercator (UTM) co-ordinates are provided using North American Datum 1983 (NAD83) in Zone 17.

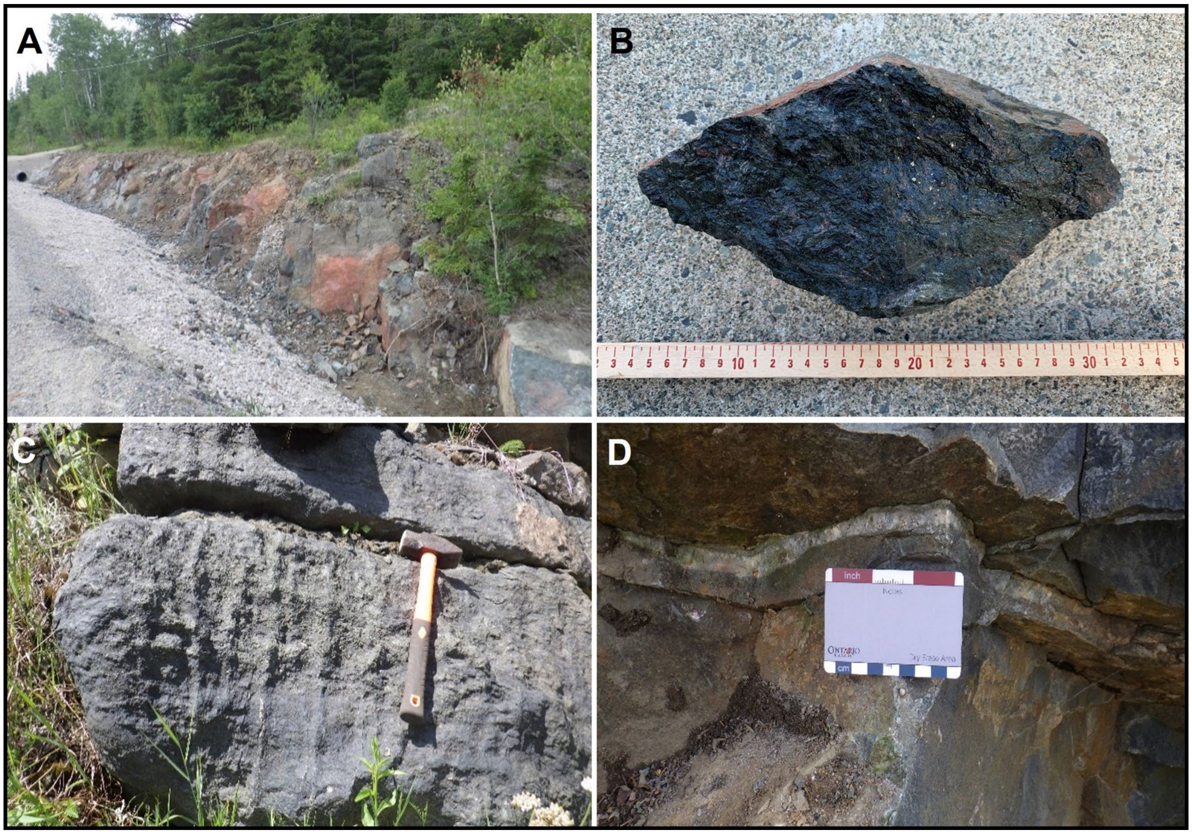

Photo 1. A) Exposed komatiitic rocks at locality A due to new culvert installation. Highway 560 is to the left of the photo. *Looking northwest*. B) Spinifex-textured komatiite sample (from locality A) with shiny specks of sulphides and reddish hematitic alteration. C) Black knobby horizon in komatiite, locality B. *Looking north*. D) Pyrite-bearing quartz vein (2.5 cm wide) in basaltic rock that yielded 0.792 ppm Au, 11.4 ppm Ag, 1.6 ppm Mo, and 7.23 ppm Te. Locality C. *Looking south*.

immiscible sulphide liquids that accumulated at the base of the units to form the ore deposits (Arndt and Lesher 2004). From their parallel trend on the map (*see* Figure 1), the komatiitic rocks proximal to the EMRLB could be channelized sheet flows. The knobby features may represent the cumulate zone of a layered komatiite flow, and the fine-grained seams may represent chilled zones near the top of a flow. Initial sampling from field investigations returned up to 860 ppm Ni (Locality C), 413.20 ppm Cu (Locality A) and 18.42 weight % Fe (Locality B). The quartz vein at Locality C yielded 0.79 ppm Au, 11.4 ppm Ag, 1.6 ppm Mo and 7.23 ppm Te. From a geophysical perspective, the study area is midway within a high gravity anomaly striking to the northeast (Figure 2).

The mafic to ultramafic metavolcanic rocks adjacent to the EMRLB are worth exploring further for nickel-copper-PGE mineralization. It is recommended to conduct a maiden diamond-drilling program by collaring directly on exposed komatiitic outcrops to target basal flow units in which mineralization is more likely to concentrate. Secondly, as part of the exploration process, it will be relevant to verify which type of flows these are, because most nickel-copper-PGE deposits worldwide are hosted by lava channels and channelized sheet flows. The thick overburden is a likely challenge, but verification may be constrained through microscopic investigation of volcanic structures and textures in drill core.

The presence of anomalous gold values in the quartz vein sampled at Locality C also suggests that the lode gold exploration potential of this area should not be overlooked.

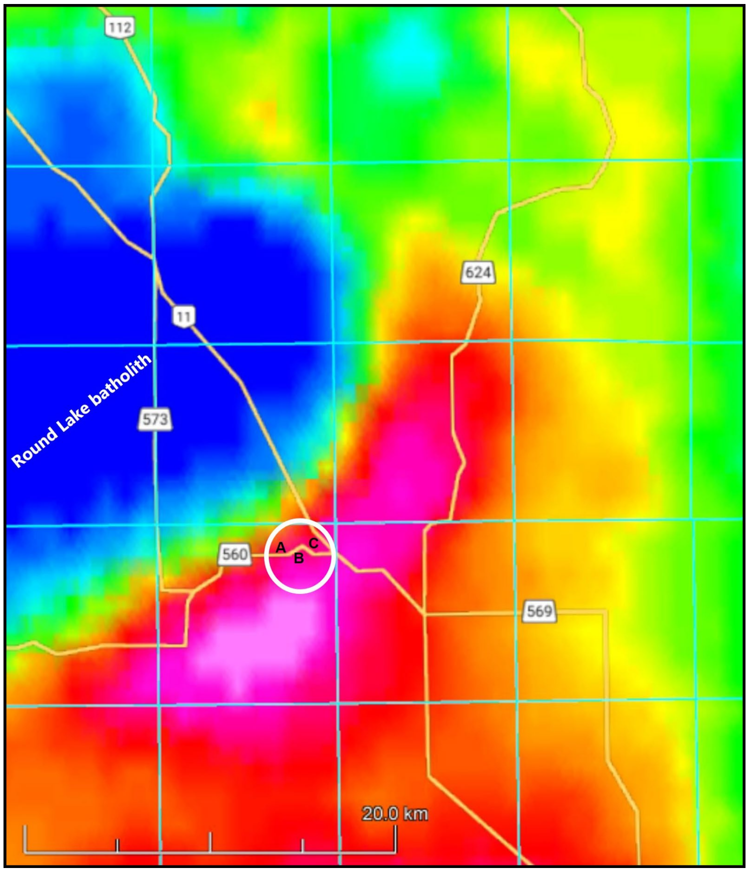

Figure 2. Regional airborne gravity anomaly map of the eastern part of the Round Lake batholith. The study area (enclosed by white circle) falls within a high gravity anomaly trending northeast. (Colors: purple and red = high, orange and yellow = moderate, green and blue = low anomalies.) Gravity anomaly *from* Ontario Geological Survey (2021).

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HIGHLIGHTS

- **Unmanned aerial vehicles (UAVs, or drones) have become an attractive option for detailed airborne magnetic surveys**
- **Use of UAVs significantly expedites data collection and survey resolution while reducing operational costs and environmental impacts**

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Enhancing Exploration Efficiency: Unmanned Aerial Vehicle Magnetic Surveying in the Timmins District

The Timmins Resident Geologist Program (RGP) District is currently experiencing a surge in the acquisition of mining claims. To stay active, these claims require financial expenditures in the form of exploration programs which promote project development, mineral discovery and contribute to public-domain geoscience knowledge. Technological advances have enabled substantial improvements to this mandatory expenditure and revolutionized the way geological data is collected. One significant innovation is using unmanned aerial vehicles (UAVs, also referred to as "drones") with magnetometers capable of performing higher resolution airborne magnetic surveys than has been previously offered. This technology is quickly becoming one of the most effective tools available for both prospectors and exploration companies and is setting a new standard for low-cost detailed geophysical surveys. The push towards green batteries and decreased reliance on fossil fuels has led to increased interest in critical minerals exploration in the Timmins District and presents more opportunities for the use of airborne geophysical surveys utilizing drones. It is crucial for exploration professionals seeking to be part of Ontario's fast-advancing exploration industry to be aware of these drone-based technologies, as well as their effectiveness for returning detailed results.

Over the past decade, remarkable advancements in drone technology have been achieved. Originally driven by military applications, technological innovations have paved the way for widespread adoption of drones in various industries, including mining, exploration and prospecting. These developments include significant improvements in drone battery efficiency, operational range, size and payload capacity. A normal magnetic survey drone today can cover 150 to 200 survey-line kilometres per day (Dai et al. 2019). The utilization of helicopter and airplane-borne surveys has been a practice dating back to the 1930s. Although these methods offer distinct advantages over terrestrial surveys, they are hampered by challenges such as high mobilization costs and limitations in resolution, particularly when it comes to examining localized targets (Porras et al. 2021). Conversely, terrestrial surveys promise superior survey resolution; however, the time and costs required for covering expansive areas render them less competitive and prohibitively expensive in comparison (Zheng et al. 2021). Some terrain in the Timmins District also makes terrestrial surveys more challenging due to swamps and muskeg limiting traverse paths.

The use of drones has emerged as the optimal solution for achieving good survey results, with resolution levels that are typically between

Krukowski, M. 2024. Enhancing exploration efficiency: Unmanned aerial vehicle magnetic surveying in the Timmins District; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.29-34.

terrestrial and conventional airborne geophysics surveys. Drone-collected magnetic surveys can produce exceptionally high-resolution data sets by flying at lower altitudes and at reduced speeds. Moreover, their survey flights are fully automated, ensuring consistent flight speeds and spacing between survey lines (Zheng et al. 2021). This results in high spatial data resolution in all directions. Conducting manned aerial surveys can become prohibitively costly, given the expenses associated with personnel, fuel and maintenance. Furthermore, most manned aerial surveys cannot achieve an equivalent level of precision compared to drone-based surveys. The use of drones comparatively has lower resource expenses and limited downtime. Hot-swapping lithium batteries allows for continuous use, and modular replacement parts keep repair costs low. Drones also excel in performing terrain-following flight missions, adeptly navigating rugged terrain, and circumventing the undesirable terrain-induced effects typically found with magnetic data collection. As an added benefit, the environmental impact of drone use in geophysical data collection is minimal and far more ecofriendly than both terrestrial and manned airborne methods. This is largely because of their reduced reliance on fossil fuels, as well as their limited ground disturbances during operation.

Figures 1 and 2, supplied by Pioneer Exploration Consultants Ltd. (M. Burns, CEO Pioneer Exploration Consultants Ltd., personal communication 2023), demonstrate how drone-collected magnetic data is far more detailed than conventional manned airborne magnetic data. Figure 1 displays the results of a helicopter-flown magnetic survey done at 80 m elevation using 100 m line spacing. This survey was able to delineate a regional fold hinge with related shear zones and structures but was unable to detect many of the individual magnetic anomalies evident on Figure 2. Figure 2 shows a detailed UAV-MAG™ drone survey of the same area completed by Pioneer Exploration Consultants Ltd. and reveals higher resolution of individual magnetic anomalies. Compared to the

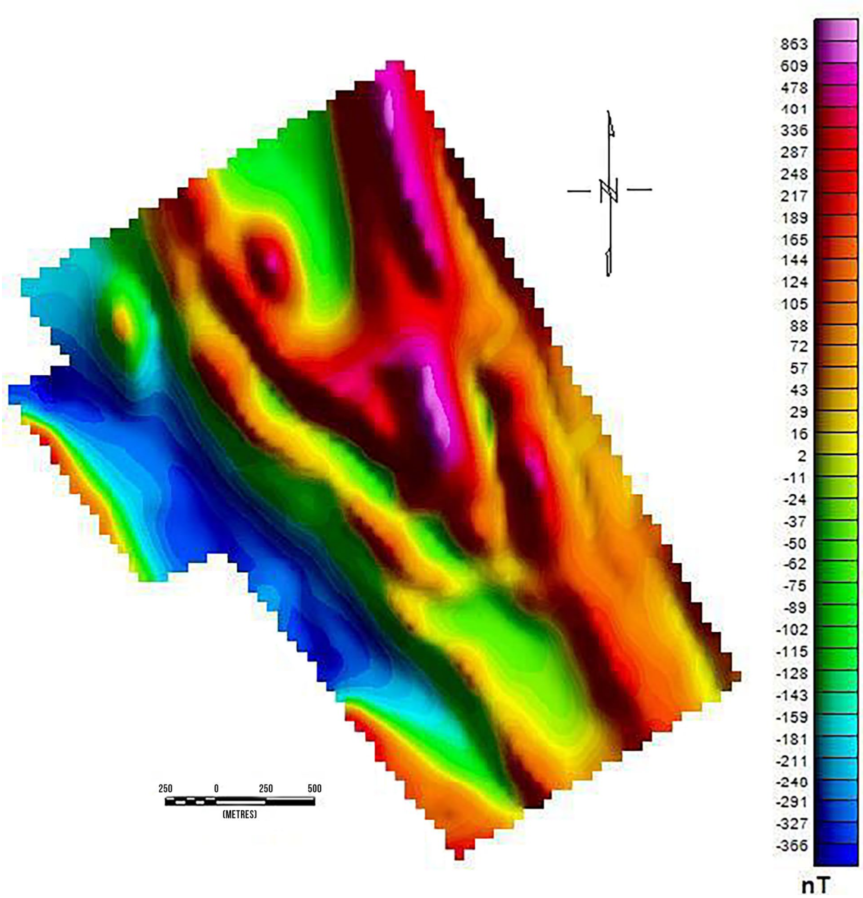

Figure 1. Helicopter-borne magnetic geophysical survey map. Total residual magnetic field data (M. Burns, CEO Pioneer Exploration Consultants Ltd., personal communication, 2023).

helicopter, the drone could fly at 25 m elevation, with 15 m line spacing. The result is a high-resolution data set of magnetic signatures showcasing individual anomalies, which allows for more detailed interpretation of rock types and structures, such as bedding, folds and shear zones. With the drone's data, individual rock types of the fold hinge can be traced much more accurately, and discrete units can be mapped with greater detail. Additionally, individual magnetic anomalies, which may correspond to ore bodies, are visible within this data set and can be targeted for further exploration and field work.

The base metal showings of the Jefferson, Stackpool and Vencan prospects in the Timmins District are excellent examples of how a high-resolution drone magnetic survey could have vastly improved exploration efforts and reduced costs. These base metal prospects are associated with the Woman River iron formation, located in Marion and Genoa townships within the Swayze area of the Abitibi greenstone belt and are recorded in the Ontario Mineral Inventory (OMI) as MDI41O16SE00010, MDI41O16SW00022 and MDI000000001529, respectively (Ontario Geological Survey 2023). The area around the Jefferson showing was originally explored for iron in the 1900s but the potential for other mineralization types was not recognized until deeper exploration efforts penetrated past the iron formation and significant intercepts of base metals were discovered (Mowbray et al. 2018). Evidently, the Woman River iron formation masked the geophysical signature of more localized sphalerite, galena and chalcopyrite, as well as the base metal stockworks stratigraphically below the iron formation in the underlying felsic to intermediate volcanic rocks (Mowbray et al. 2018).

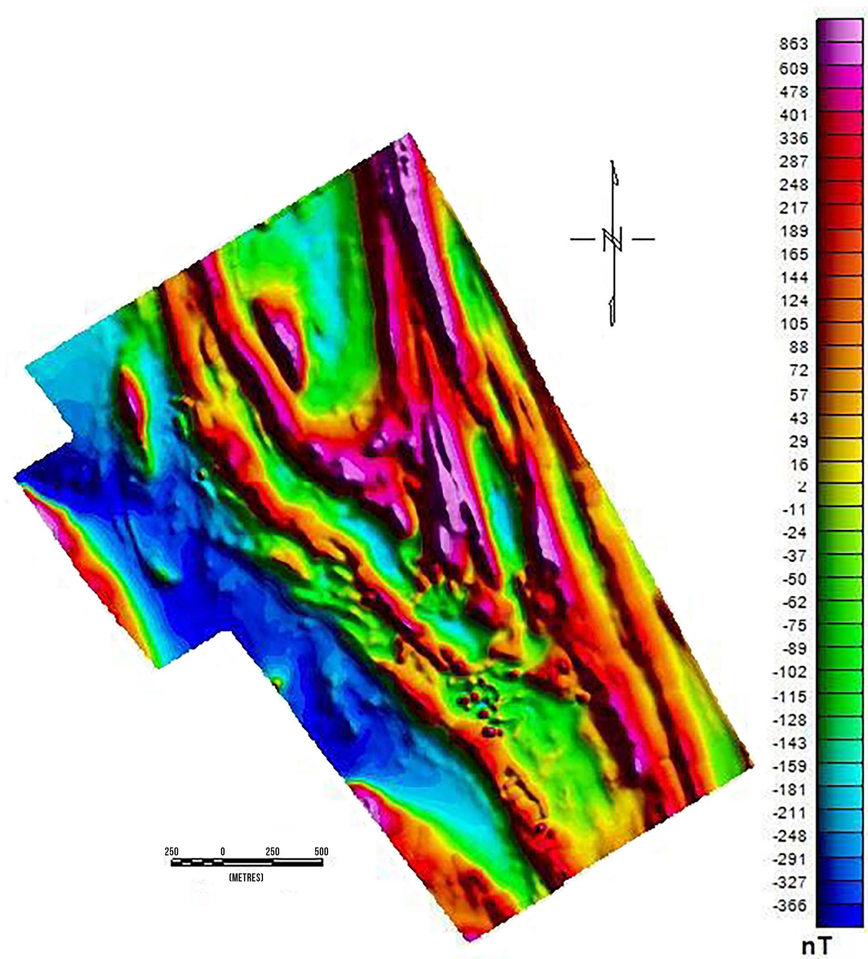

Figure 2. Drone-based magnetic survey map for same area shown in Figure 1. Residual total magnetic field data. Note the greater resolution compared with Figure 1 (M. Burns, CEO Pioneer Exploration Consultants Ltd., personal communication, 2023).

Had drone magnetic survey technology been readily available at the time, then the exploration program that resulted in the discovery of the Vencan showing could have taken a much different approach. It was discovered in 2006 by employing various exploration methods including manned airborne electromagnetic, ground gravity, induced polarization and ground magnetic surveys, as well as diamond drilling (Mowbray et al. 2018). Had the results of a higher-resolution magnetic survey conducted by drones been accessible at the outset of the exploration program, the Woman River iron formation would have easily been distinguished from the base metal mineralization. This would have expedited the discovery of the Vencan showing with fewer surveys needing to be completed, reducing costs for the company. The lower resolution results of the manned airborne magnetic survey shown in Figure 3, from Simon et al. (2006), did not present enough information to target the showing, which then prompted the additional exploration expenditures of the ground magnetic survey prior to discovery. Figure 4 (the ground-based total magnetic intensity survey from Grant (2006)) delineates the Woman River iron formation well but was cumbersome to execute, requiring days of line cutting, multi-person field crew expenses, and days spent conducting the survey. The high-resolution of a tightly spaced drone magnetic survey (such as shown in Figure 2), would have enabled more precise mapping of the iron formation, saving time, money and exploration efforts. Such a data set could have potentially pinpointed specific drilling targets along the strong magnetic signature of the iron formation, unveiling the underlying base metal mineralization (similar to what is seen in Figure 4) earlier in the exploration program.

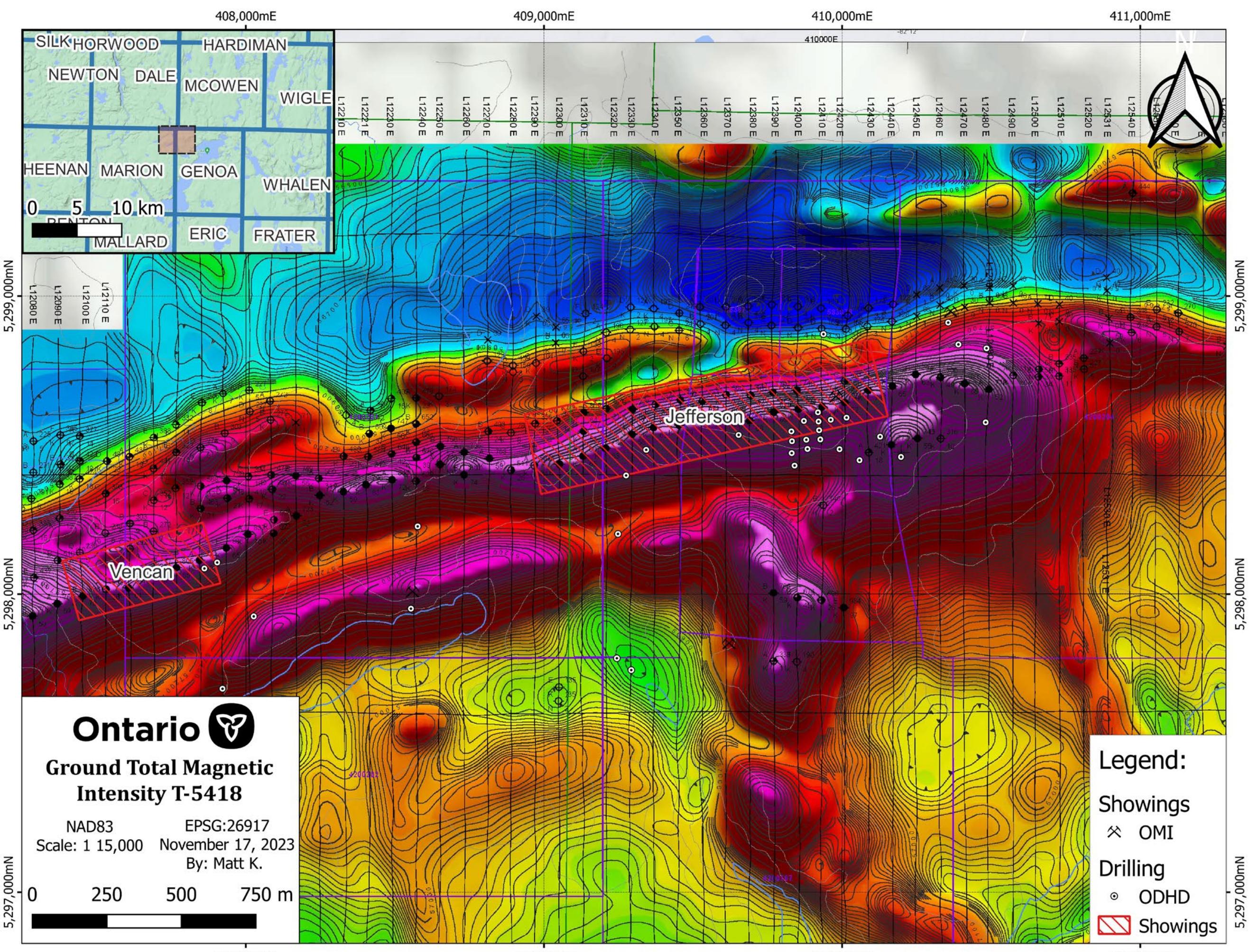

Figure 3. Airborne total magnetic intensity survey from assessment file T-5418 (Simon et al. 2006).

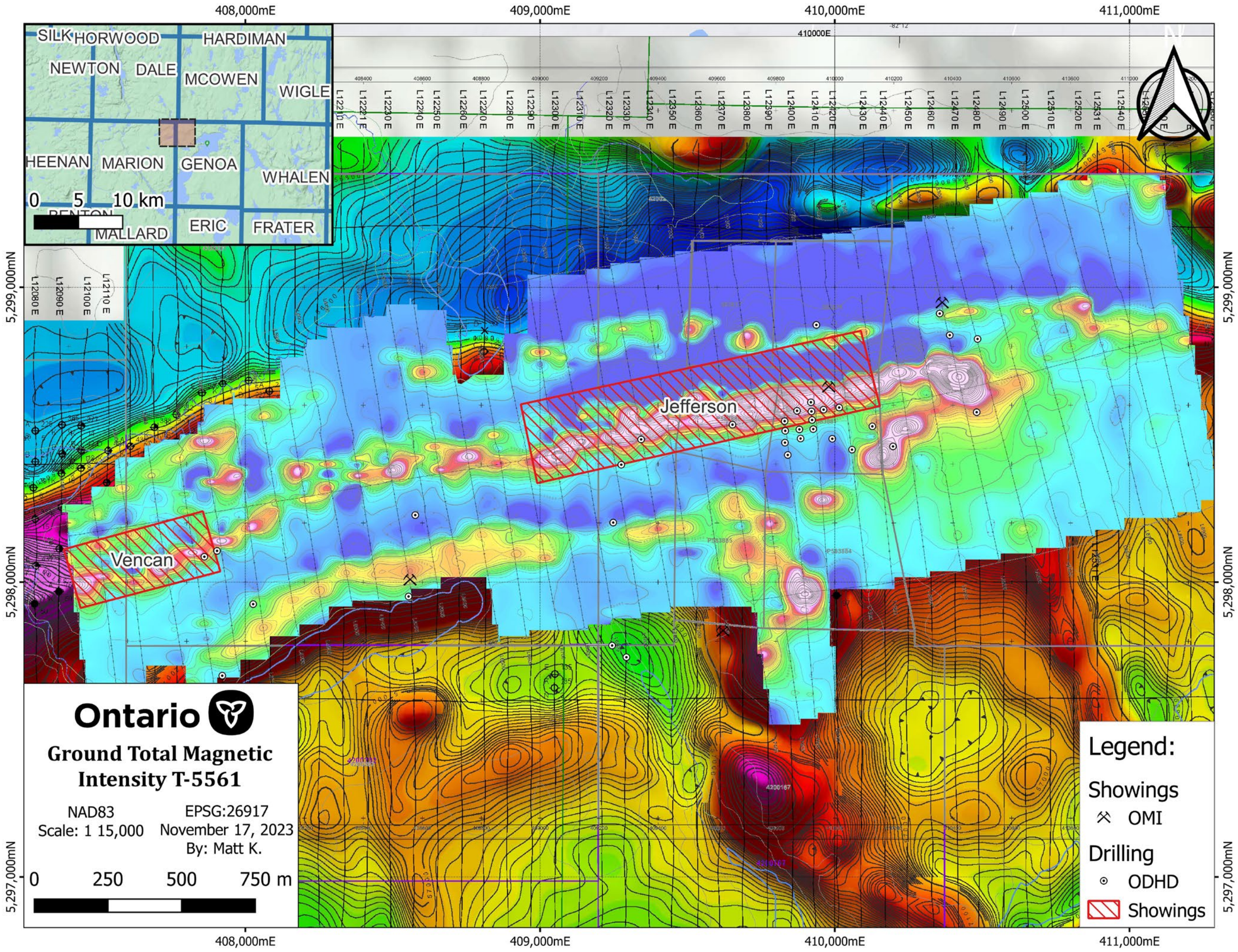

Figure 4. Ground based total magnetic intensity survey from assessment file T-5561 (Grant 2006), illustrating more detailed resolution than the manned airborne survey shown in Figure 3.

Today, high-resolution drone magnetic surveys have advanced to the point where they can play an integral role in advancing grassroots mineral exploration programs. Consequently, they are now being incorporated as standard practice in numerous early-stage exploration projects. They have been instrumental in not only improving the accuracy of geological data collection but also in significantly reducing exploration costs and aiding in decision making for new exploration targets. As technological developments continue, the application of drones within mineral exploration will only expand. Many drone companies are now offering high-resolution lidar (light detection and ranging), as well as orthophotography surveys, and are developing new hyperspectral and radiometric sensors for future implementation. Drones such as the one shown in Photo 1 are now commonplace, but the technology is constantly evolving with competition driving innovation of new services, drone types and techniques.

There are many opportunities in the Timmins District for using this drone technology on existing and newly acquired claim blocks. There is also a great potential for properties within the Timmins District, and elsewhere in Ontario, to be re-flown and re-interpreted with higher resolution drone magnetic surveys to potentially identify new targets missed by older exploration techniques. With the integration of cost-effective and efficient high-resolution drone magnetic surveys into exploration programs, exciting new mineral discoveries are right around the corner.

Photo 1. Drone with a magnetic sensor in tow (photo by Matt Krukowski).

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HIGHLIGHTS

- **Whole-rock major element analysis used to characterize geochemical alteration**
- **Indexes of alteration are weighted independently with known mineral occurrences**
- **Weights of Evidence (WofE) method used for weighting and probability calculations**
- **Mineral prospectivity map shows potential areas for exploration**

Mineral Prospectivity Mapping in the Batchawana Greenstone Belt

Lithogeochemical data, comprising whole-rock major-element oxide analyses, were used for mineral prospectivity mapping using open-source geographic information system (GIS) software and the results were compared with known mineral occurrences to identify potential areas for further exploration in the Batchawana greenstone belt (BGB; Figure 1). A subset of publicly available data (MRD 250, Haus and Pauk 2010) was used to determine multiple indexes of alteration (Table 1) from select altered samples that are assumed to reflect alteration patterns related to potential mineralization in the BGB. The resulting alteration maps (evidential themes) were weighted against the known mineral occurrences (Ontario Mineral Inventory (OMI) database, Ontario Geological Survey 2023) using the data-driven, Bayesian-theorem-based, Weights of Evidence method (WofE; Bonham-Carter, Agterberg and Wright 1989) to determine the areas of highest mineral prospectivity.

Archean rocks in the BGB in the southwestern Abitibi Subprovince, Ontario (Corfu and Grunsky 1987; and references therein), host extensive occurrences of magnetite-pyrite-chert and base and precious metals mineralization in hydrothermally altered supracrustal rocks along shear zones and proximal to felsic plutons (Grunsky 1991). Evidence of alteration in mafic rocks includes breakdown of pyroxene and olivine into amphibole and chlorite, plagioclase into saussurite and epidote, and pervasive carbonatization. Felsic rocks also exhibit evidence of sericitization and carbonatization (Grunsky 1991). Degrees of

Table 1. Indexes of alteration used for WofE analysis in this study.

Index	Expressions and Thresholds	Application
CCPI	100 (MgO + FeO) / (MgO + FeO + Na_2O + K_2O); >85 (Large et al. 2001)	Chlorite alteration of albite, potassium feldspar, sericite; carbonate alteration, pyrite, magnetite (hematite) enrichment
ACNK	Al_2O_3 / Na_2O + CaO + K_2O (m); >1.85	Alumina mobility over alkali depletion in feldspars
Volatiles	(CO_2 + H_2O^+ + H_2O^-); > 3.8 wt %	H_2O and CO_2 locked in hydrous and carbonate minerals
LOI	>6 wt % (mf), >3 wt % (fs)	Higher modes of hydrous minerals
AI	100 (MgO + K_2O) / (MgO + K_2O + CaO + Na_2O); >65 (Large et al. 2001)	Sericite and chlorite alteration of sodic plagioclase
ISER	K_2O / (K_2O + Na_2O) (m); >46.4	Sericite alteration of feldspar

Abbreviations: fs, felsic; m, molar; mf, mafic; wt, weight. Index abbreviations are defined in the text.

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metamorphism was low- to medium-grade greenschist facies in the interior of the belt, whereas it reached hornblende-hornfels facies towards the margin along the contact with intrusive plutons (Grunsky 1991).

Methods

The prior probability of finding a mineral occurrence by chance, defined as the expected outcome of an event in the absence of evidence, was determined by considering a very small area of 0.01 km^2 around each OMI point and dividing it by the total pixels in the study area (i.e., 83/479968 = 0.000173). A simplified geology map with 6 lithology classes was rasterized and weighted against the OMI points, resulting in 3 classes with positive weights and the remaining 3 with negative weights (Figure 2A; Table 2). These 6 lithology classes were reclassified into 2 groups based on their positive or negative weights and were weighted again as a binary raster layer (Figure 2B; Table 2). Whole-rock major element oxide data were used to determine 6 indexes of alteration: loss-on-ignition (LOI), excess volatiles, Hashimoto alteration index (AI), chlorite-carbonate-pyrite index (CCPI), sericite alteration index (ISER), total volatile content, and Al-Ca-Na-K (ACNK) index (*see* Table 1). Normal probability plots or other methods were used to identify samples with anomalous concentrations or thresholds (*see* Table 1). A first set of evidence maps was produced using a 1 km buffer around each geochemical data point, where 4 indexes (AI, CCPI, ACNK and ISER *in* Table 1) were combined into a single binary raster map showing Alteration Indexes (Figure 2C), LOI (Figure 2D) and total volatiles (Figure 2E). Each of these raster maps has a value of 1 for any location within a 1 km radius of an altered sample, and 0 elsewhere within the study area. A first set of WofE modelling was performed using all 4 binary evidence maps weighted separately (*see* Table 3), resulting in a posterior probability, or prospectivity, map (Figure 3). Another set of 6 binary raster evidence maps, one for each index (*see* Table 1), was produced using a 2.5 km buffer around each geochemical data point (not shown in figures). Each binary map was weighted independently with respect to the known OMI occurrences (Ontario Mineral Inventory database, Ontario Geological Survey 2023), using the WofE method (Table 4). In a second set of WofE calculations, these 6 evidence maps, combined with the binary geology raster, were weighted (*see* Table 4) to produce a prospectivity map (Figure 2F), which was compared with the prospectivity map produced in Figure 3 to identify 7 prospective areas for mineral occurrences (Table 5).

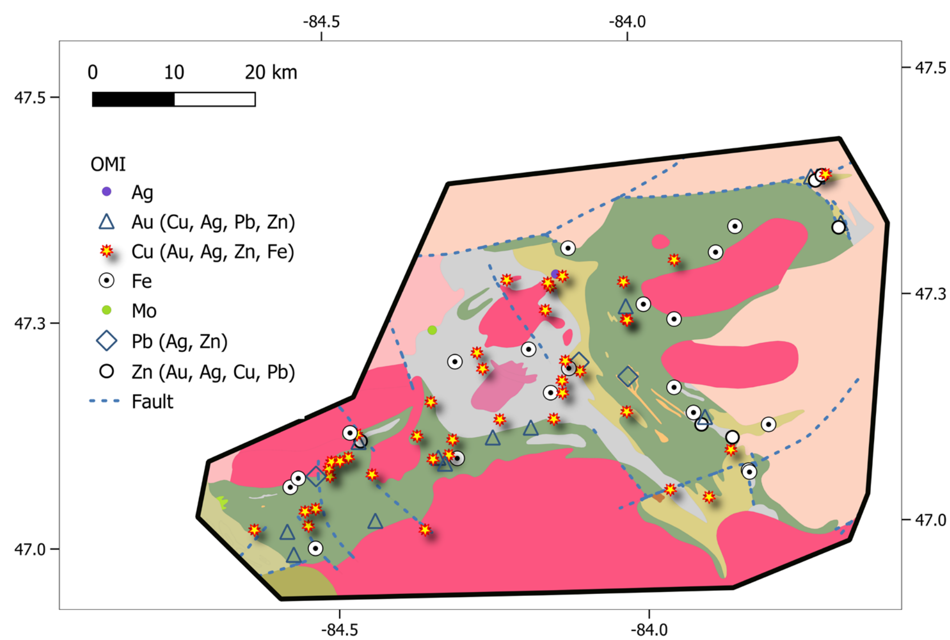

Figure 1. Geological map of Batchawana greenstone belt showing the location of known mineral occurrences (Ontario Geological Survey 2023; geology *modified after* Ontario Geological Survey 2011). Latitude and longitude co-ordinates, in degrees, are shown on the vertical and horizontal axes, respectively.

Results

The WofE statistics for the combined indexes, using a 1 km radius and the binary geology raster, are listed in Table 3 and their spatial correlation with respect to the regional geology and structure is shown in Figure 2A-E. The statistics for samples identified as being altered, with respect to all 6 indexes using a 2.5 km radius, are listed in Table 4. The general patterns of alteration zones correlate with the rock types that are positively weighted against the OMI points (*see* Table 2) and are not well-correlated with the northwest- and east-trending faults. The highest coincidence of anomalies in CCPI, LOI and total volatiles occurs in the areas of mafic metavolcanic rocks containing higher abundances of hydrous minerals. The samples with AI>65 and CCPI>85 indicate carbonate-chlorite-pyrite alteration (Large et al. 2001), most dominant in mafic tholeiitic and komatiitic metavolcanic units and to a lesser extent in the mafic intrusive rocks. The ACNK anomalies are observed predominantly in the mafic to felsic metavolcanic flows and to a lesser extent in the intrusive rocks, suggesting alkali depletion and alumina enrichment. The anomalies in AI and ISER also correlate mainly with the areas of exposed metavolcanic sequences. The intermediate to felsic metavolcanic flows exhibit a higher range in ISER (51-91), suggesting higher modes of sericitization compared to the mafic rocks (ISER 47-84). The felsic rocks also exhibit diagenetic alteration, as indicated by CCPI<15 and AI<20 (Large et al. 2001).

The statistics for the WofE method (*see* Table 4) show low to high contrast values (C) for all the indexes, ranked for their predictability of mineral occurrences. However, the 4 indexes (CCPI, AI, ACNK, ISER) combined into a single evidence raster, Alteration Indexes, show relatively high contrast and the highest studentized contrast ratio (*see* Table 3). These results reflect that the low to moderately metamorphosed supracrustal rocks, dominated by variably altered mafic rock types, contain high abundances of hydrous minerals and are also the dominant host of copper, gold, lead, silver and zinc mineralization.

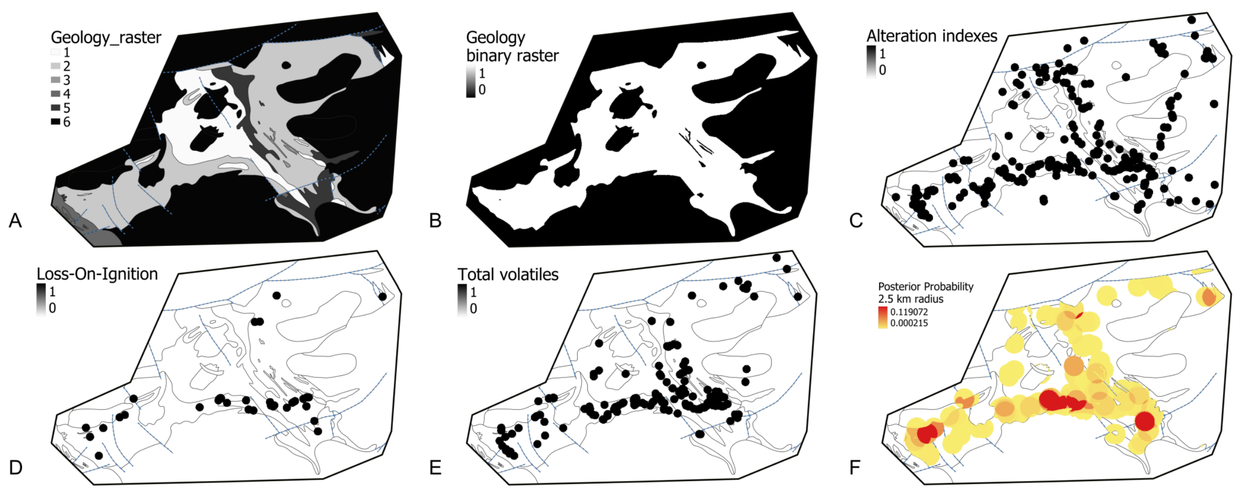

Figure 2. Binary raster evidence maps of (A) simplified geology (lithology classes in Table 2), (B) binary geology, (C) alteration indexes (AI+ACNK+ISER+CCPI; using cut-off values listed in Table 1), (D) LOI, and (E) total volatile contents, used for weighting (using WofE method, see Tables 2 to 3), with OMI points (see Figure 1) from the Batchawana greenstone belt. For calculation, a very small area of 0.01 km2 around each OMI point and a 1 km radius around each geochemical data point (black dots in C-E) were considered. (F) posterior probability, or prospectivity, map using all 7 evidence maps (see Table 4), with a 2.5 km radius around each geochemical data point, showing areas of high (>60‰, in yellow) and very high (>80‰; in red) probabilities. Note the significantly higher posterior probability of finding a mineral occurrence than the prior probability, i.e., by chance.

Table 2. WofE calculation for categorized and binary geology layers (*see* text and Figure 2).

Evidence	Class	Number of OMI Points	W^+	W^-	Contrast	Studentized Contrast
Geology_categorized	2	46	0.7877	-0.5171	1.3047	5.9074
	5	16	1.3653	-0.1642	1.5295	5.4947
	1	19	0.826	-0.1547	0.9807	3.7529
	3	0	-3.0353	0.002	-3.0373	-0.0304
	4	0	-5.3012	0.0202	-5.3214	-0.0532
	6	2	-3.1744	0.8337	-4.0081	-5.5996
Geology_binary	0	2	0.001	6.9088	-6.9078	-0.1545
	1	81	0.8879	-3.2155	4.1035	5.7348

Lithology classes: 1, metasedimentary rocks; 2, mafic to intermediate metavolcanic rocks; 3, mafic intrusive rocks; 4, Keweenawan; 5, felsic to intermediate metavolcanic rocks; 6, felsic intrusive rocks.
Abbreviations: OMI, Ontario Mineral Inventory; W^+, positive weight; W^-, negative weight.

Table 3. Statistics for a 4-layer WofE model (1 km radius around each geochemical data point) ranked as per their studentized contrast values (shown *in* Figure 2A-E).

Evidence	Number of samples	Percentage of total samples	Number of OMI Point	W^+	W^-	Contrast C = W^+ - W^-	Studentized Contrast (C/SD)
Alteration indexes	489	89	35	1.1375	-0.4032	1.5407	6.9015
Volatiles	348	63	22	1.2002	-0.2245	1.4247	5.7496
Geology binary	444	81	81	0.8879	-3.2155	4.1035	5.7348
LOI	165	30	7	1.2901	-0.0645	1.3546	3.4279

Abbreviations: LOI, loss on ignition; OMI, Ontario Mineral Inventory; SD, standard deviation; W^+, positive weight; W^-, negative weight.

Table 4. Statistics for each alteration index (with 2.5 km radius) weighted separately along with the binary geology raster map in calculation of the WofE model (*see* Figure 2F).

Index	Number of samples	Percentage of total samples	Number of OMI points	W^+	W^-	Contrast C = W^+ - W^-	Studentized Contrast (C/SD)
Volatiles	422	77	58	0.9749	-0.8941	1.869	7.8281
ACNK	468	85	41	1.0471	-0.4913	1.5384	7.0353
LOI	212	38	30	1.0667	-0.3155	1.3821	6.0686
CCPI	510	93	60	0.6453	-0.8073	1.4526	5.9064
AI	281	51	23	1.0167	-0.219	1.2356	5.0166
ISER	256	46	16	0.7161	-0.1157	0.8318	2.9796
Geology binary	444	81	81	0.8879	-3.2155	4.1035	5.7348

Abbreviations: SD, standard deviation; W^+, positive weight; W^-, negative weight. Others are defined in the text.

Table 5. Geological summary of the alteration zones (*see* Figure 3).

Zones	Alteration	Geology	Area (km^2) *Mineralization*	Townships (OMI, *disc*)
1	Volatiles, LOI, AI, ACNK, CCPI	Basalt-andesite flows, tuff, breccia, chert; felsic to intermediate flows; metasedimentary rocks; north-northwest-trending fault	10.13; *Au, Zn*	Neil (Labmin Showing, *Verse Lake North Showing*)
2	Volatiles, ISER, AI, ACNK, CCPI	felsic to intermediate flows; basalt-andesite flows, tuff, breccia, chert; minor metasedimentary rocks	18.90; *Cu, Ag*	Runnalls (Doyle Lake, Doyle Lake North, Doyle Lake Northwest), Mcaughey (*Montreal River South*), Running (Vacher Creek)
3	Volatiles, LOI, AI, CCPI	Basalt-andesite flows, tuff, breccia, chert; minor metasedimentary rocks	11.09; *Au, Cu, Zn, Fe*	Gapp (Butter Tin, Hanes Lake West, Hanes Lake North)
4	LOI, ISER, AI, ACNK, CCPI	Felsic to intermediate flows; basalt-andesite flow, tuff, breccia, chert; northeast-trending fault	17.87; *Cu*	Lunkie (Private Lake-Northwest, Loggers Lake), Gapp (Teepee Lake)
5	Volatiles, LOI, ISER, AI, ACNK, CCPI	Basalt-andesite flows, tuff, breccia, chert; metasedimentary units; northwest-trending fault	41.63; *Cu, Au*	Davieux (*Mine Pond*, Harmony River, Quinlet Lake), Desbiens, Olsen (South Paquette)
6	Volatiles, LOI, AI, ACNK, CCPI	Basalt-andesite flows, tuff, breccia, chert; minor metasedimentary units; granodiorite; northwest-trending fault	8.97; *Au, Cu, Zn, Fe*	Norberg; predicts Keweenawan intrusion-related deposits within the greenstone host
7	Volatiles, LOI, ISER, AI, ACNK, CCPI	Basalt-andesite flows, tuff, breccia, chert; minor iron formation; minor granodiorite; northwest-trending fault, Keweenawan breccia and related hydrothermal alteration	24.29; *Au, Pb, Zn, Fe, Cu*	Palmer, Nicolet; predicts Keweenawan intrusion-related deposits within the greenstone host

Abbreviations: disc, discretionary occurrences; OMI, Ontario Mineral Inventory. Alteration abbreviations are defined in the text.

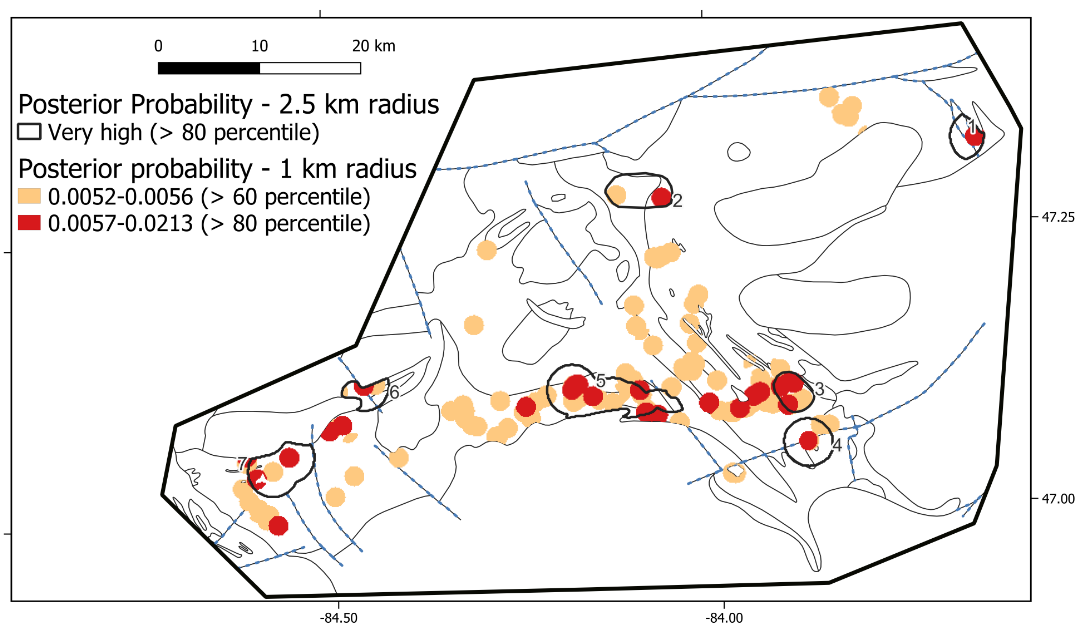

Figure 3. Posterior probability (prospectivity) map showing areas (using 1 km radius; *see* Table 3) with high (approximately 30 times higher than by chance) and very high probabilities (approximately 122 times higher than by chance; total 63.5 km^2) of finding a mineral occurrence. The thicker black outlines indicate 7 areas of very high prospectivity by comparing with Figure 2F (using 2.5 km radius; *see* Table 4). Latitude and longitude co-ordinates, in degrees, are shown on the vertical and horizontal axes, respectively.

The posterior probability (prospectivity) maps for mineral occurrences (*see* Figures 2F and 3) show the areas of highest probability for mineral occurrences in the area. Caveats of using a posterior probability map using major elements-based alteration indexes are that the individual binary alteration maps were not completely free from closure problems and conditional independence, assumptions made during calculation of the posterior probability (*see* discussions *in* Harris, Wilkinson and Grunsky 2000). Combining the 4 indexes increased conditional independence, although the posterior probability decreased, as demonstrated by comparing the 2 probability maps in Figure 3. However, each of the binary evidence maps weighted independently, one at a time (*see* Table 4), are strong indicators of their individual predictive abilities. Use of indicator trace elements or their principal components could result in better predictability. All OMI points are not well correlated to a specific deposit type, and sulphide- or oxide-facies iron formations were assumed to be extensions of ore-related stratigraphy distal to volcanogenic massive sulphide (VMS)-related hydrothermal discharge. Improvement on these caveats will result in better predictability of the posterior probability map for a particular deposit type (e.g., VMS-type vs. orogenic gold).

Recommendations

The final posterior probability map (*see* Figure 3) shows 7 favourable areas for copper, gold, silver, lead and zinc mineralization. The general geological characteristics of these prospective areas are highlighted in Table 5. Many of these occurrences were characterized as Keweenawan breccia-hosted hydrothermal deposits (zones 6 and 7 *in* Table 5), whereas others are indicative of VMS-type mineralization, the potential for which in the BGB has never been thoroughly investigated. However, the prospectivity map (*see* Figure 3) should not be used as a target map, rather an example of how the whole-rock major element oxide analyses can be used in the WofE method-based mineral prospectivity mapping as an exploration guide in a poorly explored area.

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HIGHLIGHTS

- **Peraluminous granites in the eastern English River Subprovince**
- **LCT-type pegmatite potential in the Witchwood and Morden Lake areas**

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LCT-Type Pegmatite Potential in the Witchwood and Morden Lake Areas, Eastern English River Subprovince

This report builds upon a Recommendation for Exploration that was produced last year and outlines an additional favourable location for lithium-cesium-tantalum (LCT)-type pegmatite exploration in the eastern English River Subprovince (ERS). The recommendation is based on field work and sampling that was conducted during the 2023 field season, with reference to previous work that supports the findings of this study. The area is to the south of Attwood Lake, where pegmatites with coarse muscovite and possible apatite were encountered at surface (Figure 1A). Areas that should be considered include the Witchwood and Morden Lake areas, which have many regional features favourable for rare-element pegmatites, including the presence of metasedimentary and metavolcanic rocks in proximity to peraluminous granite plutons located near the subprovince boundary (Figure 2; Selway, Breaks and Tindle 2005). Coincident with the increased interest in lithium, exploration in the eastern ERS increased dramatically in the 2023 field season. The recommended areas have been chosen because they fall outside of the currently staked and prospected claims and, at the time of writing, there is open ground in the region. The samples collected by Resident Geologist Program staff during the 2023 field season have been submitted to Geolabs in Sudbury for whole rock geochemical analysis and results are pending. Should the results appear favourable, additional analysis will be conducted, including mineralogical geochemistry.

The ERS is one of two metasedimentary-plutonic subprovinces within the Superior Province in northwestern Ontario (Breaks 1991). These subprovinces consist of east-trending belts of high-grade metasedimentary rocks that were deposited in flysch environments and subsequently underwent high temperature, syntectonic metamorphism (Breaks 1991; Corfu, Stott and Breaks 1995). The resulting migmitization of the metasedimentary rocks generated peraluminous granites, including a posttectonic suite of felsic intrusions that has been recognized and further described by Wallace (1981) and Azar and Ferguson (2014) during their mapping of the Attwood Lake area. Wallace (1981) named the intrusions the Southern Pegmatitic Zone (SPZ) and described them as white, muscovite-bearing, pegmatitic, biotite quartz monzonite. This SPZ was hypothesized to be derived via anatexis of metasediments from the Attwood Lake supracrustal rocks because of the predominance of muscovite over biotite and the common presence of garnet. The SPZ has also been described as having graphic intergrowths of feldspar and quartz, a feature which was observed in pegmatite outcrops logged during the 2023 field season (Figure 1B). These features outline a favourable environment for LCT pegmatite exploration (Selway, Breaks and Tindle 2005).

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

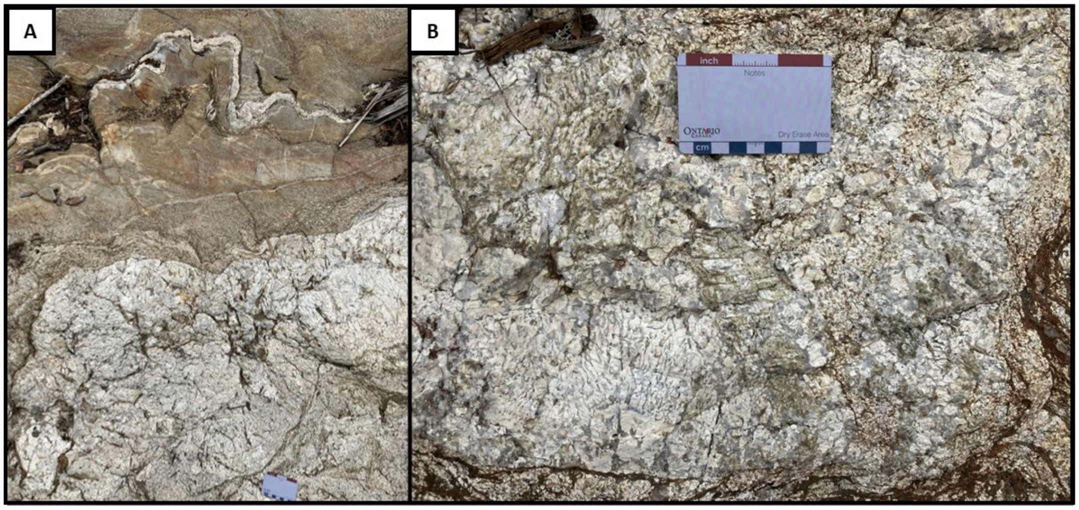

Figure 1. Exposure in recommended area, south of Attwood Lake. A) Contact between metasedimentary rocks and white pegmatite. B) Close-up image of white pegmatite with greenish muscovite that crops out in the Witchwood Lake area. The bottom left corner displays the well-developed graphitic texture seen in places.

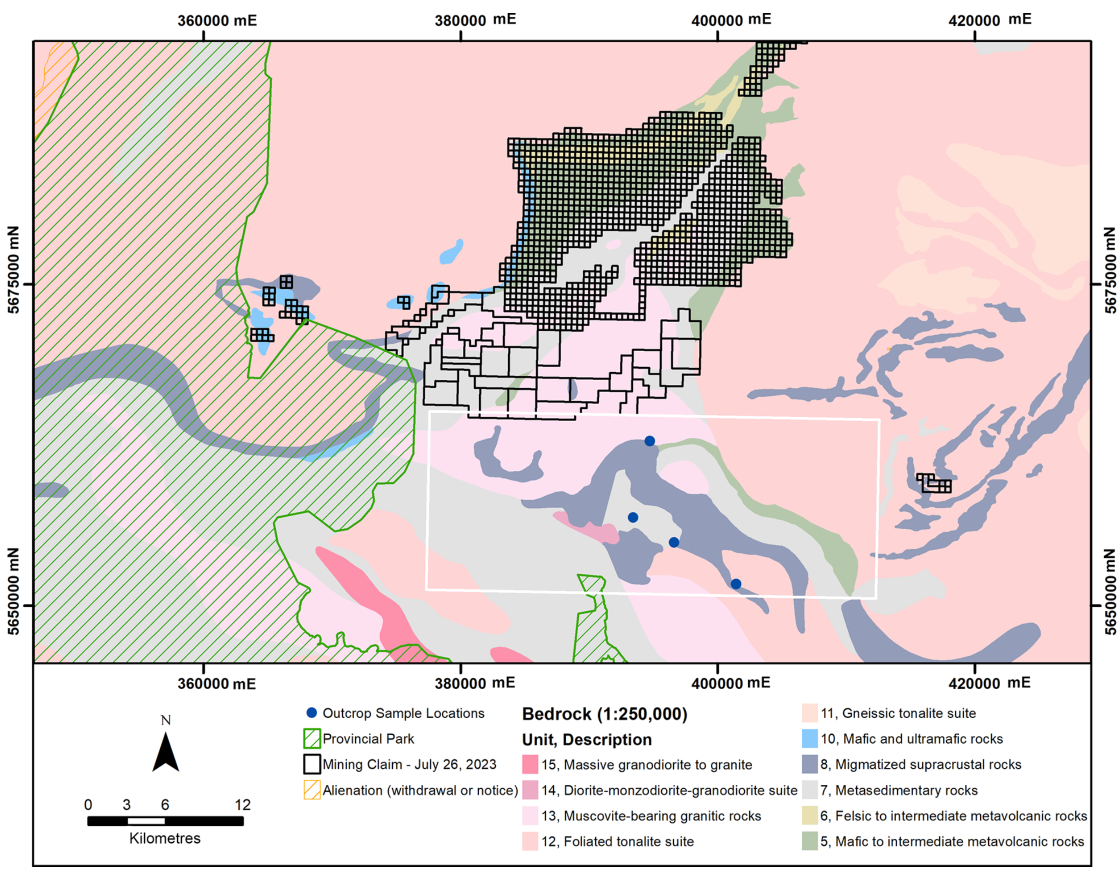

Figure 2. Map of the Attwood Lake area showing current active mining claims and the outcrop locations that were sampled during the 2023 field season. The Area of Recommendation, containing both the Witchwood and Morden Lake areas, is outlined by the white box. Geology *from* Ontario Geological Survey (2011). Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 16.

These posttectonic felsic intrusions have been described as completely undeformed and hosted within the metasedimentary package south of Attwood Lake (Azar and Ferguson 2014). The late nature of these intrusions increases the favourability of the suite for rare-metal mineralization potential. Younger intrusive suites, especially those in lower metamorphic areas near the margins of the ERS, are suggested to have higher potential for lithophile mineralization (Breaks, Cherry and Janes 1985). The data produced from the granite samples collected by Azar and Ferguson (2014) in the Attwood Lake area study can be useful in identifying peraluminous granites (Table 1; Figure 3). All granite samples produced A/CNK values that fall within the peraluminous granite field and several of the samples also have Nb/Ta ratios less than 8, a feature that is identified in fertile granites (Selway, Breaks and Tindle 2005).

The timing of intrusions, in combination with the geochemical features indicating the presence of fertile granites in the area, supports the favourability of the region for LCT-type pegmatite potential.

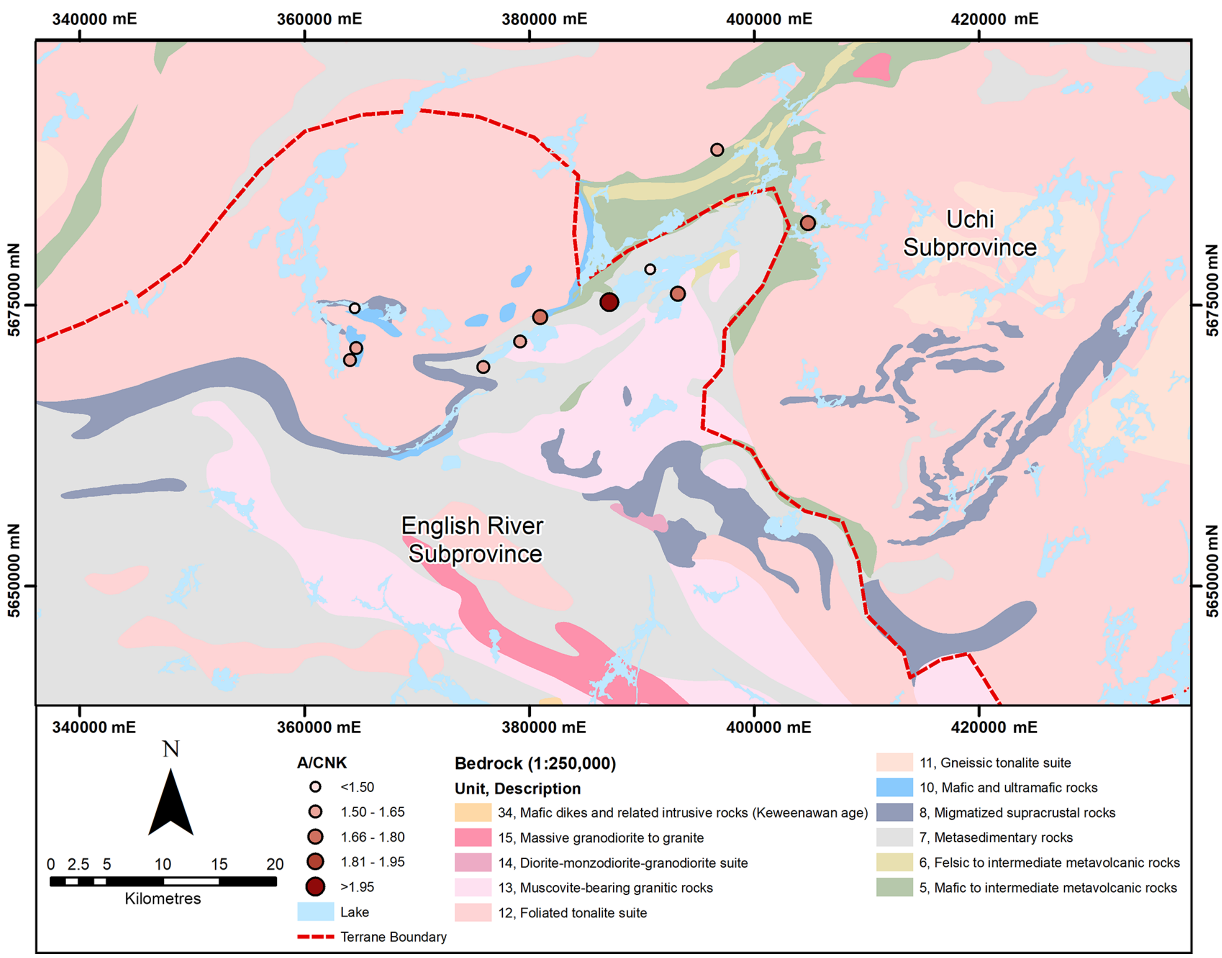

Figure 3. Distribution of the A/CNK ratios for granitic samples collected by Azar and Ferguson (2014) during their field mapping program of the Attwood Lake area. Higher ratios indicate more strongly peraluminous granitic rocks. Geology *from* Ontario Geological Survey (2011). Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 16.

Table 1. List of granites sampled by Azar and Ferguson (2014), with their corresponding A/CNK ratios, Nb/Ta ratios and Li ppm values. Data provided in Azar (2016).

Sample Number	Rock Name	Map Code	Easting	Northing	A/CNK	Nb/Ta	Li (ppm)
14BA462A	granite	10bKW	387131	5675261	2.05	5.22	15
14SF420B	granite	1xwY	404799	5682275	1.70	8.09	3
14BA474	granite	10bDKW	364464	5674695	1.39	9.81	9
14BA493B	granite	6be	390766	5678165	1.43	3.04	7
14BA462A SP	granite	10bKW	387131	5675261	1.98	5.04	12
14SF420B SP	granite	1dC	404799	5682275	1.70	8.15	2
14BA100	granite	10cD	364591	5671176	1.58	12.30	17
14BA103	granite	10dD	364035	5670086	1.61	15.33	20
14BA546	granite	10bDKE	380975	5673938	1.76	8.55	35
14BA566	granite	10bDL	375906	5669472	1.61	12.03	47
14BA579	granite	10bDKLW	379190	5671768	1.62	7.95	23
14CM087	granite	8dY	396715	5688798	1.57	12.67	29
14BA513	granite	10bKW	393242	5675993	1.66	4.21	40

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HIGHLIGHTS

- **Prospective base metal potential near known occurrences**
- **Significant contiguous areas with robust data that are available for acquisition**

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OGSFocus Base Metal Potential in Thunder Bay North

A review was done to identify prospective areas near known base metal occurrences located proximal to robust historical exploration within the Thunder Bay North District using the Ontario Mineral Inventory database and the OGSFocus tool.

The OGSFocus tool (formerly known as DIG) is a geographic information system (GIS)-based geoprocessing tool developed to quantify multiple, publicly available Ontario Geological Survey Resident Geologist Program (OGS–RGP) data sets in areas that are open for claim registration. OGSFocus considers the Ontario Assessment File Database (OAFD) polygon features, the Ontario Drill Hole Database (ODHD) point features and Ontario Mineral Inventory (OMI) database point features to assess the robustness of the data overlapping available claim cells (Cundari et al. 2020).

Using the OMI database (Ontario Geological Survey 2023a) and OGSFocus tool (Ontario Geological Survey 2023b), 5 areas within the Thunder Bay North District were identified as having an OGSFocus score in the 85th percentile or greater and which cover an area of 500 hectares or greater. These highlighted areas are prospective for nickel-copper, copper, copper-zinc, and zinc mineralization, with gold, silver, cobalt and molybdenum as possible secondary commodities, as they either contain or are proximal to known base metal occurrences and share similar geologic environments. In some cases, the known mineral occurrence itself has an operational mining claim(s) registered on it, but the surrounding land tenure is open for claim registration. As of October 17, 2023, the following 5 Hot Spot Data Areas are available for online claim registration: TN28, TN38, TN4, TN46 and TN48.

Data Hot Spot TN28

Data Hot Spot TN28 (OGSFocus Version Date: 2023-09-29) is located within the Sim Lake and Faircloth Lake areas and comprises 12724.0 ha (Figure 1). The autogenerated Hot Spot Summary listed 1 OMI record within 200 m (MDI000000000142 – Sim Lake nickel-copper occurrence), 19 assessment files and 9 drill holes within the area.

Hot Spot TN28 surrounds the Sim Lake occurrence (*see* Figure 1), which is hosted within the mafic Sim Lake intrusion. Mason et al. (1999) reports that the Sim Lake intrusion consists of 2 phases: a gabbro core and an outer pyroxenite zone. The main intrusion is exposed at surface as an approximately 300 m circular body. A narrow dike-like portion of the mineralized intrusion extends northwest of the main body for a distance of at least 800 m. The intrusion is variably textured, with fine-grained and

Paju, G.F. 2024. OGSFocus Base Metal Potential in Thunder Bay North; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.45-49.

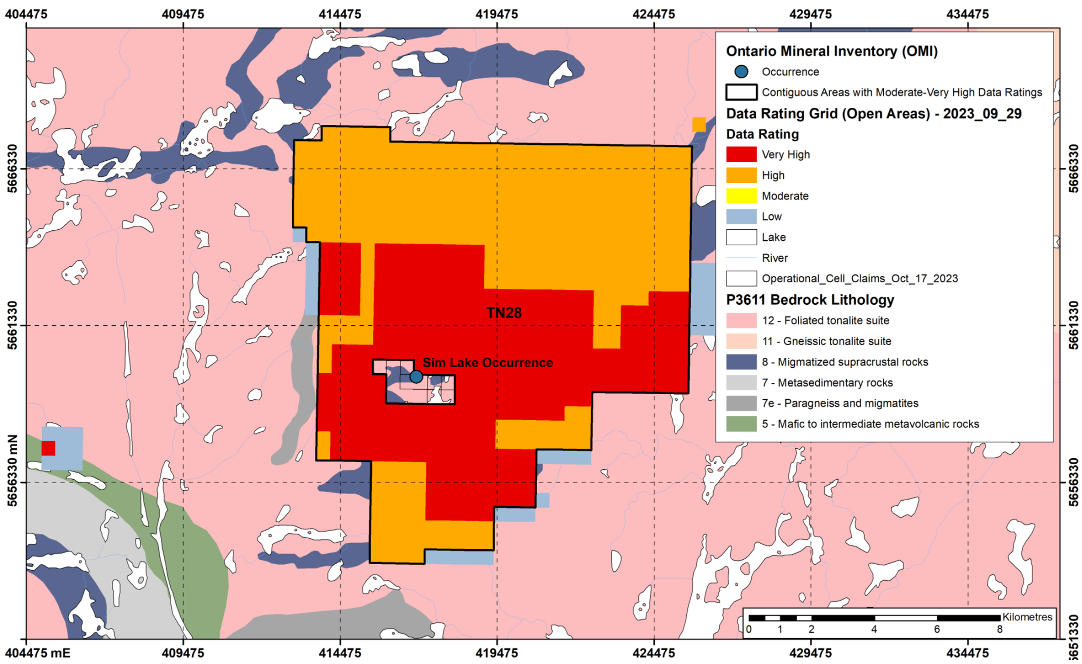

Figure 1. Location Data Hot Spot TN28. Geology *from* Madon, McIlraith and Stott (2009). Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 15. Claim units current to October 13, 2023.

pegmatitic phases. The mineralized intrusion is hosted within non-mineralized gabbro and granitic migmatites. The surrounding migmatites are highly deformed, with local open folds and variable foliation. However, the mineralized intrusion crosscuts the migmatites and shows a much lower degree of deformation.

Data Hot Spot TN38

Data Hot Spot TN38 (OGSFocus Version Date: 2023-09-29) is located within the Hurst Lake, Petawanga Lake and Kawitos Lake areas and comprises 7344.0 ha (Figure 2). The autogenerated Hot Spot Summary listed 8 OMI records within 200 m (Table 1), 28 assessment files and 26 drill holes within the area.

Hot Spot TN38 occurs within the eastern part of the Uchi Subprovince, within the Attwood Lake metavolcanic-metasedimentary belt (*see* Figure 2). The Hot Spot and the known OMI occurrences are found in the northern part of the Attwood Lake belt, a northerly and northeasterly trending belt. Metasedimentary rocks consist of arkose, greywacke, quartzite and conglomerate. Massive to foliated basalt and andesite, and layered amphibolite make up the metavolcanic assemblage. Anorthositic gabbro and granodiorite intrude the mafic metavolcanic rocks (Thurston, Carter and Riley 1969; Mason et al. 1990).

Table 1. Ontario Mineral Inventory records for Data Hot Spot TN38.

OMI Number	OMI Name	Classification	Commodity
MDI000000002502	Auger Lake	occurrence	iron
MDI000000002504	South Main Anomalies	occurrence	copper, silver, gold
MDI52P08NW00008	Nyla Occurrence	occurrence	copper, zinc, lead
MDI52P08NW00006	Ryley-Cormac Occurrence	occurrence	copper, zinc
MDI52P08NW00007	Njz-76 Occurrence	occurrence	copper, zinc
MDI52P08NW00004	Gold Fields Occurrence	occurrence	copper, zinc
MDI52P08NW00005	Alpamayo Occurrence	occurrence	copper, zinc
MDI52P08NW00003	M.J. Boylen	occurrence	copper, zinc

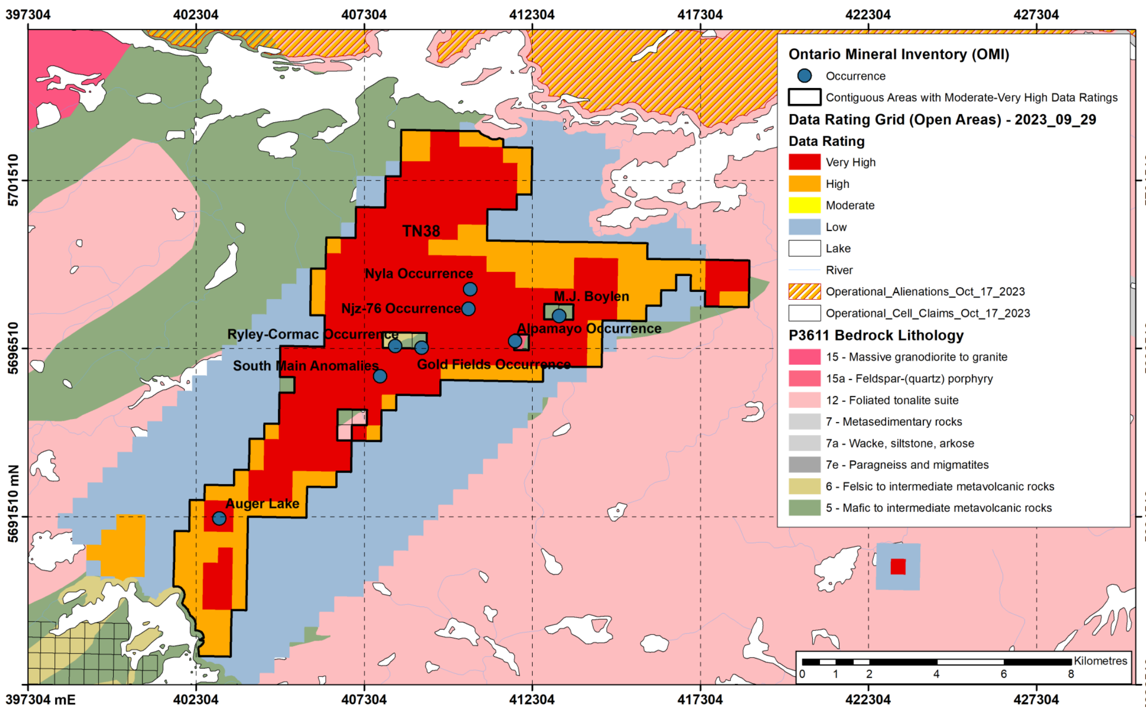

Figure 2. Location Data Hot Spot TN38. Geology *from* Madon, McIlraith and Stott (2009). Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 15. Claim units current to October 13, 2023.

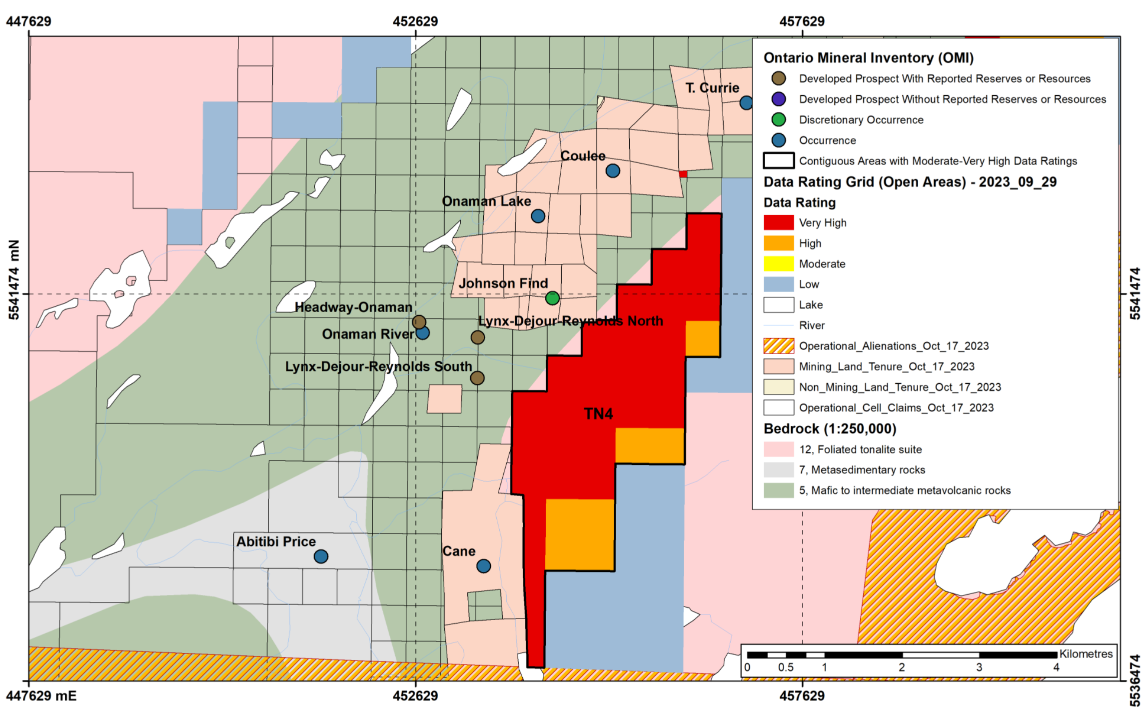

Figure 3. Location Data Hot Spot TN4. Geology *from* Ontario Geological Survey (2011). Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 16. Claim units current to October 13, 2023.

Data Hot Spot TN4

Data Hot Spot TN4 (OGSFocus Version Date: 2023-09-29) is located within the Coughlan Lake and Castlewood Lake areas and comprises 699.0 ha. The autogenerated Hot Spot Summary listed 23 assessment files and 26 drill holes within the area.

Hot Spot TN4 is underlain by mafic metavolcanic rocks of the Onaman–Tashota greenstone belt (Figure 3). The metavolcanic rocks consist of pillowed to massive mafic flows, tuff and iron formation which have been intruded by the West Onaman Lake batholith to the east, a biotite (hornblende) trondhjemite to granodiorite to quartz monzonite intrusion. The metavolcanic rocks are overlain to the west by a clast-supported polymictic conglomerate (Amukun 1980; Thurston 1980). To the west of TN4, several base metal occurrences are found.

Data Hot Spots TN46 and TN48

Data Hot Spot TN46 (OGSFocus Version Date: 2023-09-29) is located within the Stoughton Lake, Baggy Lake, Saddle Lake and McVicar Lake areas and comprises 2208.0 ha (Figure 4). The autogenerated Hot Spot Summary listed 2 OMI records within 200 m (MDI52O11SW00008 – Boyes Lake South copper occurrence; MDI52O11SW00035 – Lang Lake Belore copper-gold occurrence), 25 assessment files and 8 drill holes within the area.

Data Hot Spot TN48 (OGSFocus Version Date: 2023-09-29) is located within the Stoughton Lake and Baggy Lake areas and comprises 1465.0 ha (*see* Figure 4). The autogenerated Hot Spot Summary listed 3 OMI records within 200 m (Table 2), 25 assessment files and 10 drill holes within the area.

Table 2. Ontario Mineral Inventory records for Data Hot Spot TN48.

OMI Number	OMI Name	Classification	Commodity
MDI52O12NE00006	Saddle Lake	occurrence	zinc, lead, silver
MDI52O12NE00007	Saddle Creek	occurrence	copper, zinc
MDI52O12SE00013	Castlebar #3	occurrence	copper, zinc

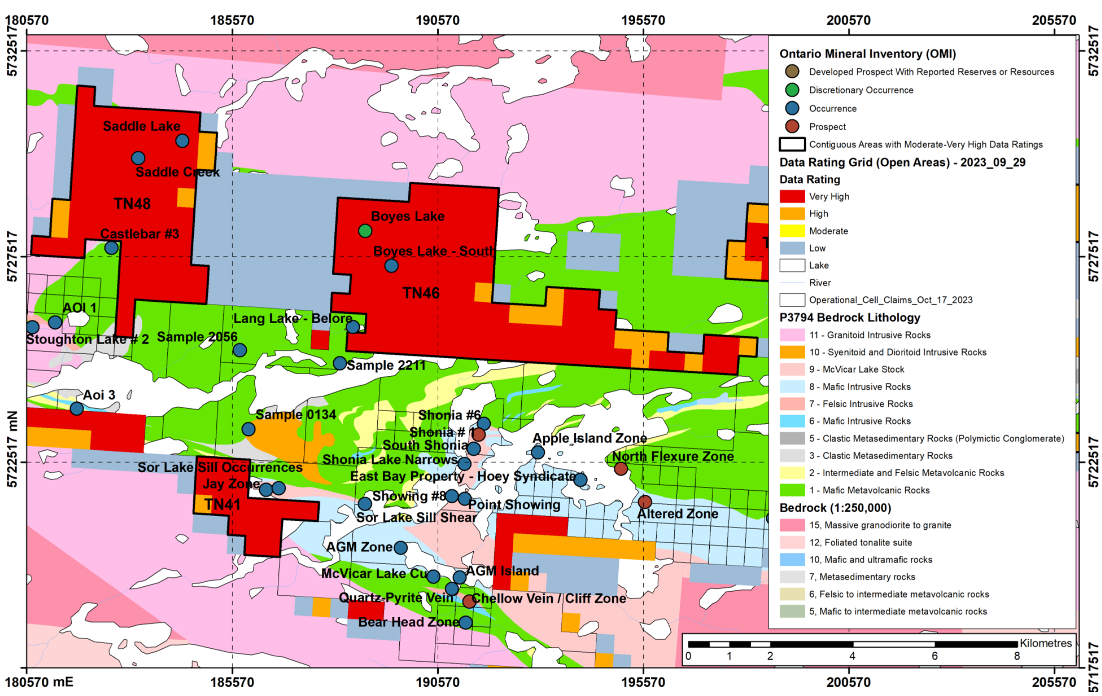

Figure 4. Location Data Hot Spot TN46 and TN48. Geology *from* Ontario Geological Survey (2011) and Magnus (2015). Universal Transverse Mercator (UTM) co-ordinates in North American Datum (NAD83), Zone 15. Claim units current to October 13, 2023.

Both Data Hot Spots TN46 and TN48 are located within the western portion of the Lang Lake greenstone belt (Magnus 2015). TN48 is located around Saddle Creek and TN46 is further to the east, covering Boyer Lake and the northeast portion of Lang Lake (*see* Figure 4). Within the western Lang Lake greenstone belt, the supracrustal rocks consist primarily of mafic metavolcanic rocks (massive to pillowed) interbedded with fine-grained volcanic-derived metasedimentary rocks, sparse beds of felsic volcaniclastic rocks and chemical metasedimentary rocks that reach across the entire strike length of the belt (Magnus 2015).

Massive to tuffaceous felsic metavolcanic rocks are more abundant in the central part of the belt, between McVicar Lake and Lang Lake, whereas the chemical metasedimentary rocks, common throughout the rest of the belt, are sparse in this area (Magnus 2015).

Conclusion

The Data Hot Spots highlighted by the OGSFocus automated GIS tool and the proximity to known base metal occurrences from the Ontario Mineral Inventory warrant further consideration by explorationists, as the known mineralization may be more extensive than previously thought.

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HIGHLIGHTS

- **OGS lake sediment rare element anomalies in unexplored areas situated near regional-scale faults or near the Winnipeg River terrane boundary**
- **Two of the highest lake sediment lithium values recorded in the province are from an OGS lake sediment geochemical survey covering the Garden Lake–Obonga Lake area**

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Rare Element Potential in the Garden Lake–Obonga Lake Area

Granitic pegmatites enriched in rare elements commonly occur along or near regional-scale faults that are associated with terrane and/or subprovince boundaries (Selway, Breaks and Tindle 2005). This article highlights Ontario Geological Survey (OGS) lake sediment rare element anomalies in unexplored areas situated near regional-scale faults or near the Winnipeg River terrane boundary, in the Obonga and Pakashkan lakes area (Figure 1). Two of the highest lake sediment lithium values (966.3 ppm and 630.4 ppm) recorded in the province are from an OGS lake sediment geochemical survey covering the Garden Lake–Obonga Lake area (Jackson and Dyer 2000a, 2000b). These 2 lake sediment lithium anomalies, referred to here as "Nine-Sixty-Six" and "Six-Thirty", are situated close to subparallel, northeast-trending regional-scale faults near Kashishibog Lake and Awkward Lake, respectively (*see* Figure 1, yellow dots). Another area of interest is a cluster of 4 lake sediment anomalies (with lithium values of 65.4 ppm, 53.9 ppm, 37.6 ppm and 27.3 ppm) on the northeast arm of Pakashkan Lake, near the Winnipeg River–Marmion terrane boundary (*see* Figure 1, yellow dots). As of December 19, 2023, claims covering the "Nine-Sixty-Six" and Pakashkan Lake lake sediment lithium anomalies are available for option from L. Boyer (Broken Rock Resources Ltd.).

Previous exploration has been rather limited in the areas underlain by granitic rocks and it has focussed mainly on gold and base metal mineralization within greenstone belts. As such, the lake sediment rare element data was not presented on proportional dot maps published by Jackson and Dyer (2000a) in Open File Report 6009; however, Jackson and Dyer's (2000b) digital data are available as Miscellaneous Release—Data (MRD) 51.

On August 30, 2023, L. Boyer and D. Campbell (Regional Resident Geologist) visited both the Nine-Sixty-Six and Six-Thirty sites, by helicopter. Descriptions of these sites are given below. All UTM co-ordinates reported in this article are in NAD83, Zone 16.

The Nine-Sixty-Six lake sediment anomaly (OGS sample site 1109, Jackson and Dyer 2000b; 287642E 5527869N; *see* Figure 1) was collected from a small lake north of Kashishibog Lake. The sample contains 966.3 ppm Li, 38.57 ppm Rb and 9.53 ppm Cs. The area surrounding site Nine-Sixty-Six is covered by thick till and a few granitic pegmatite boulders were noted and sampled. Most of these pegmatitic boulders are rounded, ranging in size from 0.5 to 2 m, and composed mainly of quartz and feldspar with local minor biotite. Although no outcrop was found in this area, large outcrops of granitic pegmatite were observed and sampled in an area 2 km to the northwest. These quartz-feldspar

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

pegmatites are buff to white, massive, and mostly coarse-grained to pegmatitic with minor finer grained phases. Coarse-grained magnetite was noted in one outcrop. Analyses for samples of the pegmatitic boulders and outcrops are pending.

Historically, the Kashishibog Lake area has seen very little exploration and geological mapping. Reportedly, vast areas of granite pegmatite dike sheets occur in the vicinity of Sparkling and Mountairy lakes, 12 to 30 km west of Kashishibog Lake, respectively (Rogers 1964). The pegmatites are situated near the Western Wabigoon–Winnipeg River terrane boundary and along the northeast-trending regional-scale faults that extend for more than 30 km in the Kashishibog and Awkward lakes area. A description of these pegmatites by Rogers (1964) is given below.

> The large granite pegmatite dike-sheets are intruded over a large area in the northeastern part of the map-area in the vicinity of Gosling, Mountairy, Hilltop, Scruffy, Rude, Robert, and Stinson lakes, and the south half of Harmon Lake. Similar pegmatites occur along the pink granite gneiss belt on Little Sparkling Lake and the upper half of Sparkling Lake.

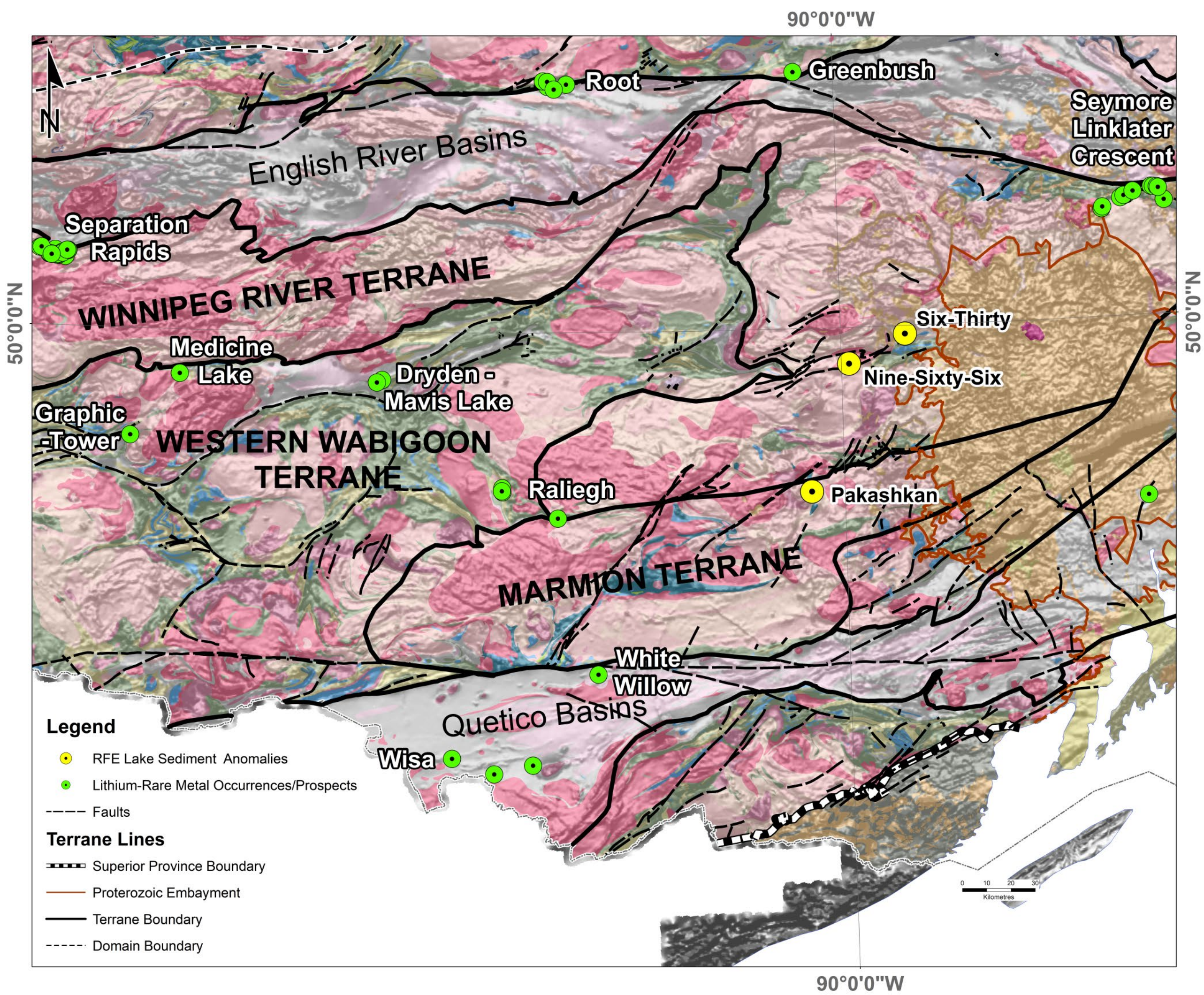

Figure 1. Regional geological map with interpreted terrane boundaries and major faults (*modified from* Stott 2011), showing known lithium and/or rare element occurrences and/or prospects (green dots; *from* Ontario Geological Survey 2023) and the location of 3 sites with highly anomalous lake sediment rare element values (yellow dots; *from* Jackson and Dyer 2000b). Note the spatial relationship between terrane boundaries or regional-scale faults and rare element occurrences and lake sediment rare element anomalies.

> These pegmatites have been intruded generally parallel to the foliation of the country rocks; in the vicinity of Mountairy Lake they dip flatly north northeast. They appear to range from 20 to several hundred feet in width, and up to 1,000-1,500 feet in length. The result is that much of the outcrop exposure in this area is pegmatite capping, and it is difficult to trace the underlying rock formation. The pegmatite is commonly a pink colour due to the potash feldspar, with lesser amounts of white feldspar (albite?) and quartz. Accessory minerals noted in some dikes were tiny red garnets in fine-grained aplitic zones in the pegmatite, and occasional books of muscovite. Inclusions of the country rocks are not uncommon. The pegmatites exhibit both lateral and strike gradation into fine-grained aplitic phases. Individual feldspar crystals up to 6 inches across were noted. Grey granite and grey granite pegmatite were also noted in this area; the grey colour is due to a predominance of white-grey feldspar over the pink potash variety. On the map, an attempt has been made to separate the two types (i.e., 7p and 6p); however, in many instances the grey pegmatites have been grouped with the pink pegmatites.
>
> In the region around Harmon Lake the coarse granite pegmatite dikes are generally concordant but steeper in dip, pink, and contain trace amounts of biotite and occasional inclusions of hornblende-biotite schist. Aplitic phases are common.

Further reconnaissance prospecting in this area is warranted based on the lake sediment data, proximity to regional-scale faults, the presence of large granitic pegmatite outcrops observed north of Kashishibog Lake, and the vast area of pegmatites mapped and reported in the Sparkling Lake area (Rogers 1964). A lake sediment resampling program at site Nine-Sixty-Six and nearby lakes is recommended to verify the highly anomalous rare element values.

The Six-Thirty lake sediment sample site (OGS sample site sample 1792, Jackson and Dyer 2000b; 311563E 5538627N; *see* Figure 1), located in the Awkward Lake area, returned 630.4 ppm Li and 144.26 ppm Cs, 201.4 ppm Mo and 2091.34 ppm total rare earth elements (REE). No granitic rocks or pegmatites were observed near this site; however, not enough time was available to effectively evaluate the area. Based on Jackson and Dyer's (2000a) description of their "Area 11" (quoted below), further reconnaissance prospecting is recommended in the Scalp Lake area because there is a southeast-trending series of samples with elevated concentrations of various elements.

> A string of lakes trending southeast from Scalp Lake toward the centre of the Awkward Lake stock contain elevated to anomalous values of W and REEs. A small lake in the centre of the Awkward Lake Intrusive (site 1792), contains highly anomalous values for silver (41.01 ppm), cadmium (120.6 ppm), cesium (144.26), lithium (630.4 ppm), molybdenum (201.4 ppm), lead (1159.4 ppm), thallium (41.39 ppm), uranium (192.97 ppm), tungsten (31.19 ppm), ytterbium (228.63 ppm) and various rare earth metals. Many of these values are the highest assays recorded from the Garden Lake–Obonga Lake survey area. A small pyrite, pyrrhotite, chalcopyrite showing is located immediately south of this lake. The presence of Ni, Cu and gold located along the contact of the Awkward Lake Stock, makes this a potential area for Au–PGE–Ni–Cu mineralization associated with gabbroic/anorthositic rocks. The southeast trend of elevated elements from the Scalp Lake area into the central portion of the Awkward Lake Stock may indicate that a pegmatitic rock and/or structure is present in the area.

A cluster of 4 OGS lake sediment samples on the northeast arm of Pakashkan Lake (*see* Figure 1; "Pakashkan" lake sediment anomaly) and near the boundary between the Winnipeg River and Marmion terranes, returned the following anomalous Li, and elevated Cs and Rb values:

- Sample Site 1319 (703965E 5475131N): 65.4 ppm Li, 2.77 ppm Cs, 13.95 ppm Rb
- Sample Site 1320 (702927E 5474420N): 53.9 ppm Li, 3.61 ppm Cs, 13.91 ppm Rb
- Sample Site 1318 (704443E 5474851N): 37.6 ppm Li, 2.84 ppm Cs, 8.19 ppm Rb
- Sample Site 1322 (702758E 5472794N): 27.3 ppm Li. 2.77 ppm Cs, 14.38 ppm Rb

Stone et al. (2002) mapped a variety of granitic rocks in the Pakashkan Lake area, including diorite, quartz diorite, minor pegmatite and aplite, biotite tonalite to granodiorite, and gneissic rocks. Further prospecting and sampling is recommended in the vicinity of the lake sediment anomalies, as reconnaissance mapping indicates outcrop is fairly sparce along the shoreline of the northeast arm of Pakashkan Lake.

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HIGHLIGHTS

- **New geochemical data reveals that portions of the Eayrs Lake pluton are geochemically fractionated**
- **LCT pegmatite exploration is recommended for metasedimentary and metavolcanic rocks to the north of the pluton**

The Eayrs Lake Pluton: A Potential Fertile Granite

The Eayrs Lake pluton is an approximately 11 by 20 km granitic pluton located near the northern boundary of the Quetico Subprovince, approximately 70 km north-northwest of Thunder Bay. The intrusion is dominantly composed of biotite granite, with leucocratic muscovite granite occurring in at least 2 areas along the northern and western portions of the pluton near the boundary between the pluton and metasedimentary host rocks. Breaks, Selway and Tindle (2003) evaluated peraluminous granite and potassic pegmatites on the eastern portion of and to the east of the Eayrs Lake pluton, noting that “Several pegmatites reveal significant fractionation and establish the area as worthy of follow-up prospecting for rare-element mineralization.”

Field visits in 2022 and 2023 by staff of the Thunder Bay South Resident Geologist Program (TBS-RGP) were conducted on portions of the Eayrs Lake pluton that Breaks, Selway and Tindle (2003) did not sample (Figure 1). Preliminary sampling of pegmatitic leucogranites by the TBS-RGP in 2022 and 2023 yielded elemental ratios and incompatible element concentrations exceeding typical values for pegmatitic leucogranite units within fertile granite plutons of the Superior Province (Černý and Meintzer 1988). In general, incompatible element concentrations exceed those reported by Breaks, Selway and Tindle (2003) in their samples from the area, indicating that leucocratic muscovite granite in the western and northern parts of the pluton is likely more fractionated than phases in and adjacent to the eastern portion. The Eayrs Lake pluton may be an example of a fertile granitic pluton, with potential representation of both the biotite granite and coarse-grained leucogranite phase from the model developed by Černý (1991; Figure 2). Work should be done to determine the relationship of the leucocratic muscovite granite phase to the biotite granite phase and to search for the presence of pegmatites in metasedimentary and metavolcanic rocks north of the pluton.

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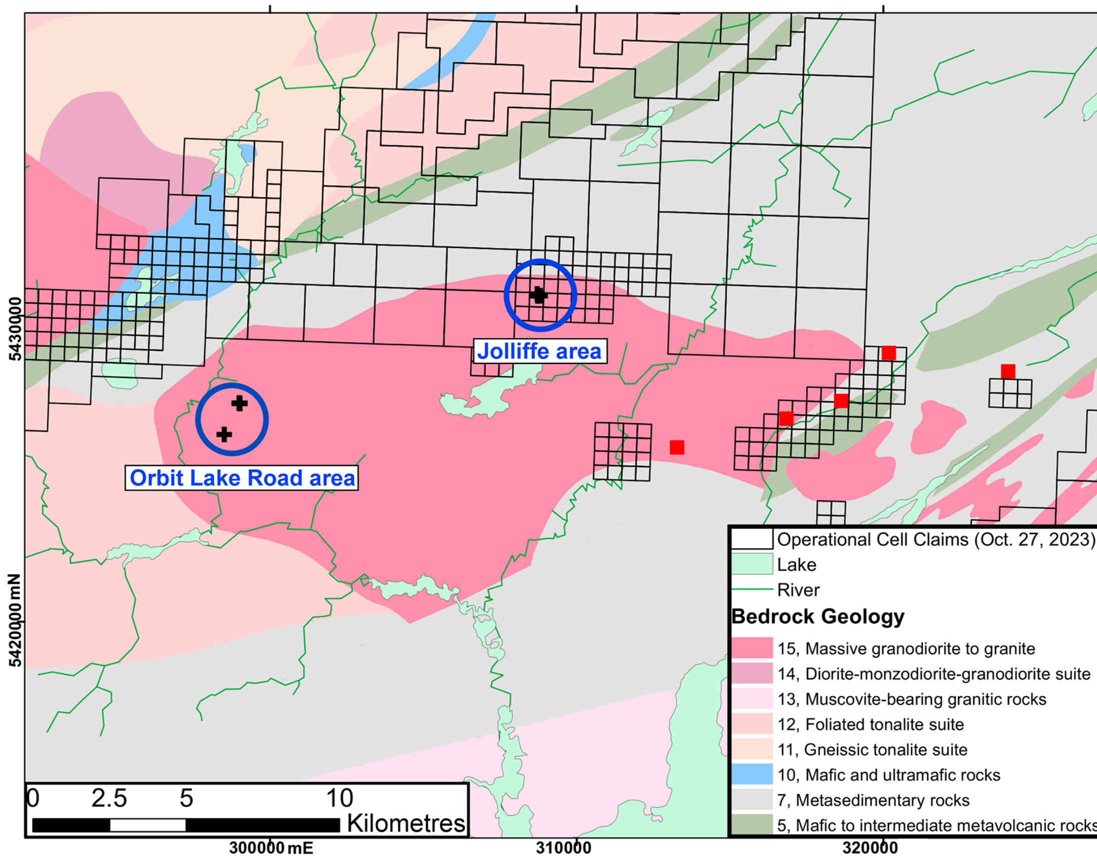

Figure 1. Sample locations by the TBS-RGP (black plus signs) and from Breaks, Selway and Tindle (2003; red squares). Geology *from* Ontario Geological Survey (2011). Claim units current as of October 27, 2023. Universal Transverse Mercator (UTM) co-ordinates in North American Datum 1983 (NAD83), Zone 16.

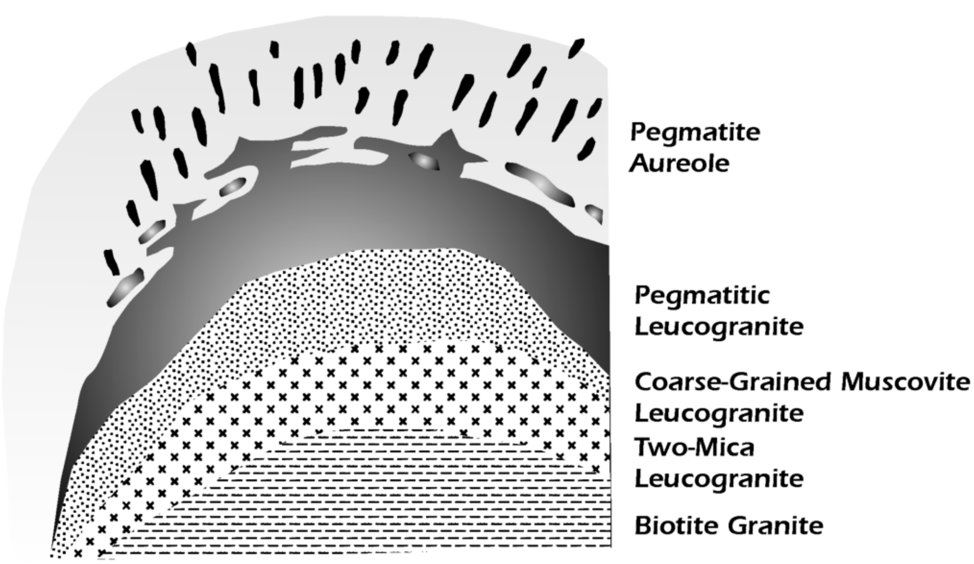

Figure 2. Idealized fertile granite model (*from* Breaks, Selway and Tindle 2003; *modified from* Černý 1991).

Geology of Leucogranites in the Eayrs Lake Pluton

The Eayrs Lake pluton has been subject to minimal historical investigation; the area has been covered by one Ontario Geological Survey mapping program (Kaye 1969a), in which the bulk of the pluton was characterized as pink-to-grey biotite and/or hornblende granite but not described in detail in the accompanying geological report (Kaye 1969b). Muscovite-albite±garnet±tourmaline±beryl±apatite leucogranite occurs in at least 2 areas within the Eayrs Lake pluton and metasedimentary rocks of the Quetico Subprovince, visited by the TBS-RGP in 2022 and 2023 and referred to in this article as the "Orbit Lake Road" and "Jolliffe" areas. These leucocratic muscovite granites are clearly distinguishable from the bulk of the Eayrs Lake pluton by the presence of white feldspar and muscovite and the absence of pink feldspar and biotite. Grain size in the leucocratic muscovite granites ranges from medium grained to pegmatitic, with grain size changes ranging from sharp to gradational.

The Orbit Lake Road area was mapped as tourmaline-muscovite granite pegmatite by Kaye (1969a), with no detailed description provided in Kaye (1969b). Leucocratic muscovite granite is present in the Orbit Lake Road area in several outcrops spanning a 1.3 km distance, and consists of white feldspar, quartz and muscovite and locally containing orange-red garnet, tourmaline and blue apatite. The majority of the leucocratic muscovite granite in the Orbit Lake Road area is medium- to coarse-grained and relatively of homogenous composition and grain size. Sampling by the TBS-RGP focused on less than 2 m wide, generally east-trending (strike of 80-100°, dip of 30-65°N) pegmatitic zones that have sharp to relatively sharp (gradational over approximately 10 cm) boundaries with the homogenous leucogranite. Pegmatitic zones contain feldspar and quartz crystals up to 30 cm in size and locally contain up to 15% tourmaline. Local, irregular aplitic zones less than 20 m from pegmatitic zones contain up to 10% garnet. A single crystal of apatite was observed within a pegmatitic zone.

The Jolliffe area was visited by and named after Jolliffe (1934), who noted the presence of beryl in a leucocratic pegmatite. Scott et al. (2011) visited the area and reported the presence of a single beryl crystal in a pegmatite consisting of "coarse- to medium-grained white feldspar, quartz, muscovite, tourmaline, biotite plus beryl". Apatite, orange-red garnet, and a single beryl crystal were observed in a 2023 field visit by the TBS-RGP; unlike in the Orbit Lake Road area, tourmaline was not observed. As in the Orbit Lake Road area, leucogranite granite in the Jolliffe area consists of a dominant medium- to coarse-grained phase cut by a discrete pegmatitic phase. The pegmatitic phase in the Jolliffe area is of similar composition and grain size to the pegmatitic phase in the Orbit Lake Road area. The orientation of the main pegmatitic phase in the Jolliffe area is difficult to determine; the contact with medium-grained leucocratic granite on the southwestern side of the outcrop strikes approximately 10° and dips steeply, while the contact on the northeastern side appears to be shallowly dipping.

Geochemistry of Leucogranites in the Eayrs Lake Pluton

Analytical results of key elements and elemental ratios from grab samples taken by the TBS-RGP in 2022 and 2023 are included in Tables 1 and 2. The reader is cautioned that although care was taken to ensure representative samples were collected, the samples are smaller (2-5 kg) than what would be ideal for representative samples of pegmatitic rocks (20-60 kg), and the results should only be used to make preliminary observations.

Table 1. Partial bulk-rock lithogeochemistry of samples from the Orbit Lake Road and Jolliffe areas. All co-ordinates in UTM NAD83 Zone 16U. Average upper continental crust values from Rudnick and Gao (2002). "Pegmatitic leucogranite" refers to average composition of internal pegmatitic leucogranite units of fertile granitic plutons in the Superior Province (*from* Černý and Meintzer 1988). "Breaks, Selway and Tindle (2003) samples" refers to the 5 samples reported by those authors from the Eayrs Lake area (locations shown in Figure 1).

Sample Number	Area	Easting	Northing	Cs (ppm)	Li (ppm)	Nb (ppm)	Rb (ppm)	Ta (ppm)
Average upper continental crust				4.9	24	12	84	0.9
Pegmatitic leucogranite (mean)				27	51.7	18	473	2.7
Pegmatitic leucogranite (range)				<0.5-51	6-288	<1-135	32-5780	0.5-8
Breaks, Selway and Tindle (2003) samples (range)				1.3-26.6	15-28	1.8-45.9	80-554	0.4-12.6
22TBS-010	Orbit	298479	5426123	5.128	26.93	5.610	221.03	0.567
22TBS-011	Orbit	298992	5427139	17.40	38.72	14.98	414.19	2.383
22TBS-012	Orbit	298982	5427138	36.55	144.9	100.4	360.69	72.29
22TBS-013	Orbit	298985	5427137	15.33	89.04	29.11	481.81	1.560
22TBS-014	Orbit	298973	5427142	281.8	15.81	99.26	1042.8	143.5
22TBS-015	Orbit	298969	5427144	7.252	75.96	35.74	302.51	3.706
22TBS-003	Jolliffe	308696	5430713	6.628	13.58	14.79	175.07	2.316
22TBS-004	Jolliffe	308710	5430643	30.16	22.84	53.65	298.42	27.03
22TBS-008	Jolliffe	308772	5430653	107.9	241.0	60.69	1610.3	11.01
22TBS-009	Jolliffe	308788	5430649	92.58	275.1	63.94	343.34	47.16

Abbreviations: Cs, cesium; Li, lithium; Nb, niobium; Rb, rubidium; Ta, tantalum.

Table 2. Bulk-rock elemental ratios of samples from the Orbit Lake Road and Jolliffe areas. All co-ordinates in UTM NAD83 Zone 16U. Average upper continental crust values from Rudnick and Gao (2002). "Pegmatitic leucogranite" refers to average composition of internal pegmatitic leucogranite units of fertile granitic plutons in the Superior Province (*from* Černý and Meintzer 1988). "Breaks, Selway and Tindle (2003) samples" refers to the 5 samples reported by those authors from the Eayrs Lake area (locations shown in Figure 1).

Sample Number	Area	Easting	Northing	K/Rb	Mg/Li	Nb/Ta
Average upper continental crust				275	623	13.3
Pegmatitic leucogranite (mean)				165	N/A	1.71
Pegmatitic leucogranite (range)				13-576	N/A	0.1-7.17
Breaks, Selway and Tindle (2003) samples (range)				56.8-316.5	6.7-33.9	0.2-19.8
22TBS-010	Orbit	298479	5426123	192.29	8.96	9.89
22TBS-011	Orbit	298992	5427139	92.99	4.67	6.29
22TBS-012	Orbit	298982	5427138	65.36	5.41	1.39
22TBS-013	Orbit	298985	5427137	95.79	4.74	18.66
22TBS-014	Orbit	298973	5427142	62.73	7.63	0.69
22TBS-015	Orbit	298969	5427144	76.01	3.97	9.64
22TBS-003	Jolliffe	308696	5430713	206.2	71.07	6.39
22TBS-004	Jolliffe	308710	5430643	57.86	2.64	1.98
22TBS-008	Jolliffe	308772	5430653	54.13	2.75	5.51
22TBS-009	Jolliffe	308788	5430649	29.50	0.22	1.36

Abbreviations: K, potassium; Li, lithium; Mg, magnesium; Nb, niobium; Rb, rubidium; Ta, tantalum.

Preliminary sampling indicates that pegmatitic leucogranite in the Orbit Lake Road and Jolliffe areas is enriched in rare elements, suggesting that it may have formed via significant fractionation of a granitic melt. Several samples from each of the Orbit Lake Road and Jolliffe areas yielded cesium, lithium, niobium and tantalum values that are higher than the average composition of a pegmatitic leucogranite within a fertile granitic system in the Superior Province (Černý and Meintzer 1988). Ratios for Mg/Li and Nb/Ta are generally lower than the values used by Breaks, Selway and Tindle (2003; <10 and <8, respectively) as thresholds for the presence of geochemical fractionation. Notably, samples 22TBS-014 and 22TBS-008 returned Rb values higher than the minimum 1000 ppm Rb value required to meet Ontario Mineral Inventory (OMI) Occurrence grade requirements. Sample 22TBS-014 also returned Ta values higher than the minimum 100 ppm Ta value required to meet OMI Occurrence grade requirements (Ontario Geological Survey 2023).

Recommendations

The relationship between the leucocratic muscovite granite and the grey-to-pink biotite granite is unclear and requires further investigation. The leucocratic granites may either represent an evolved, fractionated phase of the Eayrs Lake pluton or (a) separate, unrelated intrusion(s). Contacts between the leucocratic and pink-to-grey portions of the Eayrs Lake pluton were not reported by previous workers nor observed in the field by the TBS-RGP. Future work should involve searching for the contact between the granitic units to determine the intrusive relationship between these units.

More work is required to determine whether the Eayrs Lake pluton is a potential fertile granite that could be parental to lithium-cesium-tantalum (LCT) pegmatite mineralization. Large (>20 kg) samples should be taken to follow up on results in this article to determine if preliminary results are representative of the lithological units. Systematic geochemical sampling of both the pink-to-grey biotite granite and the leucocratic muscovite granite is recommended to determine the direction of geochemical fractionation.

Rare-element pegmatites hosted by granitic rocks are uncommon, although examples, such as the Case Lake and Greer Lake pegmatites, are present in the Superior Province. Most commonly, rare-element pegmatites are hosted by metasedimentary and/or metavolcanic rocks within less than 10 km of a fertile granitic pluton. Prospecting is recommended in the metasedimentary and metavolcanic rocks directly to the north of the Eayrs Lake pluton.

The area encompassed by this article is partially staked at the time of writing (*see* Figure 1). Claims encompassing the metavolcanic and metasedimentary rocks north of the Eayrs Lake pluton are held by Impala Canada Ltd. and 1414327 B.C. Ltd. Claims encompassing the Jolliffe area are held by T. Gallik. No claims are registered in the Orbit Lake Road area at the time of writing.

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HIGHLIGHTS

- **Delineated 7 lithium-cesium-tantalum and/or REE exploration targets by considering lake sediment data and underlying geology**
- **Regional land positions available for mineral tenure**
- **Lithium-cesium-tantalum and REE exploration methodologies provided based on recent exploration success in northwest Ontario**

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Regional Lithium-Cesium-Tantalum Pegmatite and Rare Earth Elements Opportunities in the English River and Wabigoon Subprovinces

Introduction

Northwestern Ontario (NWO) has become known for its "white gold", referring to lithium ore found in lithium-cesium-tantalum (LCT) pegmatites. Lithium reserves and resources in NWO have surpassed 100 Mt, because of the development of world-class deposits such as Frontier Lithium's PAK Lithium Project (22 Mt @ 1.55% Li_2O) and numerous smaller (5 to 20 Mt) deposits (i.e., Mavis, Raleigh, Separation Rapids, Root and Georgia Lake) (Frontier Lithium Inc., corporate presentation, accessed October 17, 2023). Observationally, these deposits occur in greenstone belts or basins, and generally, where exposed, in proximity (i.e., within 10 km) to a peraluminous S-type granite batholith and/or a subprovince terrane boundary.

Herein, 7 areas with available mineral tenure are recommended for follow-up exploration in the English River and Wabigoon subprovinces (Figure 1; Table 1). These areas were selected based on the presence of strongly elevated to anomalous LCT and/or rare earth element (REE) lake sediment data (Figures 2 to 5), considering the underlying geology, and proximity to subprovince boundaries and batholiths. Additionally, exploration strategies for these deposit types are provided based on literature review and recent discovery methodologies.

Data Compilation

Before examining the areas included in this recommendation for exploration, 3 lake sediment data sets were combined: Miscellaneous Release—Data (MRD) 88 (Ontario Geological Survey 2001), MRD 130 (Russell 2004) and MRD 145 (Felix 2005). The 3 data sets were selected because they covered areas of interest in the Kenora Resident Geologist District. Lithium and cesium were examined for LCT pegmatite potential as they are typical components of these mineral deposits. Heavy rare earth elements (HREE) and light rare earth elements (LREE) were examined for REE potential.

Lake sediment data from these surveys were analyzed by inductively coupled plasma mass spectrometry at the OGS Geoscience Laboratories in Sudbury, Ontario. When examining lithium, cesium, tantalum and rubidium, the data were normalized with loss-on-ignition (LOI) values and sorted into 90th, 95th and 98th percentiles. When compiling the data for REE potential, the data were first organized by LREE and HREE.

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Table 1. Northwestern Ontario target areas recommended for follow-up exploration.

Targets	Lake Sediment Anomaly	Bedrock Geology	Comments
Sioux Lookout domain	Li, Cs, HREE and LREE	Granite, metasediment	On trend with Mavis Lake Li deposit. Li, Cs, LREE and HREE anomalous values along boundary. Exploratory sampling by the OGS.
English Winnipeg River Boundary	Li, Cs, HREE and LREE	Granite, metasediment	Potential for unrecognized fertile granite and along subprovince boundary with Li and Cs anomalous values.
English River	Li, Cs, HREE and LREE	Granite, metasediment	Potential for unrecognized fertile granite with Li and Cs anomalous values.
South Waldhof	Li, Cs, Ta, HREE and LREE	Granite, metasediment	Muscovite granite sampled by the OGS for fertile granite study. Area marks northern extent of ~20 km southeasterly Li and Cs lake sediment anomaly trend.
Tobacco Lake	Li, Cs, Ta, HREE and LREE	Mafic, ultramafic and metavolcanic rocks	~10 km from Revell batholith, parental granite for Raleigh Lake Li and Rb deposit. ~20 km Li and Cs lake sediment anomaly trend.
Dyment	Li, Cs, Ta, HREE and LREE	Granite, metavolcanic rocks	Three "pods" of Li, Cs and Ta anomalies. Potential for unrecognized fertile granite in area.
Minnitaki East	Li, Cs, Ta, HREE and LREE	Metavolcanic and metasedimentary rocks	Significant Li, Cs, Ta, HREE and LREE anomaly in area of changing lithologies.

Abbreviations: Li, lithium; Cs, cesium; Ta, tantalum; LREE, light rare earth elements; HREE, heavy rare earth elements.

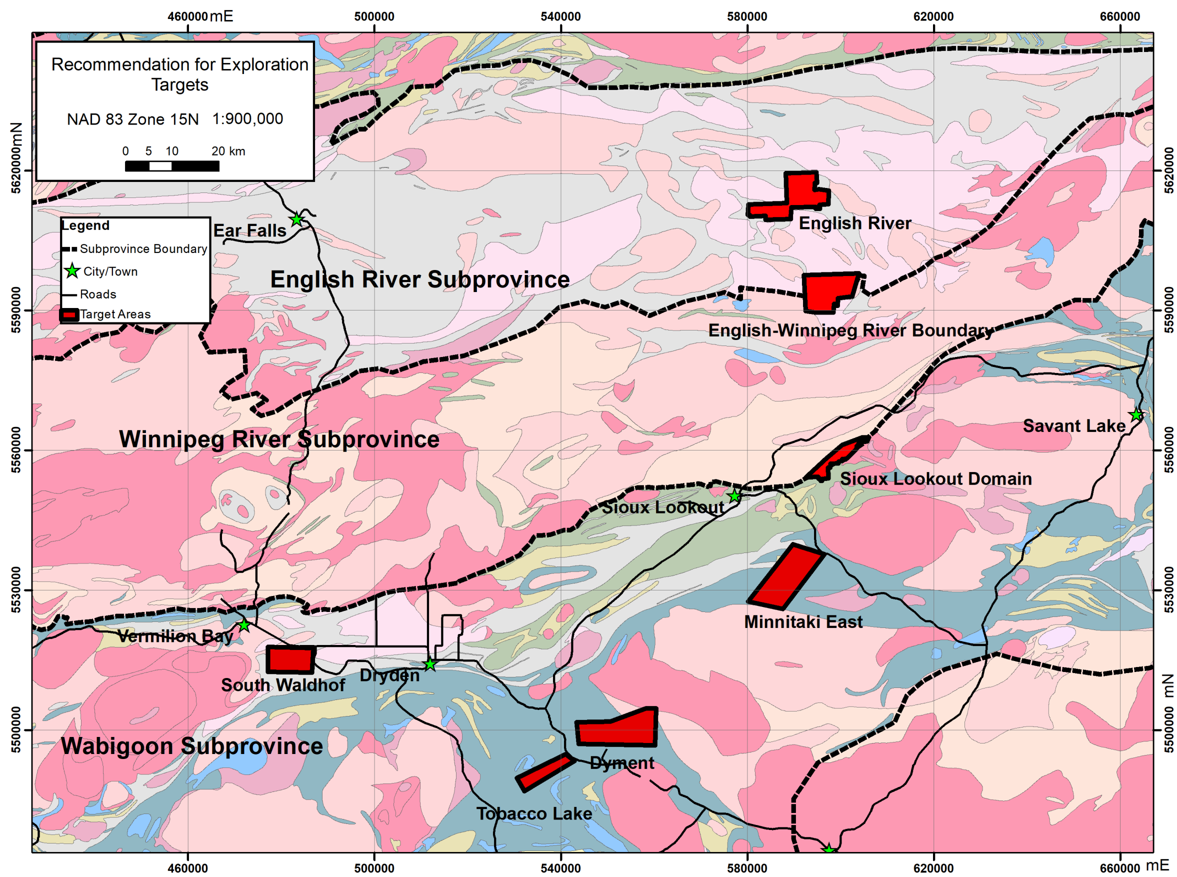

Figure 1. Recommended exploration targets highlighted in red overlying Ontario bedrock geology (*modified from* Ontario Geological Survey 2011).

The LREE included lanthanum, cerium, praseodymium, neodymium, samarium, europium and gadolinium, while HREE included yttrium, terbium, dysprosium, holmium, erbium, thulium, ytterbium, lutetium. Totals values of LREE and HREE were then normalized with loss-on-ignition data and sorted into 90th, 95th and 98th percentiles. The lake sediment data were then plotted as dot maps over bedrock geology maps. Concentrations of elements over the 95th percentile are considered anomalous, while values over the 90th percentile are considered "strongly elevated" (Paju 2023). Of note is that the total values of LREE and HREE did not include samarium and holmium results from MRD 145 (Felix 2005) because these data were not available.

Exploring for LCT Pegmatites

The recommended strategy for LCT pegmatite exploration utilizes regional and local vectors to narrow the search area. At the regional level, identification of parental fertile granites can substantially reduce the exploration area of interest, typically to approximately 10 km from the granitic body (Breaks and Tindle 1997; Breaks, Selway and Tindle 2003). However, the explorationist should note that not all LCT pegmatite deposits have the associated parental granite exposed at surface (i.e., Tanco Mine). In this case, one should consider other regional vectors, for example, consider the underlying geology, proximity to structures (i.e., faults, terrane boundaries) and batholiths, whose fertility may be unrecognized, while examining lithium (Figure 2), cesium (Figure 3), and tantalum lake sediment data.

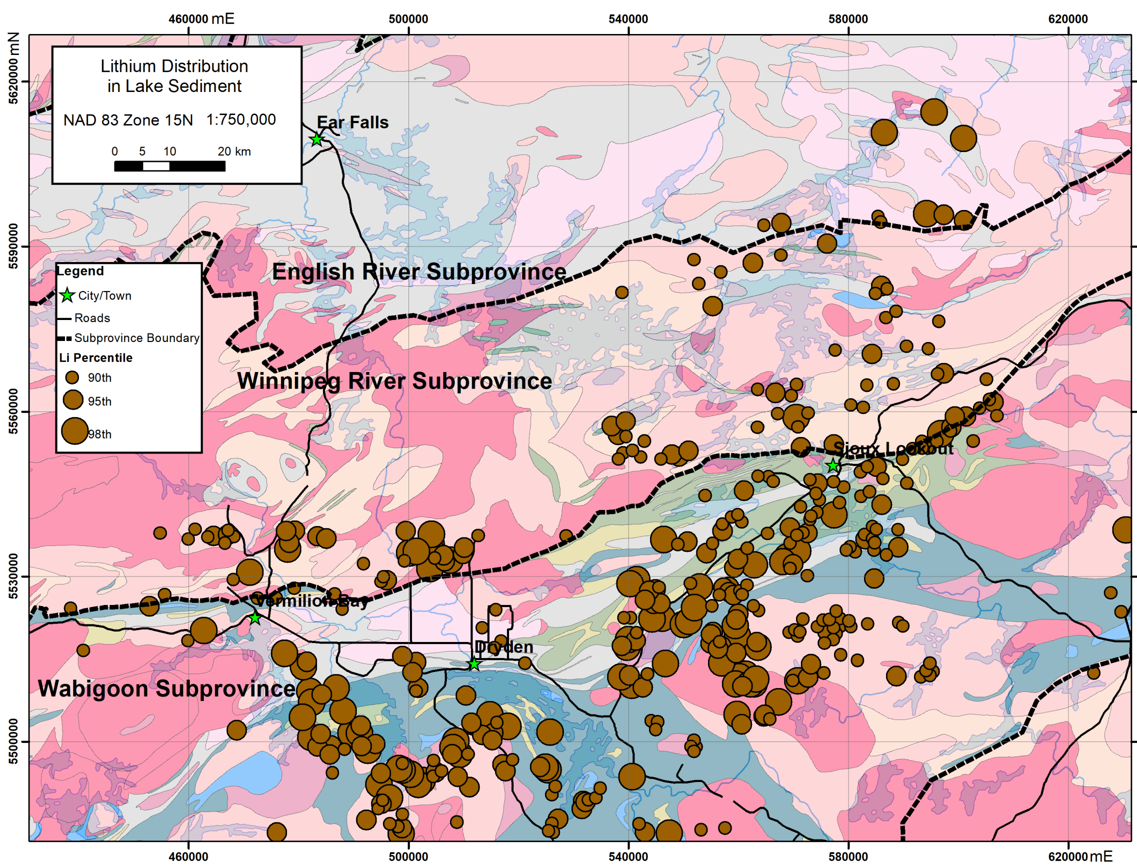

Figure 2. Distribution of lithium anomalies in lake sediment (data *from* Felix 2005; Ontario Geological Survey 2001; Russell 2004) over bedrock geology within the Wabigoon, Winnipeg River and English River subprovinces (*modified from* Ontario Geological Survey 2011).

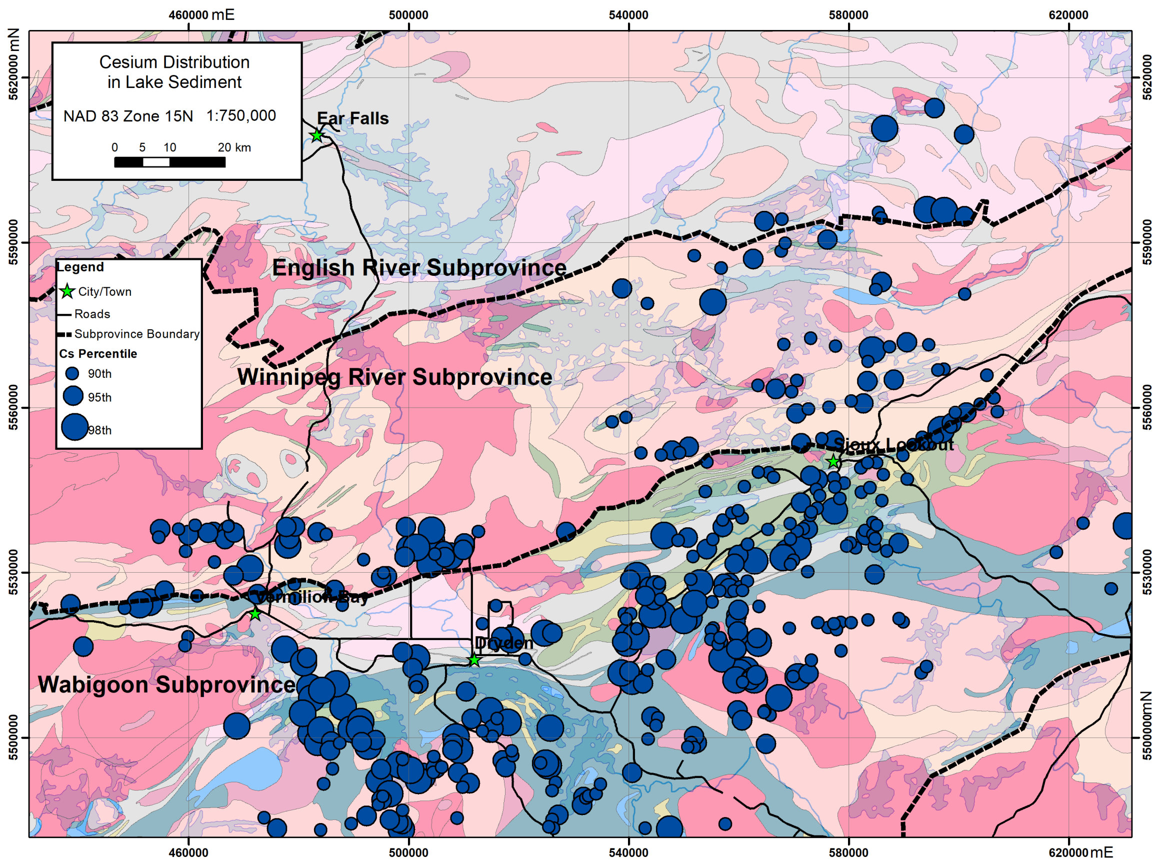

Figure 3. Distribution of cesium anomalies in lake sediment (data *from* Felix 2005; Ontario Geological Survey 2001; Russell 2004) over bedrock geology within the Wabigoon, Winnipeg River and English River subprovinces (*modified from* Ontario Geological Survey 2011).

Once a region is selected for exploration, the challenge is to narrow the search area and vector toward LCT pegmatite mineralization. Pegmatite districts typically occur as large dike swarms which have intruded into the host rock but also occur as sills. These swarms may be tens of kilometres wide and/or long with hundreds if not thousands of pegmatites from millimetre- to metre-scale width and/or length. To avoid getting overwhelmed by the barren pegmatites, the common method for vectoring toward LCT pegmatite mineralization is determining the degree of fractionation, as high degrees of fractionation are required to concentrate lithium-cesium-tantalum mineralization in a pegmatite (Selway, Breaks and Tindle 2004).

When reviewing an area for prospective pegmatites, begin qualitatively, considering the extent of albitization of the pegmatite, because as LCT pegmatites are albitized to varying extents, they typically appear as a whiter variety, compared to potassic pink pegmatites. It is recommended to look for perthitic potassium feldspar. Additionally, a second qualitative assessment is to consider the presence of index minerals and its distance from the parent fertile granite intrusion. The Černy (1991) model suggests 1) beryl; 2) beryl and ferrocolumbite; 3) beryl, tantalite and lithium-rich aluminosilicates (i.e., petalite or spodumene); and finally 4) a beryl, manganotantalite, lithium-rich aluminosilicates and pollucite suite with increasing distance from the parent fertile granite.

With prospective areas delineated, the method described by Selway, Breaks and Tindle (2004), which has yielded success, is to continue with a quantitative assessment using bulk mineral chemistry of potassium feldspar and/or muscovite to vector using fractionation. The authors suggest using bulk mineral chemistry rather than whole rock chemistry because pegmatites are quite heterogeneous and have large crystal sizes, requiring large, burdensome samples to yield representative results. The quantitative assessment would consider the ranges of compositions listed in Table 2. It could include many potassium feldspar and/or muscovite samples on a single pegmatite or a series of pegmatites, because lithium, cesium and/or tantalum minerals are often discrete and challenging to see on a first pass. A recent trend in current discoveries is for explorers to utilize a handheld laser-induced breakdown spectroscopy apparatus, which allows for real-time vectoring to occur in the field.

Table 2. Ranges of compositions of bulk potassium feldspar and muscovite analyses (*from* Tindle, Selway and Breaks 2002).

Potassium Feldspar	**Li (ppm)**	**Rb (ppm)**	**Cs (ppm)**	**K/Rb**	**Ta (ppm)**
Barren granite	NA	<400	<10	>150	NA
Fertile granite	NA	500–3000	20–100	30–150	NA
Rare-element pegmatite	NA	>3000	>100	<30	NA
Muscovite	**Li (ppm)**	**Rb (ppm)**	**Cs (ppm)**	**K/Rb**	**Ta (ppm)**
Fertile granite	200–500	1000–1500	10–100	50–100	10–65
Beryl-type pegmatite	500–2000	1500–10 000	100–500	20–50	10–65
Spodumene-subtype pegmatite	>2000	>10 000	>500	<20	>65

Abbreviations: Li, lithium; Rb, rubidium; Cs, cesium; Ta, tantalum; K/Rb, ratio of potassium and rubidium; NA, not available.

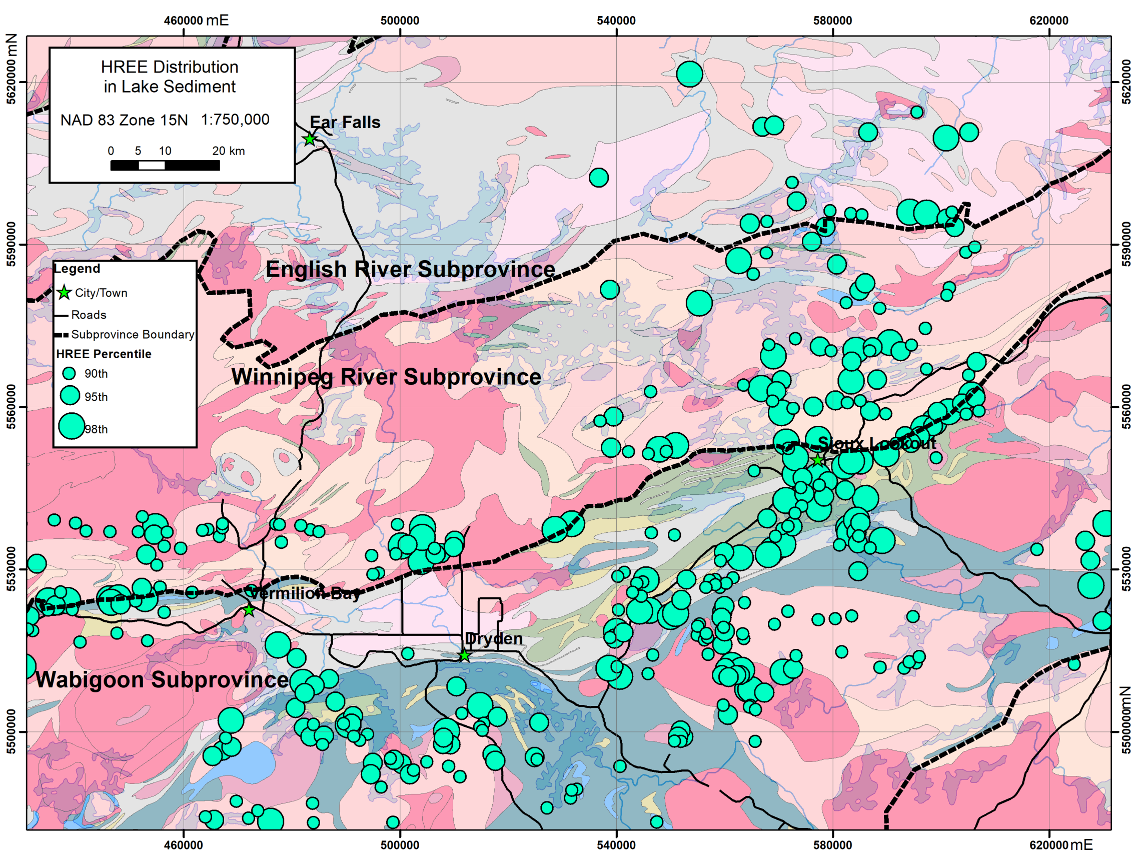

Figure 4. Distribution of HREE (includes Y, Tb, Dy, Ho, Er, Tm, Yb, Lu) anomalies in lake sediment (data *from* Felix 2005; Ontario Geological Survey 2001; Russell 2004) over bedrock geology within the Wabigoon, Winnipeg River and English River subprovinces (*modified from* Ontario Geological Survey 2011).

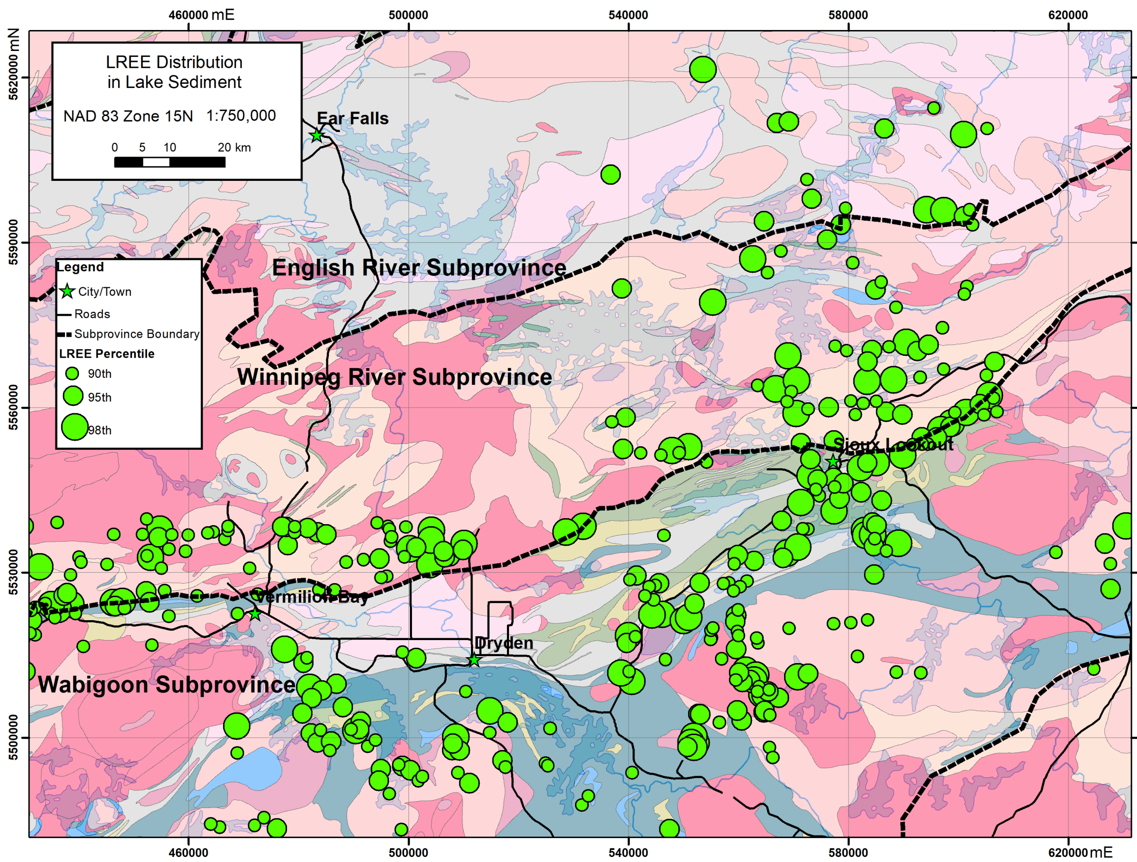

Figure 5. Distribution of LREE (includes La, Ce, Pr, Nd, Sm, Eu and Gd) anomalies in lake sediment (data *from* Felix 2005; Ontario Geological Survey 2001; Russell 2004) over bedrock geology within the Wabigoon, Winnipeg River and English River subprovinces (*modified from* Ontario Geological Survey 2011).

Exploring for REEs

Rare earth elements are a group of 17 elements which, in NWO, occur in carbonatites, alkalic intrusions, and locally in some varieties of gneiss and migmatites (Van Gosen et al. 2017). While carbonatites or alkalic intrusions are not currently recognized within the target areas of Figure 1, there is potential for economic concentrations of xenotime and monazite within the mafic gneisses of the Sioux Lookout domain and migmatites of the English River as illustrated with the HREE and LREE lake sediment anomalies in Figures 4 and 5.

Considering the HREE and LREE anomalies in the Sioux Lookout domain, Red Lake and Kenora Resident Geologist staff collected 8 samples during the 2023 field season. Numerous outcrops were observed with significant biotite and rocks that appear to be gneissic alongside felsic intrusive granitoids (Photo 1). One outcrop encountered was composed entirely of mafic metasediments. While more work is required and assay data is pending, it is an area in which the authors believe additional follow-up is warranted.

Direct exploration for REE deposits can utilize the durability and high density of xenotime and monazite which causes them to be resistant to weathering and accumulate with the heavy-mineral suite in lake sediments. Additionally, the radioactivity of monazite may be detectable by airborne or ground geophysical surveys (Van Gosen et al. 2017).

Photo 1. Outcrop (586341E, 5554844N) of gneiss and/or migmatite alongside felsic granitoid.

Conclusion

As laid out in this recommendation for exploration, 7 targets are highlighted for the LCT pegmatite or REE potential within the Kenora District. Using the publicly available lake sediment data provided by the Ontario Geological Survey is one tool that the explorer can use to begin the initial search for these important critical minerals in Ontario.

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HIGHLIGHTS

- **Underexplored granitoid units with potential for the critical mineral molybdenum in the area of the Favourable Lake greenstone belt**
- **Indications that high levels of fractionation and hydrothermal fluids existed in a regionally extensive system**
- **Conditions were favourable for the development of molybdenite mineralization**

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Porphyry Molybdenum Potential in the Favourable Lake Greenstone Belt Area

The Favourable Lake greenstone belt lies along the Bear Head fault, a major southeast-trending, transcurrent structure that separates the Berens River Subprovince to the south from the Sachigo Subprovince to the north (Figure 1). Recently, this structure has been the focus of exploration for lithium-cesium-tantalum pegmatites following the discovery of the Pakeagama Lake pegmatite ("PAK Lithium Project"; McCracken et al. 2023) by Frontier Lithium Inc. (*see also* Ontario Geological Survey 2023; Ontario Mineral Inventory (OMI) occurrence MDI53C11SW00003). This crustal-scale structure may also be favourable for hosting deposits of other critical minerals such as molybdenum. In 1968, Ayres completed detailed geological mapping identifying a molybdenum occurrence that displayed characteristics of porphyry-molybdenum-style mineralization in the Setting Net Lake stock (Ayres 1969). This bedrock geology mapping project resulted in extensive exploration being completed, including a historical (i.e., pre-dates National Instrument 43-101 (NI 43-101)) resource estimate for the Setting Net Lake occurrence (MDI53C13SE00066). Other occurrences of molybdenite have since been identified in the Favourable Lake greenstone belt but have had little or no exploration completed (*see* Figure 1 for locations).

Geological Setting

The Favourable Lake greenstone belt is divided into several assemblages that consist of flows and pyroclastic rocks that range from felsic to mafic in composition, intercalated with sedimentary units (Stone 1998). The assemblages represent episodic volcanism and sedimentation in a subaqueous to subaerial environment during the late Mesoarchean to Neoarchean (Stone 1998). The intrusive units that occur within and proximal to the Favourable Lake greenstone belt are Neoarchean and are generally younger than the youngest volcanics (Stone 1998). Intrusive units include biotite tonalite to granodiorite, two-mica granite, potassium-feldspar megacrystic biotite-hornblende granodiorite, biotite-hornblende tonalite to granodiorite, and biotite granodiorite to granite (Stone 1998). The intrusive units occur as batholiths and stocks that range from circular to elongate and irregular in shape due to progressive metamorphism and deformation.

Molybdenum Deposits

Molybdenum is listed as a critical mineral in Ontario (Ontario 2022) for its use in creating high-temperature steel alloys that can be used in

Price, R. 2024. Porphyry molybdenum potential in the Favourable Lake greenstone belt area; *in* Ontario Geological Survey, Resident Geologist Program, Recommendations for Exploration 2023–2024, p.68-72.

the mechanical, aerospace and nuclear industries. Molybdenum occurs principally as the sulphide molybdenite (MoS_2) and commonly occurs within porphyry systems forming low grade (0.03-0.22% Mo), high tonnage (>50 Mt) deposits that are typically characterized by a stockwork of molybdenite-bearing quartz veins and/or veinlets (Taylor et al. 2012). These systems are typically associated with calc-alkaline magmatism, crustal-scale fault systems, and hydrothermal alteration that can be potassic, propylitic and/or phyllic (Lundmark, Stein and Weihed 2005). The incompatible behaviour of molybdenum allows for it to concentrate during strong differentiation in a protracted magmatic system (e.g., Olsen et al. 2017). Numerous molybdenum mines in the western United States are associated with fluorine-rich granites, as the high initial fluorine content in the melt can increase the levels of magmatic differentiation (Rosera et al. 2023).

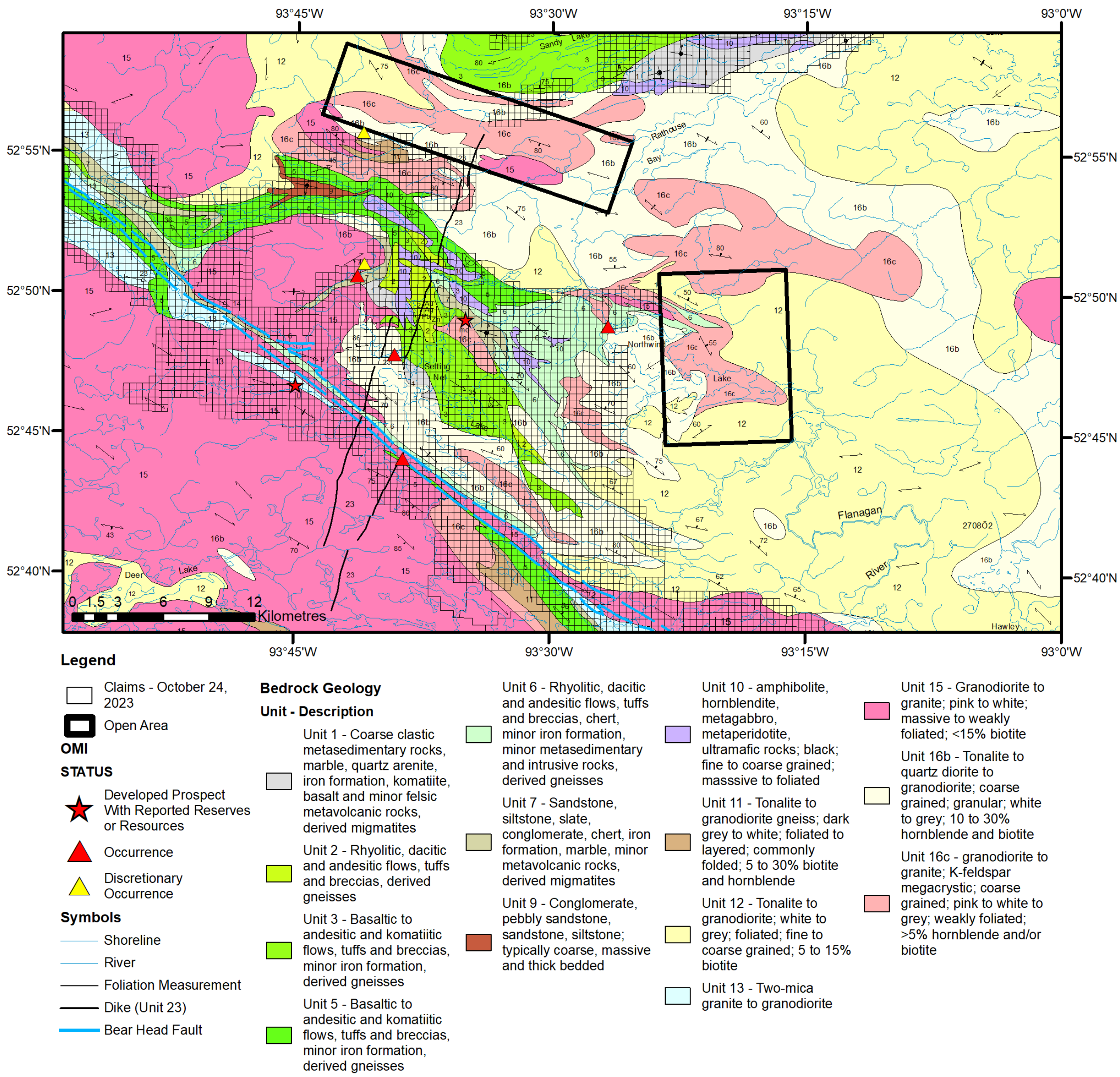

Figure 1. Geology of the Favourable Lake greenstone belt area (*modified from* Stone 1998a and 1998b). The location of the Ontario Mineral Inventory entries with molybdenum listed as a primary or secondary commodity (Ontario Geological Survey 2023; *see also* Table 1) and the recent extent of claims in the area (Mineral Development and Lands Branch 2023) are also shown. Black boxes show the location of ground open for staking with potential for molybdenum mineralization.

Setting Net Lake Prospect

According to the OMI, the Setting Net Lake occurrence is a "Developed Prospect with Reported Reserves and Resources" (the reported resource estimate is historical and pre-dates NI 43-101). *The Northern Miner* (March 23, 1978) reported drill indicated reserves of 100 million tons with a grade of 0.09% MoS_2 to a depth of 600 feet (Atkinson, Parker and Storey 1991). The Setting Net Lake occurrence has been classified by Ayres, Averill and Wolfe (1982) as a porphyry molybdenum deposit. This prospect is associated with the Setting Net Lake stock, a porphyritic granodiorite to quartz monzonite intrusion that has an oval shape in plan view and was emplaced at *circa* 2643 Ma based on a U/Pb age determination on zircon (Nunes and Ayres 1982).

The molybdenite mineralization occurs in quartz veins (Figure 2a) and along shear fracture planes (Figure 2b) as fine crystals, thin films and isolated grains (Ayres, Averill and Wolfe 1982). The molybdenite mineralization has only been observed in the northern portion of the Setting Net Lake stock (Ayres, Averill and Wolfe 1982). Pyrite, ferrimolybdite, chalcopyrite, fluorite and tourmaline have been observed in the molybdenite quartz veins (Ayres, Averill and Wolfe 1982). The mineralized quartz veins extend up to 150 m and fractures extend up to 300 m, into the host mafic volcanic rocks (Ayres, Averill and Wolfe 1982).

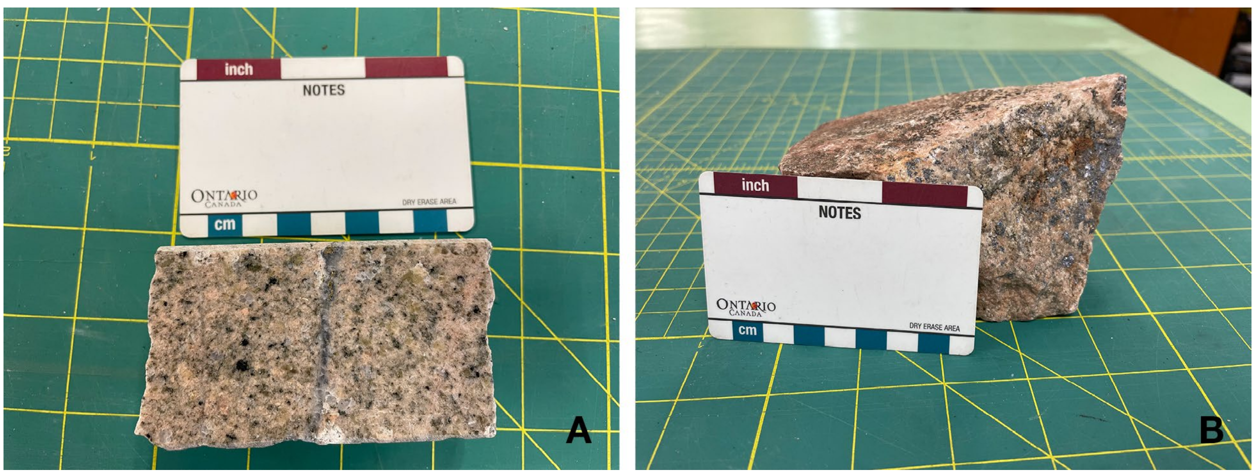

Figure 2. Samples from the Setting Net Lake prospect illustrating the characteristic style of its molybdenite mineralization. A) Drill core photo of medium- to coarse-grained granodiorite that contains disseminated pyrite and is crosscut by a molybdenite-quartz vein. B) Hand sample photo of medium- to coarse-grained granite with a fracture surface lined with molybdenite. Samples collected from the Setting Net Lake area of an unknown date (C. Storey, OGS Geologist, unpublished data, 1990–2016).

Porphyry Molybdenum Potential

The Favourable Lake greenstone belt contains several occurrences with molybdenum listed as either the primary or secondary commodity in the OMI (*see* Table 1 and *see* Figure 1). Compilation map Map 2262 (Ayres et al. 1973) also highlights numerous other occurrences of molybdenum in the Favourable Lake greenstone belt. Collectively, these occurrences, particularly those classified as "porphyry" in the OMI, occur in intrusions of monzonite, tonalite or granodiorite, based on mapping completed by Stone (1998) (*see* Figure 1). Arc-related porphyry molybdenum deposits are cogenetic with calc-alkalic granitoid intrusions, commonly granodiorite or quartz monzonite (Taylor et al. 2012). Strong differentiation of the magmatic system to produce granodiorite and granite melts can enrich the late-stage porphyry intrusions in molybdenum because of its incompatible behaviour (Olsen et al. 2017).

Molybdenum mineralization at the Favourable Lake occurrences is characterized by molybdenite along the margins of quartz veins or as films on fracture surfaces, consistent with a late-stage hydrothermal system. Rosera et al. (2023) indicate that melts with higher initial fluorine can have high levels of differentiation that favour the development of porphyry molybdenum deposits. The fluorite identified in the Setting Net Lake occurrence suggests that fluorine-rich melts could have been involved in its genesis and may be representative of the source melt for the other molybdenum-mineralized intrusive rocks in this region. Burrows and Spooner (1987) identified molybdenite mineralization in the Mink Lake stock, an Archean granodiorite stock in the northwest portion of the Uchi greenstone belt, and concluded that extreme fractionation concentrated the molydenum, which partitioned into the hydrothermal fluids and was subsequently deposited in late dikes and fractures. The intrusive rocks in the area of the Favourable Lake greenstone belt have the potential to concentrate molydenum by the same mechanism recognized at Mink Lake.

Table 1. Ontario Mineral Inventory entries with molybdenum listed as a primary or secondary commodity in the Favourable Lake greenstone belt area (Ontario Geological Survey 2023).

OMI Number	Inventory Status	Name	Easting	Northing	Primary Commodity	Class
MDI53C13NE00006	Discretionary Occurrence	North Trout Lake	453923	5864649	Molybdenum	Porphyry
MDI53C13SE00061	Developed Prospect with Reported Reserves	Bear Head Lake Prospect	449411	5847969	Uranium	Pegmatite
MDI000000000402	Occurrence	Noramco NBW-88-08	453518	5855167	Gold	Porphyry
MDI53C13SE00063	Discretionary Occurrence	Favourable Lake	453971	5855964	Molybdenum	Porphyry
MDI53C13SE00062	Occurrence	Cam	455937	5849951	Molybdenum	Porphyry
MDI53C12NE00012	Occurrence	Mattless Lake Zn-Be-Bi-Mo Occurrence	456488	5843074	Beryl, Bismuth, Zinc	Vein
MDI53C13SE00066	Developed Prospect with Reported Reserves	Setting Net Lake	460657	5852290	Molybdenum	Porphyry
MDI53C14SW00021	Occurrence	Northwind Outlet	470071	5851821	Copper, Molybdenum	Porphyry

The most recent geological mapping in the Favourable Lake greenstone belt was completed 25 years ago (i.e., Stone 1998). Most of the molybdenum occurrences are located in the granodiorite to granite units identified by Stone (1998), suggesting a favourable magmatic system existed for the development of molybdenum mineralization. There are several plutons of this unit that have had little or no exploration and are in areas that are currently open for staking (*see* Figure 1). The potential for molybdenum mineralization in the the Favourable Lake greenstone belt area is owed further consideration and exploration.

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Notes

Notes

Back cover photos, clockwise from top:

Drill core, Remote Drill Core Storage Site in Timmins (credit: Zeinab Azadbakht, Resident Geologist Program, Timmins District).

Obonga Lake area reconnaissance exploration near site "Nine-Sixty-Six" (966 ppm Li) (credit: Dorothy Campbell, Resident Geologist Program, Thunder Bay South District).

James Suma-Momoh (District Geologist, Resident Geologist Program, Kirkland Lake District) tests the depth of a shallow beaver pond before attempting to cross with a utility task vehicle (UTV) to gain access to a mafic intrusive outcrop immediately behind the tree line, southeast of Sulphur Island area in the Abitibi Batholith, Kirkland Lake District.

Sleepy field assistant (credit: Justin Jonsson, Resident Geologist Program, Thunder Bay South District).

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Kenora	807-456-1780
Kirkland Lake	705-718-8735
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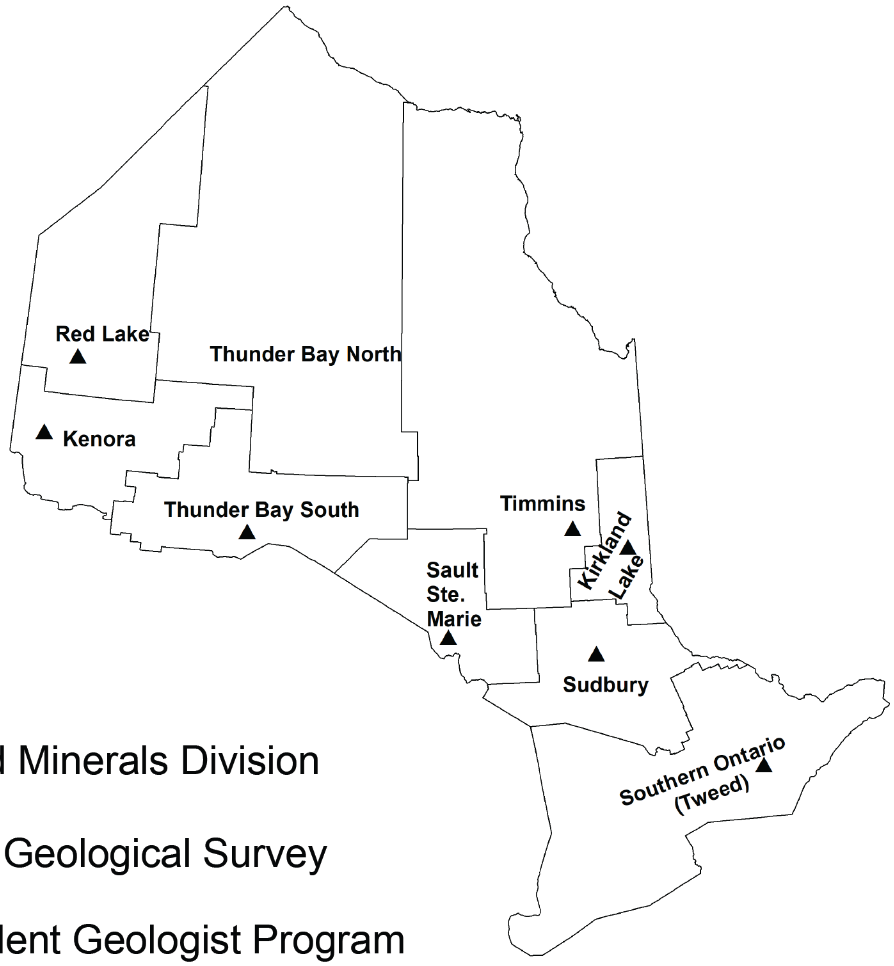
Thunder Bay (North and South)	807-475-1332
Timmins	705-235-1615
Tweed (Southern Ontario)	613-243-0739
Toll Free (General)	888-415-9845



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